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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 (>10,000 km^2), 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 3.3 km^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 have moved us closer to achieving international biodiversity targets (e.g., Aichi Target 11; Boonzaier and Pauly, 2016). LMPAs differ from small MPAs because

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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 this is often expanded to include other factors such as improvement or maintenance of fisheries and social wellbeing (Wilhelm et al., 2014). Diversity of objectives leads to LMPAs taking a variety of forms (e.g., no-take, multi-use, etc.) and thus encompassing complex social-ecological interactions, which means the evaluation of both social and ecological outcomes is important (Agrawal and Benson, 2011; Ferraro and Hanauer, 2015).

From the ecological perspective, LMPAs are considered 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), and also have less negative social impacts through better accommodation of multiple uses (Balmford et al., 2004). However, it is important to note that some argue LMPAs are largely used as a vehicle for meeting global marine conservation targets (e.g., Aichi Target 11), and as such contribute more to achieving political goals rather than strengthening biodiversity conservation (Devillers et al., 2015). Nonetheless, the further increase in the number and total size of LMPAs (Boonzaier and Pauly, 2016; S1) will undoubtedly continue in the near future.

Given this reality, empirical investigations of LMPA 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 a range of conservation outcomes – including improved ecosystem health, fisheries, and social wellbeing – would help improve management of existing LMPAs and inform the establishment of others (Gruby et al., 2016).

Our aim is to assess the social and ecological performance of LMPAs through the lens of 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). We evaluated factors from these thematic hypotheses against three outcomes: trends in ecosystem health, fisheries, and social wellbeing. Our study is the first to empirically examine multiple outcomes in LMPAs, and provides insights that can help guide management of current and future LMPAs.

1.1. Hypotheses framing

Given the paucity of data and information on LMPAs in the literature, we approached framing hypotheses based upon a review of recent findings regarding the management of marine resources (Claudet et al., 2010; Cinner et al., 2013), the design and management of small-scale MPAs (Edgar et al., 2014), and the management of common-pool resource at large spatial scales (Fleischman et al., 2014; Cox et al., 2016). Whereas the first two sets of hypotheses – ecological and economic attributes of species or ecosystems, and attributes of the MPA – are salient because of similarities in the biophysical context (i.e., marine environments); institutional design principles were included as hypotheses because of similarities in the spatial scale of analysis (i.e. large, >10,000 km^2). Finally, a fourth set of hypotheses investigates multiple measures of participation because of its particular importance for helping groups to achieve long-term sustainable governance that balances conservation with livelihoods (Persha et al., 2011; Bennett and Dearden, 2014).

Thematic hypothesis I: Ecological and economic attributes of the species or ecosystem. Recent studies highlight 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 exhibit positive responses to protection (Claudet et al., 2010; Collette et al., 2011a). Therefore, we hypothesized that if the species and ecosystems within LMPAs have high productivity, high ecological resilience and low mobility, in addition to a lower market value, and greater distance to market, they would be more likely to be correlated to improved ecosystem health and fisheries trends.

Thematic hypothesis II: Attributes of the MPA. A recent study found that certain attributes of MPAs have a disproportional effect on ecological outcomes. In a review of 87 MPAs worldwide, Edgar et al. (2014) found that MPAs that include no-take areas, are well-enforced, old (>10 years), large (>100 km^2), and isolated are more likely to be ecologically effective (i.e. as measured through higher fish biomass). 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). We hypothesized that MPAs that are older, have a larger spatial extent, larger proportion of no-take areas, more isolation, high levels of compliance and enforcement, in addition to explicit inclusion of MPA design criteria (comprehensive, adequate, representative) in MPA selection and zoning will be more likely to have improved trends in fisheries and ecosystem health.

Thematic hypothesis III: Institutional design principles. 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). We hypothesized that presence of the institutional design principles would lead to improved fisheries, ecosystem health, and social wellbeing.

