Social and ecological effectiveness of large marine protected areas

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Abstract

Large marine protected areas are increasingly being established to meet global conservation targets and promote sustainable use of resources. Although the factors affecting the performance of small-scale marine protected areas are relatively well studied, there is no such body of knowledge for large marine protected areas. We conducted a global meta-analysis to systematically investigate social, ecological, and governance characteristics of successful large marine protected areas with respect to several social and ecological outcomes. We included all large (>10,000km2), implemented (>5 years of active management) marine protected areas that had sufficient data for analysis, for a total of twelve cases. We used the Social-Ecological Systems Meta-Analysis Database, and a consistent protocol for using secondary data and key informant interviews, to code proxies for fisheries, ecosystem health, and the wellbeing of user groups (mainly fishers). We tested four sets of hypotheses derived from the literature on small-scale marine protected areas and common-pool resources: (i) the attributes of species and ecosystems to be managed in the marine protected area, (ii) adherence to principles for designing small-scale marine protected areas, (iii) adherence to the design principles for common-pool resource management, and (iv) stakeholder participation. We found varying levels of support for these hypotheses. Improved fisheries were associated with older marine protected areas, and higher levels of enforcement. Declining fisheries were associated with several ecological and economic factors, including low productivity, high mobility, and high market value. High levels of participation were correlated with improvements in wellbeing and ecosystem health trends. Overall, this study constitutes an important first step in identifying factors affecting social wellbeing and ecological performance of large marine protected areas.

1. Introduction

Global concerns about declines in marine biodiversity (Cheung *et al.* 2009) have led to increasing commitments to establish marine protected areas (MPAs) (Convention on Biological Diversity 2010). Marine protected areas – "a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Day et al. 2012) – have been used as a resource and biodiversity conservation tool for centuries (Johannes 2002). Although most MPAs are relatively small in size (median size 3.3km^2; Boonzaier and Pauly 2016), recent years have seen an increase in the designation of very large MPAs (Boonzaier and Pauly 2016).

Large MPAs (LMPAs, also referred to as large-scale MPAs), some of which exceed one million km^2, have become a high profile marine conservation strategy that now constitute a disproportionate proportion of the ocean's protected area and have moved us closer to achieving international biodiversity targets (e.g., Aichi Target 11; Boonzaier and Pauly 2016). LMPAs differ from small-scale MPAs because they encompass more extensive areas, including biologically connected ecosystems, and a greater diversity of habitats, including pelagic and deep benthic areas (Wagner *et al.* 2013), as well as different human dimensions, that may include a greater number or diversity of human populations (Gruby *et al.* 2016). Thus, LMPAs have unique management requirements and challenges, including education and enforcement over vast areas, and management of dynamic seascapes (Maxwell *et al.* 2014). The primary objective of LMPAs is biodiversity conservation (Day *et al.* 2012), although they may take a variety of forms (e.g., no-take, multi-use, etc.) and also have other goals, such as social and economic (Wilhelm *et al.* 2014). As yet, no study has empirically evaluated different outcomes of LMPAs.

The contributions of LMPAs to biodiversity conservation are debated. Proponents argue that very large protected areas are essential for meeting global marine conservation targets (e.g., Aichi Target 11), are ecologically critical because they encompass entire ecosystems, enable synergistic links to adjacent ecosystems (Toonen *et al.* 2011; Sheppard *et al.* 2012), and may be more resilient to large-scale disturbances (McLeod *et al.* 2009; Toonen *et al.* 2013). Furthermore, they are thought to provide benefits to wide-ranging species, such as seabirds and tunas (Maxwell and Morgan 2013; Young *et al.* 2015). However it has also been argued that LMPAs may contribute more to political targets rather than biodiversity conservation (Devillers *et al.* 2015). While both of these arguments are potentially valid, there is a large and growing need to better understand factors influencing the effectiveness of LMPAs, particularly on the diverse social and ecological outcomes these areas are expected to achieve.

Given the rapid increase in the number and total size of LMPAs (Boonzaier and Pauly 2016; S1), empirical investigations of their effectiveness are urgently needed to validate the development and maintenance of such areas. More specifically, understanding the social, ecological, and governance mechanisms that contribute to outcomes (e.g., protecting marine species, restoring fish stocks, minimizing conflicts among user groups) would help improve management of existing LMPAs and inform the establishment of others (Gruby *et al.* 2016). Fortunately, there is an abundance of research from related literatures – especially MPA design and common-pool resources – that can provide guidance regarding potentially influential factors. For example, recent studies demonstrate the importance of the ecological and economic attributes of species and ecosystems being managed: systems or species that are more productive, resilient, less mobile, sheltered from major markets, and have lower market value are more likely to have a positive response to protection (Claudet *et al.* 2010; Collette *et al.* 2011a). The attributes of the MPA have also been shown to influence outcomes: a recent study found that MPAs that include no-take areas, are well-enforced, old (>10 years), large (>100km^2), and isolated are more likely to be ecologically effective (i.e. as measured through higher fish biomass) (Edgar *et al.* 2014). In addition, a growing body of research and guidance on MPA design argues that MPAs or MPA networks that are explicitly designed to be comprehensive, adequate, and representative are more likely to be ecologically effective (Margules and Pressey 2000).

The social and governance attributes of MPAs have also been shown to play a critical role in conservation outcomes. First, the literature on common pool resources provides insights on several institutional factors collectively known as the "institutional design principles" (Ostrom 1990; Cox *et al.* 2010) that could affect the performance of MPAs. This literature suggests that the persistence of governance arrangements – and hence resource sustainability – is more likely in the presence of one or more of a number of facilitating conditions, including: clearly defined boundaries of the resource (e.g., the MPA, and resources within it) and the actors eligible to extract resources therein; the fit between rules and the attributes of the problems they are meant to address; monitoring of users and ecological conditions; sanctioning of rule-breakers; conflict resolution mechanisms; and coordination among jurisdictions for larger systems (Ostrom 1990; Cox *et al.* 2010). Second, stakeholder participation is widely considered essential for effective management of natural resources (Berkes 2009). In the context of MPAs and fisheries, direct and active involvement of fishers in the decision making process often enhances their willingness to negotiate agreements and comply with the subsequent rules and regulations (McCay and Jentoft 1996; White *et al.* 2002). And critically, a lack of such engagements has been identified as one of the key components contributing to poor performance of many MPAs throughout the world (Ferse *et al.* 2010).

Our aim is to assess the social and ecological performance of LMPAs (>10,000km^2). To focus our investigation, we identified factors demonstrated to influence outcomes at small-scales, and grouped them into four thematic hypotheses based on their origin in the literature: 1) Ecological and economic attributes of the species or ecosystem; 2) Attributes of the MPA; 3) Institutional design principles; and 4) Participation (S2). Our study is the first to empirically examine outcomes in LMPAs, and provides insights that can help guide management of current and future LMPAs.

2. Methods

2.1 Selection of cases: LMPAs were selected for analysis based upon 1) biodiversity conservation as a primary goal; 2) large size, defined as >10,000km^2 because it encompasses MPAs several magnitudes larger than the median size 3.3km^2 (Boonzaier and Pauly 2016); 3) more than five years of active management (defined as having legislation and/or management plans in place, and some actions to implement these); five years - to provide enough time for ecological and social effects of management to be evident (Halpern and Warner 2002), our cut-off was 2014 when coding was started; and 4) enough data available to assess key outcomes. We selected LMPAs from MPAtlas.org (Marine Conservation Institute 2015) based on goal, size and age criteria, and then conducted a preliminary literature search to determine whether management actions were occurring, and the level of data available. Globally, 16 MPAs met the first three of our criteria. Four were excluded because they either lacked active management or adequate data on outcomes, resulting in a final sample of 12 MPAs (Figure 1; see S1 for a complete list of LMPAs, including those that did not meet our criteria).

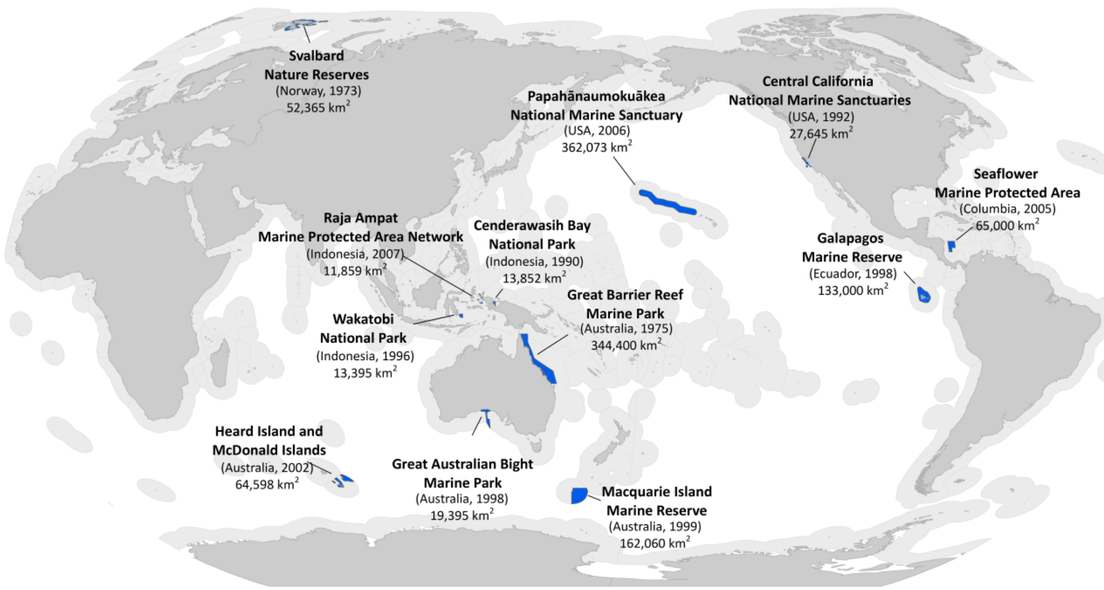

Figure 1. MPA name, country of origin, date designated, and total size of large MPAs used in this study, (see S1 for complete list of LMPAs).

2.2 Coding framework: The Social-Ecological Systems Meta-Analysis Database (SESMAD) (Cox 2014) was used to structure our investigation and provide a consistent approach for coding the 12 LMPA cases. SESMAD is structured around the social-ecological systems framework (Ostrom 2009b), which recognises that actor groups influence social and ecological outcomes through interactions between the governance systems, other actor groups, and environmental commons (Cox 2014). For each LMPA, we coded one or more governance system (the act or management plan(s) that provides the framework for management of the MPA), an actor group (one manager group that implements the governance system, and at least one user group dependent on marine resources, typically a fisher, where such users were present), and two components relating to the ecological system: a proxy for ecosystem health, and a proxy for fished species. We refer to these proxies as “environmental commons” because they relate to the resource systems or units being managed. Both proxies were selected based on a) measurability: availability of data on condition trends over time; and b) sensitivity: ability to reflect general trends at the scale of the MPA (e.g., a proxy for ecosystem health was chosen based on its ability to reflect the overall ecosystem integrity of the MPA, such as coral cover, or a higher trophic-level species). Interactions were structured around the environmental commons, creating two interactions for each MPA: one for the fished species proxy and another for the ecosystem health proxy. Each MPA was coded for a time period where management was relatively consistent, referred to as a ‘snapshot’ (e.g. major legislative changes or policy reforms would be coded as a separate snapshot). Thus, each interaction focussed on a specific snapshot, and included the key components (governance system, actor groups) that most directly interact with the selected environmental commons at the scale of the MPA.

2.3. Coding approach: For each LMPA, we conducted a detailed literature review, including peer-reviewed studies, management plans, government publications, and NGO reports. LMPAs varied in the documentation available; we provide a summary of confidence in the data in Table 1 (level of documentation). From the literature review, we identified the most influential or impactful governance system, user group, and manager for each interaction. We then added these key components to SESMAD (S3), with variables coded using knowledge from secondary data identified in the detailed literature review, as far as possible. Most variables were categorical (e.g., high, medium, low); the categorical nature of the data allowed us to compare across cases where different metrics might be used for the same variable. We then verified the choice of components coded for each LMPA, and the general trends through semi-structured interviews with one or more key informants for each LMPA. Key informants were identified using the following criteria: long (>5 years) involvement in management of the LMPA, and having published on the LMPA. Both of these criteria were aimed at identifying key informants who could provide an overview of experiences and different perspectives of the LMPA, rather than providing a sectoral perspective. The main purpose of these interviews was to gain an understanding of how the LMPA was operating 'on-the-ground' and to sense-check findings. Interviews were not a primary source of data for the variables used in this study

2.4 Inter-coder reliability: We used several approaches to ensure inter-coder reliability: 1) we developed clear descriptions of the variables being coded (S2); 2) all cases were coded by pairs of coders, to allow two people to gain in-depth understanding of the case, and discuss the coding process; 3) we held regular discussions among the research team to ensure consistent interpretation of variables across cases.

2.5 Variables coded: We coded two key outcome variables for the snapshot being assessed in each case. Outcome variables were: 1) the trend in the condition of the environmental commons (fished species and ecosystem health proxies; options are decreased, remained the same, and increased); and 2) the trend in the wellbeing of the user group dependent on the fishery has changed; options are declined, remained the same, improved. We selected potential explanatory variables to test four thematic hypotheses (also referred to as "theories" by Cox *et al.* 2016; S2). We use hypotheses to refer to proposed relationships between factors and outcomes in marine protected areas or common pool resources as suggested in the literature; and we refer to them as thematic hypotheses because we have grouped factors based on their origin in the literature.

2.6 Data Analyses: All analyses were conducted using R (version 3.2.2; R Core Team 2015). To test for any association between our four thematic hypotheses and MPA outcomes (trends in fisheries, ecosystem health, and wellbeing) we used a Multiple Correspondence Analysis (MCA) for the categorical variables, and Principal Components Analysis (PCA) for the continuous variables, using the FactoMineR package (Husson *et al.* 2015). Both methods are conceptually similar; their main objective is to simplify the data by reducing the dimensionality of the dataset to reveal relationships (Lê *et al.* 2008). These methods reduce complex sets of variables into dimensions that comprise subsets of variables (that are correlated with one another, but relatively independent of other variables) to represent the variation in the data, and can be interpreted as representing underlying factors that lead to patterns in responses. Each of the three outcomes (trends in fisheries, ecosystem health, and wellbeing) were analysed with respect to the four sets of hypotheses. Response variables (outcomes) are included as 'supplementary variables' in MCA and PCA to assist in data interpretation (Lê *et al.* 2008). The variables for each hypothesis (predictor variables) were included as 'active' variables in the analysis, meaning that they contribute to the formation of the dimensions. The outcome of interest was included as a 'supplementary variable', because these variables are not involved in the formation of dimensions but are overlaid onto the same space; any association between active and supplementary (response) variables indicates there is a strong correlation (i.e., between the predictor and response variables) (Husson *et al.* 2010). We assessed relationships in the data both visually using biplots with confidence ellipses for the outcomes, and analytically using the *dimdesc* function (Husson *et al.* 2015) to extract all variables with a significant contribution ($p<0.10$) to the first two dimensions. This function provides the correlation coefficient, and also performs a test to determine if the variables and the variable categories are significant (Husson *et al.* 2010). All cases were included in the analyses as appropriate. Prior to analysis, any variables with no variation (i.e., all coding values were the same) were removed, and missing data were imputed using an iterative logarithm using the MissMDA package to prevent the results being disturbed by missing values (Husson and Josse 2015). We focus our results on the first two dimensions for each analysis because they were sufficient to explain a high proportion of the variance (minimum 49%; S4). We demonstrate this approach in detail for the first analysis - ecological and economic attributes variables and the fisheries trend outcome (see S5 and S6), and then summarize these for the remaining analyses (see S7 for full results).

3. Results

3.1 Thematic hypothesis 1- Ecological and economic attributes of the species or ecosystem:

MPAs were hypothesized to be more successful if the species and ecosystems have high productivity, high ecological resilience and low mobility, in addition to a lower market value, and greater distance to market (Claudet *et al.* 2010; Collette *et al.* 2011a; Cinner *et al.* 2013).

The fisheries trend (n=11) was correlated to the first dimension (R^2 0.75; $p<0.01$; S5; S6). This dimension was characterised by the variables: fisheries productivity, economic value, and distance to market and explained 29% of the data variation. Overall, the first two dimensions explained a total of 50% of the data variation. Decreasing fishery trends were correlated ($p<0.01$) with low fisheries productivity, high resource value, high mobility, and distance to markets (>

1000 km) (Table 3). Increasing fisheries trends were correlated ($p=0.08$) with intermediate resource value and intermediate fisheries productivity (S7). Declines in wellbeing ($n=10$) were associated with intermediate fisheries productivity, intermediate resource value ($p<0.05$), and close proximity to markets ($p<0.1$) (Dimension 1, 29%). No significant relationships were found for ecosystem health outcomes.

The association between trends in fished species, low fisheries productivity, and high economic value is consistent with other findings (Claudet *et al.* 2010; Collette *et al.* 2011b). However, the relationship between market distance and fishery declines was unexpected, as many studies indicate that close proximity to markets leads to overexploitation (Liese *et al.* 2007; Cinner *et al.* 2013; Table 2). However, in our study, decreased fishery trends were also associated with high value fisheries, including Southern bluefin tuna in the Great Australian Bight Marine Reserve, and Patagonian toothfish in the Heard and Macdonald Islands and Macquarie Island Marine Reserves. Southern bluefin tuna are a highly mobile species, and the population is not very productive (i.e., they are long lived and late maturing), with population estimates at 9% of the initial spawning stock biomass (Commission for the Conservation of Southern Bluefin Tuna 2014). Southern bluefin tuna are targeted in the Great Australian Bight where they are caught using purse seines and subsequently placed in ranches before being sold to Japanese markets. Despite their stock declines they remain the most valuable fishery in South Australia (Skirtun *et al.* 2013). Similarly, Patagonian toothfish that also have low productivity are targeted around the Subantarctic Heard and Macdonald Islands and Macquarie Island. Despite difficult fishing conditions and vast distances to market, the high value of the Patagonian toothfish means that fishing in these remote areas can be commercially profitable. The Patagonian toothfish stocks in these areas have been exploited since the mid-1990s, and although the biomass has decreased, estimates suggest that they remain at healthy levels (i.e., >50% of unfished levels).

The correlation between increasing fisheries trends and resources with intermediate levels of productivity and value is likely driven by the incentives that actors face to manage these types of resources (Basurto and Ostrom 2009; Ostrom 2009b). Fisheries with a sufficiently high value and productivity generate incentives for actors to invest in management (e.g., gear restrictions and/or no take zones (Basurto and Ostrom 2009; Ostrom 2009b)), but not so high as to promote unsustainable rates of exploitation. However, the same attributes were also correlated with a decline in wellbeing, reflecting a possible trade-off between effective management of fisheries and associated wellbeing in LMPAs. For example, within the time period we investigated, in the Great Barrier Reef Marine Park, a decline in wellbeing occurred as a result of the extensive establishment of no-take areas (33% of the MPA) that reduced the availability of fishing grounds to fishers (Ban *et al.* 2015), but has also seen an increase in fish biomass (Emslie *et al.* 2015).

Table 1. Summary of LMPAs included in this study, with their associated ecological and wellbeing trends (outcomes) for both the fishery and ecosystem health proxies. Trends were assessed over a stable governance time period (S3). Up arrows indicate improvements in wellbeing or conditions of fisheries and ecosystem health indicator, down arrows indicate declines, and dashes indicate that outcomes have remained stable or have mixed results. The coloured boxes for fishery and ecosystem health trends reflect the state of the resource, and broadly reflect ‘stable states’: green boxes indicate an ecosystem or species in good condition, orange boxes indicate potential proximity to a threshold, red boxes indicate a degraded or

overexploited condition. The state was not available for wellbeing. The state was not included in the analysis, but is noted here for information only. NA denotes not applicable, and x means no information available. Level of documentation was judged on a three-point scale and was based on the number of Google scholar results for each case (low < 1,000; medium 1,001-9,999; high >10,000).

Case	Fishery trend	Wellbeing trend	Ecosystem health trend	Level of documentation
Cenderawasih Bay National Park (Indonesia)	–	–	–	Low
Central California National Marine Sanctuaries (USA)	↑	↓	↑	High
Galapagos Marine Reserve (Ecuador)	↓	↓	–	High
Great Australian Bight Marine Park (Australia)	↓	↑	↓	Medium
Great Barrier Reef Marine Park (Australia)	↑	↓	↓	High
Heard Island and McDonald Islands (Australia)	↓	–	–	Medium
Macquarie Island Marine Reserve (Australia)	↓	–	–	Medium
Papahānaumokuākea Marine National Monument (USA)	–	NA	–	High
Raja Ampat MPA network (Indonesia)	–	↑	–	Medium
Seaflower MPA (Colombia)	–	x	↓	Low
Svalbard Nature Reserves (Norway)	↑	↓	–	Medium
Wakatobi National Park (Indonesia)	–	↓	–	Medium

Table 2. Hypotheses with the associated variables and their expected impact on trends and wellbeing, and the corresponding support found in our study for the fisheries and ecosystem health interactions (for additional detail on findings please refer to Table 3)

✓ = evidence found, ○ = unexpected finding: result was either not linked to a hypothesis or counter-intuitive to the hypothesis.

Hypothesis	Variable category	Expected fisheries trend	Evidence	Expected wellbeing trend	Evidence	Expected ecosystem health trend	Evidence
1	Low productivity	↓	✓		○	↓	
	High ecological resilience	↑			○	↑	
	High mobility of the commons	↓	✓			↓	
	High market value	↓	✓		○	↓	
	Close proximity to market	↓	○			↓	
2	High compliance and enforcement	↑	✓			↑	
	Older MPA	↑	✓				
	Larger spatial extent	↑					
	Larger proportion no-take areas	↑					
	Greater isolation	↑					
	Explicit inclusion of MPA design criteria	↑				↑	
3	Clear boundaries between users and non-users	↑		↑		↑	○
	Clear resource boundaries	↑		↑		↑	○

	Good fit between ecological and social conditions	⬆		⬆	○	⬆	✓
	Proportionality of cost and benefits	⬆		⬆	✓	⬆	
	High participation in rule-making	⬆	○	⬆	✓	⬆	○
	Self-monitoring of users	⬆		⬆		⬆	
	High environmental monitoring by users	⬆	○	⬆		⬆	✓
	Graduated self-sanctions	⬆		⬆		⬆	
	Presence of conflict resolution mechanisms	⬆		⬆		⬆	
	Some autonomy of users	⬆	○	⬆	○	⬆	
	Coordination among multiple jurisdictions	⬆		⬆		⬆	
	High compliance	⬆		⬆	✓	⬆	✓
	Some or total outsider exclusion	⬆	○	⬆	✓	⬆	
4	High participation in rule-making	⬆	○	⬆	✓	⬆	
	High participation in MPA siting	⬆	○	⬆	✓	⬆	
	High participation in MPA zoning	⬆		⬆	✓	⬆	
	High participation in environmental monitoring	⬆	○	⬆	✓	⬆	

	High participation in social monitoring	⬆		⬆	✓	⬆	

3.2 Thematic hypothesis 2 - Attributes of the MPA: MPAs that are older, have a larger spatial extent, larger proportion of no-take areas, more isolation, high levels of compliance and enforcement (Edgar *et al.* 2014), in addition to explicit inclusion of MPA design criteria (comprehensive, adequate, representative) in MPA selection and zoning were hypothesized to result in more successful outcomes (Margules and Pressey 2000).

The fisheries trend (n=12) was correlated with the second dimension (R^2 0.73; $p<0.01$); which was characterised by the variables: age since designation, duration of current governance regime (snapshot), and enforcement; this dimension explained 25% of the data variation. Improved fisheries trends were associated with older MPAs and higher levels of compliance and enforcement (Table 3). No significant associations were found for other outcomes.

Although our study differed from Edgar *et al*. (2014), which was based on an examination of MPAs globally (n=87) and used measures of fish biomass across sites as metrics of effectiveness, we also found older MPAs and higher levels of compliance and enforcement to be associated with positive fisheries trends. Enforcement has been discussed as crucial for achieving conservation goals in LMPAs, which our data supports. The age of the MPA could be important because it provides time for species to recover (Lester *et al.* 2009), for trust to develop among actors (Ostrom 2009a), and for management to be adapted and improved (Armitage *et al.* 2008). For instance, the adaptive management approach used to govern the Great Barrier Reef Marine

Park is the result of approximately 40 years of investments in conservation and opportunities for stakeholders to gain knowledge and experience with management and enforcement (McCook *et al.* 2010). In particular, long-term ecological monitoring and environmental research has provided knowledge to support the development of more effective zoning and fisheries management regimes for improved fisheries outcomes (Harrison *et al.* 2012). Similarly, in the central California National Marine Sanctuaries, the Gulf of the Farallones has 35 years of monitoring and enforcement experience that has allowed managers and scientists to improve planning, engage with complementary resource agencies (i.e., the National Marine Fisheries Service), create informed spatial plans for essential fish habitats and adaptive rockfish conservation areas, and to observe recovery (de Marignac *et al.* 2009).

3.3 Thematic hypothesis 3 - social and governance attributes: the institutional design principles: We examined the institutional design principles from the literature on common pool resources (Ostrom 1990; Cox *et al.* 2010). We hypothesized that presence of the institutional design principles would lead to more successful outcomes.

The fisheries trend (n=11) was correlated to the second dimension (R^2 0.73; $p<0.01$), which explained 24% of the data variation. A declining fisheries trend ($p=0.003$) was correlated with moderate external recognition, intermediate levels of participation and environmental monitoring, and total outsider exclusion ($p<0.05$), no self-monitoring or sanctions, intermediate social-ecological fit, and proportionality of cost and benefits ($p<0.1$).

Improvements (p=0.07) and declines (p=0.08) in the wellbeing of fishery user groups (n=10) were correlated with the second dimension, which explained 25% of the data variability. Improved wellbeing was associated with the variable categories: high compliance, proportionality of cost and benefits, intermediate social-ecological fit (p<0.05), rigid boundaries, moderate external recognition, and intermediate environmental monitoring (p<0.10). A decline in wellbeing was associated with the variable categories: some compliance, no proportionality of cost and benefits, low participation, low external recognition, no outsider exclusion (p<0.05), low social-ecological fit, and low environmental monitoring (p<0.10).

Improved ecosystem health trends (n=10) were associated with the first dimension, which explained 27% of the data variation, and were correlated with the variable categories: high environmental monitoring, high social-ecological fit, intermediate participation, moderate boundary negotiability, unclear user boundaries, high compliance (p<0.05), and fuzzy user boundaries (p<0.10; Table 3).

While the presence of the institutional design principles is commonly thought to lead to improved trends in resource conditions, we found outsider exclusion plus the partial presence (intermediate or moderate values) of three of the institutional design principles to be associated with a declining fisheries trend. Given the theoretical mechanisms by which such principles can work to enable sustainable commons management, these are surprising results that warrant unpacking, particularly with respect to the principle of outsider exclusion. Three of the Australian LMPAs experienced declining fisheries yet had intermediate levels of participation in management and were active participants in environmental monitoring programs such as tagrecapture surveys. Southern bluefin tuna are fished in the Great Australian Bight Marine Park, but have also been intensively fished throughout their range since the 1950s and have experienced severe population declines (Commission for the Conservation of Southern Bluefin Tuna 2014). In contrast, the declines in Patagonian toothfish in the Australian Sub-Antarctic LMPAs (Heard and Macdonald Islands, and Macquarie Island) are an intentional management action: relatively recently exploited stocks that are considered above Maximum Sustainable Yield. Outsider exclusion is postulated to be an important factor to ensure that a commons is not over-exploited (Ostrom 1990; Basurto and Ostrom 2009; Cox *et al.* 2010). However, the effects of exclusion might also depend upon the extent to which actors are dependent upon a particular stock. The same companies hold rights to fish for toothfish in both the Heard and MacDonald Islands and Macquarie Islands fisheries (and other areas) and as a result have lower incentives to lobby for conservation of any individual stock. Similarly because of the high economic value of the fished species (Southern bluefin tuna and Patagonian toothfish); short-term harvests might be rationally preferred over long-term conservation (and see thematic hypothesis 1). More generally, it appears that the presence of individual factors is neither necessary nor sufficient for success, highlighting the limitations of institutional theory when applied to complex cases.

Improved wellbeing related to fisheries was associated with more equitable distribution of social impacts and a system where rules are adjusted to fit local conditions (e.g., proportionality of costs and benefits, intermediate social-ecological fit, intermediate external recognition). Where the benefits of managing resources are distributed in proportion to the costs that actors incur in managing them, actors are more likely to make long-term investments of time and resources in activities such as monitoring and rule-making (Cox *et al.* 2010); providing benefits to the group as a whole. Conversely, a decline in wellbeing was linked to the absence of many of these conditions including a lack of proportionality of cost and benefits, low participation, and low external recognition: suggesting a situation where there is a lack of recognition and rights in LMPA governance, the rules do not necessarily reflect local conditions or needs, and the fishers are bearing costs of management actions (e.g., no-take zones). In the Wakatobi National Park (WNP), the Bajau depend almost exclusively on marine resources and fishing is central to their culture and society (Clifton 2013). The governance of the WNP is poorly adapted to local institutions and marine system dynamics (von Heland and Clifton 2014) and the Bajau have had limited involvement in the rules of the park and ongoing environmental monitoring. Bajau have been marginalised through both state and NGO initiatives in the WNP (Clifton 2013) and their wellbeing can be considered to have declined, with reported changes in social customs and perceived loss in freedom, which are elements central to their identity (C.Tam, pers comm). Conversely, another LMPA in Indonesia is the Raja Ampat marine network that was established 11 years after the WNP through a bottom-up approach. This network has a higher percentage of no-take zones than WNP and each of the MPAs in the LMPA network are managed collaboratively between local communities, NGOs, and government (intermediate social-ecological fit, and proportionality). Consequently there is high compliance, and improvements have been noted across a range of wellbeing indicators (Glew *et al.* 2015).

An improved trend in ecosystem health was also linked to the factors that suggest the rules are appropriate for local conditions and needs, with involvement of groups with environmental monitoring and high compliance. This configuration is illustrated with the Central California National Marine Sanctuaries (CCNMS). The CCNMS maintains high levels of ecosystem health

(Office of National Marine Sanctuaries 2008) and has also successfully mitigated threats to ecosystem health in recent years (e.g., oil exploitation) (Office of National Marine Sanctuaries 2010). Within the CCNMS there are a number of user-led long-term monitoring projects, and the Sanctuary Advisory Council formally incorporates stakeholder input into the management of the LMPA, and compliance is high. While the user boundaries are unclear, this reflects the flexibility and inclusivity of the rule system to incorporate any potential user, which in this instance does not appear to adversely affect trends in ecosystem health.

3.4 Thematic hypothesis 4 – social attributes of the MPA: Participation: Participation is commonly linked to successful resource management in the literature on common pool resources. However, the design principles are limited by using a single aggregate indicator of participation; neglecting the multiple aspects of participation that are potentially relevant for LMPAs. We hypothesized that LMPAs are more successful when there is participation at all stages in rule-making; including MPA siting, MPA zoning, as well as environmental and social monitoring.

The fisheries trend (n=11) was correlated to the second dimension (R^2 0.59; p=0.03), characterised by the participation variables: rule-making, zoning, environmental monitoring, and siting, and explained 31% of the data variation. A declining fisheries trend (p=0.01) was associated with intermediate levels of participation in environmental monitoring, siting, rule-making, and zoning (Table 3). Improvements in user wellbeing (n=10) were correlated to the first dimension (p=0.05), and associated with high participation in zoning, social monitoring, siting, rule-making, and environmental monitoring ($p<0.05$; Table 3). No significant associations were found for other outcomes.

Intermediate levels of participation in different activities were associated with declines in fished species, whereas high levels of participation were linked to improved wellbeing. The Raja Ampat Marine Network illustrates the importance of participation, as it has high levels of participation in all aspects, and is unique among our sample of LMPAs in that it was initiated and established through a collaborative effort between communities, government, and International NGOs. Local communities originally designated the sites through customary law (*adat* declarations), building on local marine tenure and traditional management, and they remain formally involved in the management of the MPAs. A variety of wellbeing indicators including food security and school enrollment, have been recorded as improving across the sites (Glew *et al.* 2015). By contrast, the sea cucumber fishery in Galapagos Marine Reserve has experienced dramatic declines, and is now considered overexploited and economically extinct (Toral-Granda 2008). The Galapagos Marine Reserve had intermediate levels of participation because it has a two-tier governance framework, including the Participatory Management Board, a decision making body comprised of local representatives of tourism, naturalist guide, and fishing sectors, Galapagos National Parks Service, and (until 2008) the Charles Darwin Foundation. Although the creation of the Participatory Management Board was a milestone in community participation, the first five years were dominated by social unrest and conflict (Jones 2013). During this time, the Participatory Management Board established sea cucumber quotas that were based on political considerations rather than scientific data, which contributed to the overexploitation of sea cucumbers (Wolff *et al.* 2012). However, in more recent years, the Participatory

Management Board has been able to reach consensus, and the sea cucumber fishery which was closed for four years (it was opened in 2015), although it has not yet shown signs of recovery.

Table 3. Summary of the variable categories correlated with outcomes (p<0.05) for each thematic hypothesis. Green text = associated with improved outcome; red text = associated with decline. Where no correlations to outcomes were found, the cell has been shaded grey.

	Outcomes		
	Fisheries	Wellbeing	Ecosystem health
1. Ecological & economic attributes	Low productivity; High economic value; Distance to market > 1000km; High mobility	Intermediate productivity; Intermediate economic value	
2. Attributes of MPAs	Older; High enforcement		
3. Design principles	Moderate external recognition; Intermediate participation; Intermediate environmental monitoring; Total outsider exclusion	High compliance; Proportionality of cost & benefits; Intermediate social-ecological fit Some compliance; No proportionality of cost & benefits; Low participation; Low external recognition; No outsider exclusion	High environmental monitoring; High social-ecological fit; Intermediate participation; Moderate boundary negotiability; Unclear user boundaries; High compliance
4. Participation	Intermediate participation in: siting; rulemaking; environmental monitoring	High participation in: zoning; social monitoring; siting; rulemaking; environmental monitoring	

4. Discussion and Conclusions

Marine protected areas (MPAs) remain an important tool for biodiversity conservation and there has been an increase in the implementation of LMPAs (Spalding *et al.* 2013; Boonzaier and Pauly 2016). Our study is the first to examine the extent to which findings from small-scale MPAs and common pool resource theory apply to LMPAs. We found that: (i) targeted species with low levels of productivity, high mobility, and high market value were related to fisheries decline; (ii) older MPAs with higher levels of compliance and enforcement were associated with improved fisheries trends; (iii) low levels of participation by resource users and limited external recognition were related to declines in wellbeing, whereas (iv) high participation in zoning, social monitoring, siting, rulemaking and environmental monitoring were associated with improvements in wellbeing (Table 3).

There were also a number of unexpected results. For instance, we expected to observe improvements in fished species with an increasing distance to market, but rather found the opposite relationship. Similarly, the association between declining fisheries and intermediate levels of external recognition, participation, and high levels of outsider exclusion are somewhat at odds with Ostrom's (1990) institutional design principles. We also expected intermediate or high (as opposed to low) levels of participation in siting, rulemaking, and environmental monitoring to be associated with improvements in targeted fish stocks. We assessed the thematic hypotheses against trends in fisheries, ecosystem health, and wellbeing, whereas many studies from which the theory is derived have used static outcome measures (e.g., relative biomass, subjective assessments of environmental conditions, state of the system, etc.). Trends provide a different way of thinking about effectiveness than state (e.g., has governance halted or reversed declining trends?). Additionally, there are many challenges to scaling up theory from the small-scale to large-scale systems, and indeed the applicability of the design principles to large-scale environmental governance has been questioned (Young 2002; Araral 2014). Although our results provide partial support for the design principles at the large-scale, they also reveal some of the limitations of institutional theory when applied to complex cases.

Stakeholder participation is now synonymous with protected area design and environmental management more broadly for both instrumental (better outcomes) and ethical reasons (people should be involved in decisions that affect them) (Berkes 2009). Indeed, we found improvements in wellbeing associated with high participation in zoning, social monitoring, siting, rule-making, and environmental monitoring. At smaller scales, although many groups may have a stake in management decisions, it is far easier to identify who those stakeholders are and develop mechanisms to mitigate impacts from MPAs. Furthermore, transaction costs associated with participation are likely to rise precipitously at larger scales particularly for tasks such as enforcement and environmental monitoring. For these reasons, designing (and indeed coding) governance arrangements based on the autonomy and participation of resource users are challenging at large-scales. Many LMPAs have invested considerable effort in designing processes for stakeholder engagement, and yet, given the size of LMPAs, these initiatives only reach a subset of stakeholders. Moreover, stakeholder groups often struggle to achieve broad-scale representation of their members in response to LMPAs because of the challenge in organizing and mobilizing a large group with typically diverse interests, values, and perspectives (Wilhelm *et al.* 2014). In large-scale systems it is therefore relatively rare to achieve high levels of citizen control or user participation in management. Importantly, our data suggest that even in the absence of improving fisheries, high levels of participation and proportionality of costs and benefits among stakeholders contributes to improvements in the wellbeing of user groups.

Our analysis of LMPAs is limited by a number of factors. First, the small number of LMPAs with at least 5 years of active management limits our ability to detect statistically significant relationships (although we note that this was the full sample of cases available; S1). Furthermore, where cases did not have a direct user of fishery resources (Papahānaumokuākea, which is all no-take and far from human populations) or information available on wellbeing trends (Seaflower) they were excluded from certain analyses, which further eroded statistical power of some tests. Even though all of the LMPAs in our sample have been actively managed for at least five years, long-term data were not always readily available. Studies were also biased towards the ecological aspects of the MPA, with lower levels of documentation for social data. In addition, there is a known publication bias of 'positive' studies and it is likely that negative impacts or outcomes from LMPAs are under-reported due to concerns about exposing shortcomings. We encourage improved monitoring and reporting from LMPAs to enable cross-fertilization of lessons across the growing population of LMPAs, including failures and successes. Finally, global meta-analyses are inherently challenged by the variability of cases and different metrics across variables. We overcame this limitation by measuring variables with 3-point Likert scales and binary variables (S2), but this approach masks more nuanced information for cases where more detail exists. Despite these limitations, our study demonstrates a first attempt at investigating the applicability of hypotheses developed from small-scale systems for LMPAs that can be used for the design of future studies and the collection of comparable data in multiple LMPAs.

Our findings allow us to provide some general guidance for LMPA management. First, compliance and enforcement matters across multiple outcomes: increased trends in ecosystem health and fished stocks, and improved wellbeing. Thus improving compliance and enforcement should be a priority for managers of LMPAs, and should be considered in their design and implementation. Second, participation appears to influence various outcomes, with intermediate levels of participation being linked to declines in fished species but improvements in ecosystem health, and high participation being associated with improvements in wellbeing. Engaging in meaningful participation in all aspects of design, implementation, and management of LMPAs should be a priority for managers. Finally, some attributes of MPAs and species also matter, and thus management activities should consider the productivity, mobility, and economic value of targeted species. Some of these variables can be directly influenced by the design and management of LMPAs (e.g., compliance and enforcement, participation), whereas others (e.g., productivity, mobility, market value) are outside of the influence of managers.

While some of our findings can lead to general recommendations, there are unlikely to be fail-safe panaceas for creating socially and ecologically effective LMPAs. Rather, it is important to craft management to fit the local context (Young 2002). Our MPA cases may have had positive outcomes for a diversity of reasons that are tied to the diversity of the ecological environment, the actors, or the governance system itself. Improved monitoring and reporting of a range of social and ecological outcomes will aid further understanding of factors of success in LMPAs.

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S1. Full list of designated large Marine Protected Areas (>10,000km^2), ordered from oldest to newest. LMPAs that fulfilled our selection criteria (1: Primary goal of biodiversity conservation; 2: Large; 3: > 5 years active management; 4: Enough data available to assess key outcomes) and were included in our study are marked in **bold**. The rationale for LMPAs that appear to fit our criteria but were not used in our study has been noted. Information from MPAtlas.org.

LMPA name	Date designated	Size (km^2)	Included (Y/N)	Rationale
East Svalbard Nature Reserves	**1973**	**52,365**	**Y**	
Greenland National Park	1974	110,600	N	Not enough data
Great Barrier Reef Marine Park	**1975**	**344,400**	**Y**	
Dominican Republic Marine Mammal Sanctuary	1986	66,670	N	Not enough data
Cenderawasih Bay National Park	**1990**	**13,852**	**Y**	
Central California National Marine Sanctuaries	**1992**	**27,645**	**Y**	
Franz Josef Land	1994	26,000	N	No active management of the marine area
Wakatobi National Park	**1996**	**13,395**	**Y**	
Galapagos Marine Reserve	**1998**	**133,000**	**Y**	
Great Australian Bight Marine Park	**1998**	**19,395**	**Y**	
Macquarie Island Marine Reserve	**1999**	**162,060**	**Y**	
Pelagos Sanctuary	2001	87,492	N	No active management
Heard Island and McDonald Islands	**2002**	**64,598**	**Y**	
Seaflower MPA	**2005**	**65,000**	**Y**	
Papahanaumokuakea Marine National Monument	**2006**	**362,073***	**Y**	
Phoenix Islands Protected Area	2006	408,224	N	Management plan introduced in 2010
Raja Ampat MPA Network	**2007**	**11,859**	**Y**	
LMPAs below had not had active management for five years (at time of coding)				
Marianas Trench Marine National Monument	2009	250,488	N	Management in development
Pacific Remote Islands Marine National Monument	2009	1,271,525	N	Management in development
Rose Atoll Marine National Monument	2009	34,838	N	Management in

				development
South Orkney Islands Southern Shelf MPA	2010	93,818	N	Management introduced in 2013
Chagos MPA	2010	640,000	N	Interim management framework 2014-15
Charlie-Gibbs South High Seas MPA	2010	145,420	N	
Josephine Seamount High Seas MPA	2010	19,370		
Marine Park of Mayotte	2010	68,345	N	
Mid-Atlantic Ridge North of the Azores (MARNA)	2010	93,416	N	
Milne Seamount Complex MPA	2010	20,913	N	
Australia Commonwealth Marine Reserves (n=18)**	2012	1,871,668	N	
Charlie-Gibbs North High Seas MPA	2012	178,651	N	
Gloriosos Islands Marine Nature Park	2012	48,350	N	
South Georgia and South Sandwich Islands Marine Protected Area	2012	1,070,000	N	
Fagatale Bay National Marine Sanctuary	2012	35,174	N	
Prince Edward Islands MPA	2013	180,000	N	
Natural Park of the Coral Sea	2014	1,292,962	N	
Savu Sea (Tirosa Batek)	2014	29,454	N	
Motu Motivo Hiva Marine Park	2015	720,000	N	
Nazca Desventuradas	2015	297,000	N	
Palau National Marine Sanctuary	2015	500,000	N	
Pitcairn Islands Marine Reserve	2015	834,334	N	
Kermadec Ocean Sanctuary	2016	620,000	N	
Marae Moana Cook Islands (Cook Islands Marine Park)	2016	1,100,000	N	

* On 26th August 2016 Papahānaumokuākea Marine National Monument was extended to 1,508,870 km^2.

** Australia Commonwealth Marine Reserves >10,000km^2: Abrolhos; Argo-Rowley Terrace; Central Eastern; Coral Sea; Flinders; Freycinet; Gascoyne; Kimberly; Lord Howe; Murray; Norfolk; Oceanic Shoals; Shark Bay; South Tasman Rise; South-west Corner; Tasman Fracture; Western Eyre; Zeehan.

S2. Descriptions of the variables analysed for each thematic hypothesis.

Thematic hypothesis 1- Ecological and economic attributes of the species or ecosystem		
Variable	Question (and definition)	Options
Commons mobility	What is the mobility of this commons?	*High:* Commons is highly migratory and capable of regularly travelling great distances (>500 km, but often >5000km), and is typically considered a 'migratory species'; *Medium:* Commons may be fairly site specific but capable of larger movements (e.g. ontogenetic migration), or have a relatively large home-range >1-500 km; *Sessile/Low:* Commons is sessile or can move small distances (within 1 km)
Commons productivity	How productive is the commons?	*Very productive:* The unit or system produces at very high levels, and can withstand extensive human extraction and use, typical of modern large-scale industrial operations, for a period of time; *Moderately Productive:* The unit or system produces at moderate levels, and can withstand an equivalently moderate level of human extraction and use; *Poorly productive:* The unit or system produces at very low levels, and cannot withstand much human extraction and use beyond subsistence levels.
Ecological resilience	Given the current state of the system, how ecologically resilient is this commons to the threats that it can be expected to face?	Highly resilient; Moderately resilient; Poorly resilient
Resource market value	If it is traded in a market, how high is the market value of this resource?	*High:* Only very few actors have the purchasing power to purchase the commons (e.g., rare but highly desirable fish, e.g., bluefin tuna); *Medium:* Some actors have purchasing power to purchase the commons *Low:* Almost all actors have the purchasing power to

		purchase the commons (e.g., a very common, small fish such as sardines)
Distance to market	What is the approximate distance between the boundaries of this governance system and the nearest market in which the commons within this system are sold? (Only if commons are sold). *Definition:* Calculate or estimate the shortest distance from the governance boundary to the nearest market for the resources contained within the system. Major market could be a trading centre, large town or provincial capital and even a local middleman, but does not refer to local subsistence use.	Less than 10km; Between 10-100km; Between 100km-1000km; More than 1000km
Thematic hypothesis 2 - Attributes of the MPA		
Variable	Question (and definition)	Options
No take	What percentage of the area of this protected area is covered by no take zones (IUCN Ia, Ib, and II)?	Numerical
Age	What is the total age (years) of this governance system from	Numerical

	when it was originally designated to the end of this interaction?	
Snapshot age	What is the total age (years) of this governance system from the start of the interaction being considered to the end?	Numerical
Size	What is the total size (km2) of this protected area at the end of this snapshot?	Numerical
Efficient enforcement	What is the extent of compliance to regulations that restrict fishing, both through overt policing and through community support for regulations?	*High:* Appears to be well enforced, although clandestine poaching may occur; *Medium:* A moderate level of policing attempted, although infractions were apparent; *Low:* Little attempt at control, a 'paper park'
Isolated	Does the marine protected area protect an ecologically coherent area (i.e., limited or protected by deep water or sand) within no-take zones?	*High:* MPA zone isolated from fishing areas by depth (.25m) or sand barriers of at least 20m width. (if an island is all no take then it is classed as high); *Medium:* A small (1–20%) percentage of zone boundary breached by continuous shallow reef habitat; *Low:* Shallow (.25m) reef habitat extends continuously across MPA boundary
CAR principles	Were the ecological principles of Comprehensive, Adequate, Representative considered in the design of this MPA?	*Yes:* The CAR principles were fully considered in the design of the MPA and applied in practice, and the MPA is considered an appropriate size, shape and management level to ensure the ecological viability and integrity of the populations, species and communities, which have been selected as conservation features; *Partially:* Consideration was given to the CAR principles in the design of the MPA but their

		application was compromised, either through size, shape (some features bisected), or insufficient management or protection; *No:* The CAR principles were not considered in the design of the MPA (i.e. little or no consideration was given to the size and/or shape of the sites, and/or entire features are not sufficiently protected);
Thematic hypothesis 3 - social and governance attributes: the institutional design principles		
Variable	Question (and definition)	Options
Actor group boundary clarity	Are there clear rules that are followed about who and who isn't a member of this group?	*No boundaries:* Entire lack of common understanding regarding group membership; *Unclear boundaries:* Some of the members of this group are aware of who is and who isn't a member, and there is some enforcement of any rules associated with membership; *Clear boundaries:* The great majority of the members of this group are aware of who is and who isn't a member, and there is strong enforcement of any rules associated with membership
Actor group boundary fuzziness	Is membership in this actor group subject to ongoing negotiations (fuzzy boundaries)? Or are the boundaries the group more rigid?	*Rigid:* Changes in membership and the rights and obligations associated with membership change infrequently and are not changeable based on short to medium-term fluctuations; *Fuzzy:* Changes in membership and the rights and obligations associated with membership can change in a relatively ad hoc basis, based on the needs of users and potential members to access the benefits associated with membership
Commons boundaries	Are the boundaries that define the spatial extent of this commons clearly defined and highly visible?	*Very unclear boundaries:* The boundaries of a commons are difficult to identify with precision. That is usually the case with the boundaries of migratory species and with many groundwater aquifer systems; *Somewhat unclear boundaries:* The boundaries of a commons are somewhat identifiable. *Clear boundaries:* The limits of the commons are

		physically evident. This includes both natural elements and human-made artifacts that constrain the commons. Natural elements would include the biogeophysical limits of a watershed. Human-made artifacts would include fences that constrain a population of species.
Commons boundary negotiability	How negotiable is access by non-members of this actor group to this environmental commons?	*Rigid:* Negotiations to access this environmental commons by non-members are not possible or not fruitful; *Moderate:* Some negotiations can be made by non-members; *Negotiable:* Ad-hoc negotiations can be and are commonly made by non-members to obtain access to this environmental common
Outsider exclusion	To what extent are members of this commons user group able to exclude non-members (outsiders) from using this commons?	*No exclusion:* Outsiders face no impediments from the user group in their attempts to use the commons; *Some exclusion:* Members of a commons using actor group somewhat effectively prevent non-members for using a commons that they use; *Total exclusion:* Users are able to prevent the great majority to all incursion by outsiders
Social-ecological fit	To what extent (low, medium, or high) do the institutional arrangements of this governance system fit well with the ecological or physical features of the commons on which they are implemented?	*High:* If achieve all three of the following, *Medium:* If achieve two of the following, *Low:* If achieve zero or one of the following: a. Does the governance system encompass the distribution or range of the resource (spatial fit) or do mechanisms exist to ensure their consistency across the range of this resource? b. Are the rules for the use of resources within the MPA consistent with the current scientific consensus? c. Does the governance system include rules or mechanisms to address threats to resources from other environmental commons (i.e. species or invasive species) social-ecological systems (i.e. land areas/runoff) and human activities (i.e. oil and mineral exploration affecting habitat)? (exclude climate change threats)
Proportionality	Is there general	*Yes:* Costs and benefits are balanced in a way that is

(of costs and benefits)	proportionality between the amount of costs group members incur and the amount of benefits received?	expected and considered legitimate by members of the group *No:* Costs and benefits are unbalanced (Not about the size or profitability, or outcomes – just the proportional distribution within a user group)
Participation in rule making	How high is the level of participation of this actor group in the process that determines how this environmental commons is governed?	*High:* Actors have active engagement in decision-making processes, including, but not limited to the ability to meaningfully make changes in important rules when appropriate; *Medium:* Actors have some engagement, e.g. the actor group may participate in electing representatives who have some say in rule changing, but the actor group itself does not participate; *Low:* Members of the actor group do not have any ability to participate in rule changing processes (although they may be informed of these processes, or have access to extreme ways of changing rules, such as, e.g. violent protests or acts of resistance of the type described by Scott (1985))
Self monitoring	Does this actor group monitor its own activities with respect to the use of this commons?	*Yes:* Members of this actor group monitor each others' behavior towards the commons; *No:* Members of this actor group do not monitor each others' behavior towards the commons
Environmental monitoring	How much environmental monitoring of this commons does this actor group engage in?	*High:* This actor group engages in frequent and systematic monitoring efforts that are sufficient to adequately; observe changes in commons conditions; *Moderate:* This actor group engages in some monitoring of the conditions of this commons; *Low:* This actor group engages in very little to no monitoring of the conditions of this commons. Consequently, it cannot detect changes in commons conditions
Self sanctions	Are sanctions applied by and to the members of this	*Graduated sanctions*; *Non-graduated sanctions*; *No sanctions*

	group for violations of rules regarding extraction or emission? And if so, are these sanctions graduated (increasing with severity and repetition of offenses)?	(Sanctions can include a diversity of forms of social shunning, fines, extra regulations or the complete prohibition of resource use or pollution emissions (Ostrom 1990))
External recognition	Within this governance system, do larger governmental jurisdictions (i.e. International agreements, Nation states) recognize the autonomy of lower-level jurisdictions (States, regions, communities), and their right to make decisions regarding this commons?	*High*: Complete recognition of larger governmental jurisdictions' recognizing lower level jurisdictions' autonomy in decision-making regarding the commons in question; *Moderate:* Some recognition; *Low:* No recognition
Multiple levels	Does this governance system contain multiple levels, with each level having a set of actors who conduct tasks with respect to the management of this commons? If so, is there active coordination across	Single-level governance; Coordination among multiple levels; Multiple levels but no coordination

	these levels, or not?	
Compliance	Do members of this actor group follow the rules of this governance system with respect to the emission or appropriation of this commons?	*No:* This actor group does not usually comply with the formal rules of a governance system that regulate the emission or appropriation of a given commons; *Somewhat:* This actor group sometimes complies with rules, or complies with only a subset of the rules; *Yes:* This actor group almost always or always complies with formal rules
Conflict resolution	Are mechanisms in place to address conflicts that arise over the use of this commons by this actor group?	*Yes:* Conflict resolution mechanisms, whether formal and/or informal, exist; *No:* No conflict resolution mechanism exists
Thematic hypothesis 4 – social attributes of the MPA: Participation		
Variable	Question (and definition)	Options
Participation in rule making	How high is the level of participation of this actor group in the process that determines how this environmental commons is governed?	*High:* Actors have active engagement in decision-making processes, including, but not limited to the ability to meaningfully make changes in important rules when appropriate; *Medium:* Actors have some engagement, e.g. the actor group may participate in electing representatives who have some say in rule changing, but the actor group itself does not participate; *Low:* Members of the actor group do not have any ability to participate in rule changing processes (although they may be informed of these processes, or have access to extreme ways of changing rules, such as, e.g. violent protests or acts of resistance of the type described by Scott (1985))
Participation in protected area siting	How high was the level of participation of this actor group or their representatives	*High:* The actor group is in charge of the siting of the MPA with or without the support of the lead management agency; *Medium:* The lead management agency consults the actor group during the decision-making process; *Low:* The lead management agency informs the actor group of their decisions;

	in siting of the marine protected area?	*None:* The lead management agency does not seek input from the actor group
Participation in protected area zoning	How high was the level of participation of this actor group or their representatives in the (most recent) zoning of this marine protected area?	*High:* The actor group is in charge of zoning of the MPA with or without the support of the lead management agency; *Medium:* The lead management agency consults the actor group during the decision-making process; *Low:* The lead management agency informs the actor group of their decisions; *None:* The lead management agency does not seek input from the actor group
Participation in environmental monitoring	How high is the level of participation of this actor group or their representatives in environmental monitoring?	*High:* The actor group is in charge of the environmental monitoring of the commons with or without the support of the lead management agency; *Medium:* The lead management agency consults the actor group during the decision-making process; *Low:* The lead management agency informs the actor group of their decisions; *None:* The lead management agency does not seek input from the actor group
Participation in social monitoring (enforcement)	How high is the level of participation of this commons user group or their representatives in social monitoring (enforcement)?	*High:* The actor group is in charge of social monitoring (enforcement) of the commons with or without the support of the lead management agency; *Medium:* The lead management agency consults the actor group during the decision-making process; *Low:* The lead management agency informs the actor group of their decisions; *None:* The lead management agency does not seek input from the actor group

S3. Summary of the key components coded for the fisheries and ecosystem health interactions for each large-scale MPA. To ensure consistency across cases, we focused on coding the most influential or impactful governance system, user group, and manager for each interaction at the scale of the MPA. Snapshot refers to a time period where management was fairly consistent (e.g., after legislative or policy reform).

Case	**Fisheries-interaction**		**Ecosystem health-interaction**	
Central California National Marine Sanctuaries (USA)	*Governing org.:*	Fisheries managers	*Governing org.:*	Managers
	Gov. system:	Management plan	*Gov. system:*	Management plan
	Snapshot:	1992-2015	*Snapshot:*	1992-2015
	User:	Commercial fisher	*User:*	Researchers
	Commons:	Groundfish habitat	*Commons:*	Rocky intertidal
Cenderawasih Bay National Park (Indonesia)	*Governing org.:*	Co-managers	*Governing org.:*	Co-managers
	Gov. system:	System of Laws	*Gov. system:*	System of Laws
	Snapshot:	2002-2015	*Snapshot:*	2002-2015
	User:	Artisanal fisher	*User:*	Artisanal fisher
	Commons:	Target reef fish	*Commons:*	Coral cover
Galapagos Marine Reserve (Ecuador)	*Governing org.:*	Managers	*Governing org.:*	Managers
	Gov. system:	Management plan	*Gov. system:*	Management plan
	Snapshot:	1998-2015	*Snapshot:*	1998-2015
	User:	Artisanal fisher	*User:*	Tourism
	Commons:	Sea cucumber	*Commons:*	Sharks
Great Australian Bight Marine Park (Australia)	*Governing org.:*	Managers	*Governing org.:*	Managers
	Gov. system:	Management plan	*Gov. system:*	Management plan
	Snapshot:	2000-2012	*Snapshot:*	2000-2012
	User:	Commercial fisher	*User:*	Commercial fisher
	Commons:	Southern bluefin tuna	*Commons:*	Australian sea lion
Great Barrier Reef Marine Park	*Governing org.:*	Co-managers	*Governing org.:*	Co-managers
	Gov. system:	Management plan	*Gov. system:*	Management plan

(Australia)	*Snapshot:*	2004-2015	*Snapshot:*	2004-2015
	User:	Commercial fisher	*User:*	Recreational fisher
	Governing org	Fisheries managers	*User:*	
	Commons:	Target fish	*Commons:*	Coral cover
Heard Island and McDonald Islands (Australia)	*Governing org.:*	Fisheries managers	*Governing org.:*	Managers
	Gov. system:	Management plan x2	*Gov. system:*	Management plan
	Snapshot:	2002-2012	*Snapshot:*	2002-2012
	User:	Commerical fishers	*User:*	
	Commons:	Toothfish	*Commons:*	King penguin
Macquarie Island Marine Reserve (Australia)	*Governing org.:*	Fisheries managers	*Governing org.:*	Managers
	Gov. system:	Management plan x3	*Gov. system:*	Management plan x2
	Snapshot:	2001-2015	*Snapshot:*	2001-2015
	User:	Commercial fishers	*User:*	
	Commons:	Toothfish	*Commons:*	King penguin
Papahānaumokuā kea Marine National Monument (USA)	*Governing org.:*	Co-managers	*Governing org.:*	Co-managers
	Gov. system:	Management plan	*Gov. system:*	Management plan
	Snapshot:	2006-2015	*Snapshot:*	2006-2015
	User:		*User:*	Researchers
	Commons:	Lobster	*Commons:*	Trophic density
Raja Ampat MPA network (Indonesia)	*Governing org.:*	Co-managers	*Governing org.:*	Co-managers
	Gov. system:	System of Laws	*Gov. system:*	System of Laws
	Snapshot:	2009-2015	*Snapshot:*	2009-2015
	User:	Artisanal fisher	*User:*	Artisanal fisher
	Commons:	Target reef fish	*Commons:*	Coral cover
Seaflower MPA (Colombia)	*Governing org.:*	Manager	*Governing org.:*	Manager
	Gov. system:	System of Laws	*Gov. system:*	System of Laws

	Snapshot:	2005-2015	*Snapshot:*	2005-2015
	User:	Artisanal fisher	*User:*	Artisanal fisher
	Commons:	Groupers (6 species)	*Commons:*	Coral cover
Svalbard Nature Reserves (Norway)	*Governing org.:*	Co-managers	*Governing org.:*	Co-managers
	Gov. system:	System of Laws	*Gov. system:*	System of Laws
	Snapshot:	2002-2012	*Snapshot:*	2002-2012
	User:	Commercial fishers	*User:*	Tourism
	Commons:	Shrimp	*Commons:*	Polar bear
Wakatobi National Park (Indonesia)	*Governing org.:*	Co-managers	*Governing org.:*	Co-managers
	Gov. system:	Management plan	*Gov. system:*	Management plan
	Snapshot:	2008-2015	*Snapshot:*	2008-2015
	User:	Artisanal fisher	*User:*	Artisanal fisher
	Commons:	Fish spawning	*Commons:*	Coral cover

S4. The total variation (%) explained by the first two dimensions from the analyses (PCA/MCA) for each thematic hypothesis and corresponding outcome. (N.B. each outcome and hypothesis corresponds to a separate unit of analysis).

Thematic hypothesis	Fisheries trend	Fisheries-associated wellbeing	Ecosystem health trend	Test used
1: Ecological and economic attributes of species and ecosystems	50.12	53.19	58.72	MCA
2: Attributes of the MPA	67.22	59.54	49.31	PCA
3: Social and governance attributes: the institutional design principles	54.10	56.12	49.31	MCA
4: Social and governance attributes: participation	74.51	79.74	74.7	MCA

S5. The categorical variables in thematic hypothesis 1 – ecological and economic attributes of species or ecosystem (productivity, market value, distance to market) that significantly contribute to the first dimension in the MCA for the fisheries trend data. The outcome variable (fisheries trend) was also correlated to the first dimension indicating a strong correlation. Ecological resilience and mobility did not contribute to the formation of the first dimension. (R^2 and p-values are calculated using ANOVA in the *dimdesc* function in FactoMineR).

	R^2	p-value
Productivity	0.92	<0.01
Fisheries trend (outcome)	**0.75**	**<0.01**
Market value	0.75	<0.01
Distance to market	0.68	<0.05

S6. 2D visual representation of the relationship between the fisheries trend outcome (improved, same, worse), and the variables in thematic hypothesis 1 – ecological and economic attributes of the species or system (productivity, mobility, ecological resilience, market value, distance to market). Variable categories that were significant correlated to the trend are coloured based on their correlation. Variable categories that were non-significant are in grey. The plot is based on the MCA output with 95% confidence ellipses are for the fisheries trend categories, with the larger symbol noting the centre of the ellipse.

S7 Supplementary Results:

This section details the full descriptions of the dimensions from all analyses (MCA/PCA for each thematic hypothesis, interaction, and outcome), including instances where no association between the outcome and dimensions was found. Results are ordered by the four thematic hypotheses, and are presented by outcome for: fisheries trend, fisheries associated wellbeing, and ecosystem health trend. Results focus on the first two dimensions from the MCA or PCA and the total amount of variation explained by the first two dimensions is shown in brackets for each hypothesis and outcome. The description of the dimensions first shows the variables that are linked to the dimensions, followed by the variable categories that are linked to the dimensions. Where an outcome was found to be significantly correlated with a dimension it has been highlighted in **bold**.

The dimension description is the output from the *dimdesc* function (from the FactoMineR package: Lê *et al.* 2008), which identifies the most correlated variables with a given dimension (Husson *et al.* 2010). Only significant variables are shown (p<0.10).

Thematic hypothesis 1- Ecological and economic attributes of the species or ecosystem

1.1 Fisheries – trend (total variation explained by first two dimensions: 50%):

Description of the First Dimension by the categorical variables

	R2	p.value
productivity	0.92	<0.001
trend	**0.75**	**0.004**
market value	0.75	0.004
distance to market	0.68	0.036

Description of the First Dimension by variable categories

	Estimate	p.value
productivity_low	0.8	<0.001
market value_high	0.87	0.001
fishery trend worse	**0.90**	**0.001**
market distance >1000km	1.03	0.016
mobility_high	1.01	0.082
fishery trend improved	**-0.62**	**0.082**
market value_med	-0.60	0.040
productivity_med	-0.82	<0.001

Description of the Second Dimension by the categorical variables

	R2	p.value
Distance to market	0.78	0.010
mobility	0.62	0.021
fishery trend	**0.62**	**0.022**
market value	0.55	0.041

Description of the Second Dimension by variable categories

	Estimate	p.value
Market distance <10km	0.70	0.039
mobility_low	0.32	0.045
Market distance 10-100km	-0.76	0.010
value_low	-0.73	0.009
fishery trend same	**-0.71**	**0.006**
mobility_med	-0.73	0.004

1.2 Fisheries – social wellbeing (total variation explained by first two dimensions: 53%):

Description of the First Dimension by the categorical variables

	R2	p.value
productivity	0.87	<0.001
market value	0.75	0.007
distance to market	0.63	0.092

Description of the First Dimension by variable categories

	Estimate	p.value
productivity_low	0.78	<0.001
market value_high	0.86	0.003
Market distance >1000km	0.93	0.045
mobility_high	1.02	0.088
Market distance <10	-0.71	0.087
Wellbeing trend worse	**-0.67**	**0.037**
Market value_med	-0.69	0.035
productivity_med	-0.78	<0.001

Description of the Second Dimension by the categorical variables

	R2	p.value
Distance to market	0.88	0.004
Market value	0.62	0.035
mobility	0.61	0.038

Description of the Second Dimension by variable categories

	Estimate	p.value
Wellbeing trend worse	**0.52**	**0.069**
mobility_low	0.28	0.085
less10	0.72	0.091
Wellbeing trend same	**-0.48**	**0.098**
Market value_low	-0.79	0.009

mobility_med	-0.77	0.008
market distance 10-100	-1.01	0.004

1.3 Ecosystem health – trend (total variation explained by first two dimensions: 59%):

Description of the First Dimension by the categorical variables

	R2	p.value
productivity	0.92	<0.001
mobility	0.84	<0.001
distance to market	0.85	0.001

Description of the First Dimension by variable categories

	Estimate	p.value
productivity_med	0.85	0.003
mobility_high	0.60	0.010
more1000	1.16	0.017
10to100	-1.06	0.013
mobility_low	-0.98	<0.001
productivity_high	-1.00	<0.001

Description of the Second Dimension by the categorical variables

	R2	p.value
productivity	0.62	0.013
distance to market	0.63	0.039
resilience	0.29	0.069
mobility	0.44	0.076

Description of the Second Dimension by variable categories

	Estimate	p.value
productivity_low	0.86	0.004
mobility_med	0.83	0.019
100to1000	0.79	0.020
Resilience_poor	0.40	0.069
Resilience_mod	-0.40	0.069
more1000	-0.84	0.031

Thematic hypothesis 2 - Attributes of the MPA:

2.1 Fisheries – trend (total variation explained by first two dimensions: 67%):

Description of the First Dimension by the quantitative variables

	correlation	p.value
Notake	0.92	<0.001
Isolated	0.83	0.001
CAR	0.79	0.002
Size	0.64	0.026

Description of the Second Dimension by the quantitative variables

	correlation	p.value
Age	0.76	0.004

Snapshot_age	0.71	0.010
enforcement	0.51	0.090

Description of the Second Dimension by the variable categories for the fisheries trend outcome (categ orical): (fishery trend) and the categories of this categorical variable

	Estimate	p.value
Fishery trend improved	**1.55**	**0.002**
Fishery trend same	**-1.29**	**0.016**

2.2 Fisheries – social wellbeing (total variation explained by first two dimensions:60%):

Description of the First Dimension by the quantitative variables

	correlation	p.value
Notake	0.90	<0.001
Isolated	0.81	0.004
CAR	0.81	0.004
Age	-0.57	0.085

Description of the Second Dimension by the quantitative variables

	correlation	p.value
Age	0.71	0.021
Size	0.71	0.022
Snapshot_age	0.65	0.041

2.3 Ecosystem health – trend (total variation explained by first two dimensions: 49%):

Description of the First Dimension by the quantitative variables

	correlation	p.value
Notake	0.92	<0.001
Isolated	0.83	0.001
CAR	0.79	0.002
Size	0.64	0.026

Description of the Second Dimension by the quantitative variables

	correlation	p.value
Age	0.76	0.004
Snapshot_age	0.72	0.009
enforcement	0.51	0.090

Thematic hypothesis 3 - social and governance attributes: the institutional design principles:

3.1 Fisheries – trend (total variation explained by first two dimensions: 54%)

Description of the First Dimension by the categorical variables

	R2	p.value
Compliance	0.65	0.003
Outsider exclusion	0.77	0.003
selfmonitoring	0.64	0.003
self_sanctions	0.64	0.003
participation	0.67	0.011
external recognition	0.51	0.057

multi_levels	0.33	0.064

Description of the First Dimension by variable categories

	Estimate	p.value
Compliance_high	0.52	0.003
self_sanctions_Graduated	0.67	0.003
selfmonitoring_Yes	0.67	0.003
outsider_exclusion_some	0.77	0.003
participation_high	0.72	0.020
single level	0.64	0.064
commons boundary negotiability_rigid	0.62	0.072
coordinated levels	-0.64	0.064
external recognition_low	-0.68	0.022
participation_low	-0.71	0.022
outsider_exclusion_no	-0.69	0.005
self_sanctions_No	-0.67	0.003
selfmonitoring_No	-0.67	0.003
Compliance_some	-0.52	0.003

Description of the Second Dimension by the categorical variables

	R2	p.value
External recognition	0.93	<0.001
Fishery trend	**0.73**	**0.005**
Environmental monitoring	0.44	0.026
outsider_exclusion	0.60	0.026
self-monitoring	0.34	0.059
self-sanctions	0.34	0.059
participation	0.45	0.091
costs.benefits	0.28	0.093

Description of the Second Dimension by variable categories

	Estimate	p.value
External recognition_high	0.54	0.015
fishery trend same	**0.52**	**0.018**
environmental monitoring_low	0.39	0.026
self_sanctions_Graduated	0.44	0.059
selfmonitoring_Yes	0.44	0.059
outsider_exclusion_some	0.73	0.059
costs.benefits_No	0.32	0.093
costs.benefits_Yes	-0.32	0.093
Social-ecological_fit_med	-0.50	0.083
self_sanctions_No	-0.44	0.059
selfmonitoring_No	-0.44	0.059
outsider_exclusion_total	-0.76	0.040
envir_monitor_med	-0.39	0.026
participation_med	-0.52	0.024
fishery trend worse	**-0.63**	**0.003**
external recognition_mod	-0.73	0.000

3.2 Fisheries – social wellbeing (total variation explained by first two dimensions: 56%)

Description of the First Dimension by the categorical variables

	R2	p.value
Compliance	0.77	0.001
costs.benefits	0.66	0.004
participation	0.64	0.029
Social-ecological fit	0.61	0.038
External recognition	0.60	0.040
outsider_exclusion	0.56	0.059
environmental monitoring	0.34	0.079

Description of the First Dimension by categories

	Estimate	p.value
Compliance_high	0.60	0.001
costs.benefits_Yes	0.57	0.004
Social-ecological fit_med	0.76	0.009
commons_boundary negotiability_rigid	0.69	0.065
wellbeing improved	**0.63**	**0.073**
external recognition_mod	0.47	0.079
environmental monitoring_med	0.40	0.079
environmental monitoring_low	-0.40	0.079
Social-ecological fit_low	-0.27	0.078
Wellbeing worse	**-0.58**	**0.077**
outsider_exclusion_no	-0.78	0.020
external recognition_low	-0.75	0.009
participation_low	-0.83	0.009
costs.benefits_No	-0.57	0.004
Compliance_some	-0.60	0.001

Description of the Second Dimension by the categorical variables

	R2	p.value
External recogntion	0.95	<0.001
Self-monitoring	0.54	0.016
self_sanctions	0.54	0.016
outsider_exclusion	0.66	0.022
environmental monitoring	0.49	0.024

Description of the Second Dimension by variable categories

	Estimate	p.value
External recogntion_high	0.94	<0.001
self_sanctions_Graduated	0.76	0.016
selfmonitoring_Yes	0.76	0.016
outsider_exclusion_some	1.12	0.016
environmental_monitoring_low	0.44	0.024
external_recognition_mod	-0.66	0.024
environmental_monitoring_med	-0.44	0.024
self_sanctions_No	-0.76	0.016
selfmonitoring_No	-0.76	0.016

3.3 Ecosystem health – trend (total variation explained by first two dimensions: 49%):

Description of the First Dimension by the categorical variables

	R2	p.value
Social-ecological fit	0.82	0.003
costs.benefits	0.57	0.012
user boundaries	0.51	0.020
environmental monitoring	0.67	0.021
participation	0.65	0.024
Compliance	0.41	0.047
Commons boundary negotiability	0.56	0.056
user boundary fuzziness	0.37	0.061
Ecosystem health trend	0.52	0.077

Description of the First Dimension by variable categories

	Estimate	p.value
Environmental monitoring_high	0.92	0.005
Social-ecological fit_high	0.83	0.005
costs.benefits_Yes	0.51	0.012
participation_med	0.66	0.013
commons_bound_nego_mod	1.06	0.020
user_boundaries_unclear	0.75	0.020
ecos health trend improved	**0.98**	**0.020**
Compliance_high	0.50	0.047
user_boundary fuzziness_fuzzy	0.48	0.061
user_ boundary fuzziness_rigid	-0.48	0.061
Compliance_med	-0.50	0.047
participation_low	-0.61	0.047
Social-ecological fit_low	-0.71	0.022
user_boundaries_clear	-0.75	0.020
costs.benefits_No	-0.51	0.012

Description of the Second Dimension by the categorical variables

	R2	p.value
participation	0.93	<0.001
self-monitoring	0.76	<0.001
Compliance	0.45	0.033

Description of the Second Dimension by variable categories

	Estimate	p.value
selfmonitoring_No	0.55	0.001
Compliance_med	0.48	0.033
participation_low	0.72	0.033
external recognition_low	0.54	0.043
Social-ecological fit_med	-0.45	0.084
commons_boundary negotiability_rigid	-0.48	0.080
Compliance_high	-0.48	0.033
selfmonitoring_Yes	-0.55	0.001
participation_high	-0.82	0.001

Thematic hypothesis 4 – social attributes of the MPA: Participation:

4.1 Fisheries – trend (total variation explained by first two dimensions: 75%):

Description of the First Dimension by the categorical variables

	R2	p.value
MPA zoning	0.98	<0.001
MPA siting	0.96	<0.001
social_monitoring	0.96	<0.001
rule_making	0.71	0.007
environmental monitoring	0.71	0.007

Description of the First Dimension by variable categories

	Estimate	p.value
MPA zoning_high	1.60	<0.001
MPA siting_high	1.58	<0.001
rule_making_high	1.18	0.001
enviro_monitoring_high	1.16	0.001
social_monitoring_medium	0.79	0.028
social_monitoring_high	0.79	0.028
fishery trend same	**0.69**	**0.087**
social_monitoring_low	-1.57	<0.001

Description of the Second Dimension by the categorical variables

	R2	p.value
rule_making	0.92	<0.001
MPA zoning	0.91	<0.001
enviro_monitoring	0.66	0.013
MPA siting	0.64	1.766
fishery trend	**0.59**	**0.029**

Description of the Second Dimension by variable categories

	Estimate	p.value
MPA zoning_low	0.93	<0.001
rule_making_low	0.99	<0.001
enviro_monitoring_low	0.75	0.013
MPA siting_low	0.62	0.021
fishery trend same	**0.63**	**0.044**
enviro_monitoring_medium	-0.76	0.011
fishery trend worse	**-0.77**	**0.011**
MPA siting_medium	-0.78	0.006
rule_making_medium	-0.85	0.003
MPA zoning_medium	-0.84	0.001

4.2 Fisheries – social wellbeing (total variation explained by first two dimensions: 80%):

Description of the First Dimension by the categorical variables

	R2	p.value
social_monitoring	0.94	<0.001
MPA zoning	0.97	<0.001
MPA siting	0.95	<0.001
rule_making	0.59	0.044
enviro_monitoring	0.59	0.045

Description of the First Dimension by variable categories

	Estimate	p.value
MPA zoning_high	1.98	<0.001
social_monitoring_high	1.46	<0.001
MPA siting_high	1.94	<0.001
rule_making_high	1.16	0.011
enviro_monitoring_high	1.13	0.012
wellbeing improved	**0.97**	**0.045**
social_monitoring_low	-1.46	<0.001

Description of the Second Dimension by the categorical variables

	R2	p.value
rule_making	0.92	<0.001
MPA zoning	0.91	<0.001
enviro_monitoring	0.66	0.024
MPA siting	0.64	0.028

Description of the Second Dimension by variable categories

	Estimate	p.value
MPA zoning_low	0.83	<0.001
rule_making_low	0.94	<0.001
enviro_monitoring_low	0.71	0.016
MPA siting_low	0.54	0.022
enviro_monitoring_medium	-0.73	0.013
MPA siting_medium	-0.79	0.006
rule_making_medium	-0.81	0.003
MPA zoning_medium	-0.85	<0.001

4.3 Ecosystem health – trend (total variation explained by first two dimensions: 75%):

Description of the First Dimension by the categorical variables

	R2	p.value
MPA zoning	0.93	<0.001
social_monitoring	0.82	0.001
rule_making	0.85	0.003
MPA siting	0.84	0.004
enviro_monitoring	0.72	0.022

Description of the First Dimension by variable categories

	Estimate	p.value
MPA zoning_high	1.36	0.001
MPA siting_high	1.28	0.001
rule_making_high	1.21	0.001
social_monitoring_medium	0.87	0.001
enviro_monitoring_high	0.91	0.014
MPA zoning_low	-1.02	0.062
MPA siting_low	-0.80	0.055
enviro_monitoring_low	-0.86	0.019
social_monitoring_low	-0.87	0.001

Description of the Second Dimension by the categorical variables

	R2	p.value
MPA zoning	0.80	0.008
MPA siting	0.70	0.027
rule_making	0.58	0.074

Description of the Second Dimension by variable categories

	Estimate	p.value
MPA zoning_low	0.55	0.049
eco. health trend same	**0.72**	**0.062**
rule_making_low	0.70	0.063
enviro_monitoring_medium	-0.68	0.081
rule_making_medium	-0.69	0.049
MPA siting_medium	-0.97	0.005
MPA zoning_medium	-0.83	0.002