Thematic hypothesis IV: Participation. Stakeholder participation is widely considered essential for effective management of natural resources (Ostrom, 1990; McCay and Jentoft, 1996; Berkes, 2009). Although participation of stakeholders in rule-making is considered one of the institutional design principles outlined in the previous thematic hypothesis, it has multiple aspects not explored in the design principles that are potentially relevant for LMPAs. 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). Furthermore, the structure of participatory arenas changes from MPA siting and implementation to MPA management activities and often contains different deliberation approaches (Nenadovic and Epstein, 2016). Lack of participatory engagements across these different arenas has been identified as one of the key components contributing to poor performance of many MPAs globally (Ferse et al., 2010). We hypothesized that LMPAs are more likely to have improved trends in ecosystem health, fisheries and social wellbeing when there is participation at all stages in rule-making; including MPA siting, MPA zoning, as well as environmental and social monitoring.

2. Methods

2.1. Selection of cases

LMPAs were selected for analysis based upon 1) biodiversity conservation as a primary goal (and thus fulfilling the IUCN definition of a MPA); 2) large size, defined as >10,000 km^2 because it encompasses MPAs several magnitudes larger than the median size 3.3 km^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 was chosen to provide enough time for ecological and social effects of management to be evident (Halpern and Warner, 2002), and our cut-off was 2014 when coding was finalized; 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 (i.e., presence of a management plan, or reports detailing actions such as monitoring, enforcement etc.), 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 (Fig. 1; see S1 for a complete list of LMPAs, including those that did not meet our criteria).

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), actor groups (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.

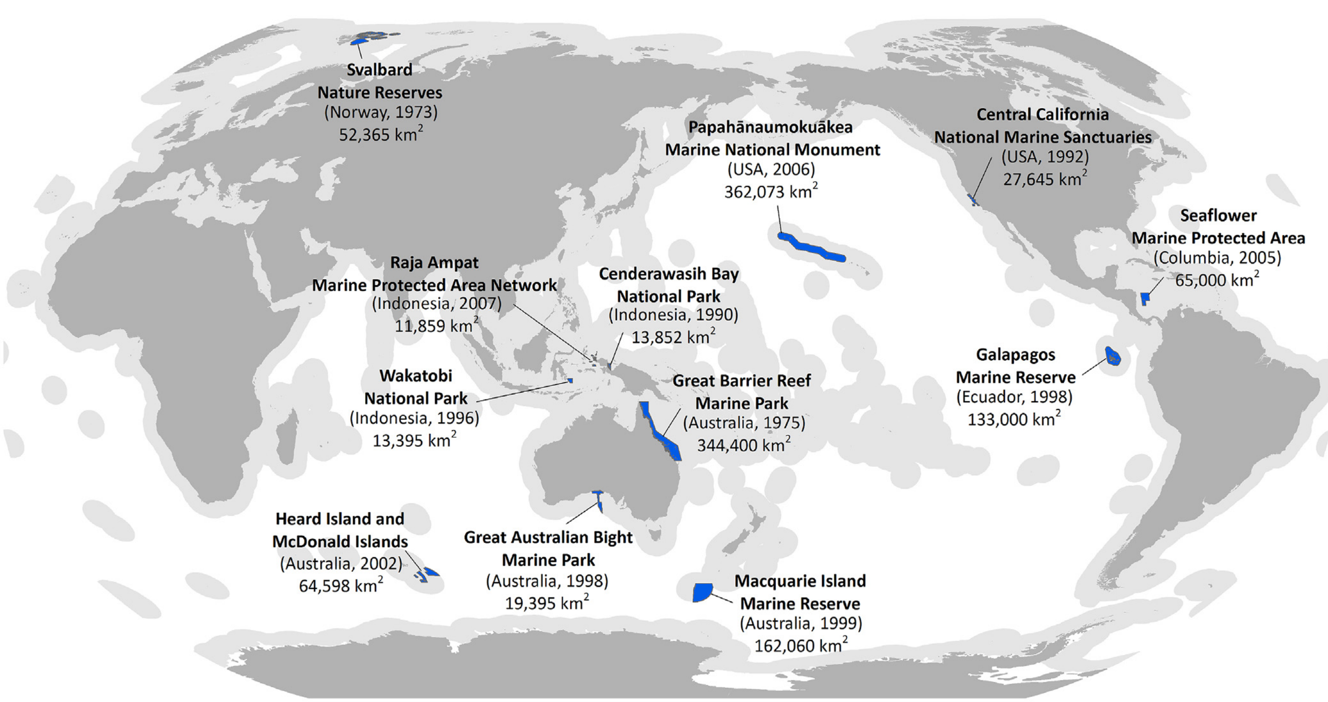

Fig. 1. MPA name, country of origin, date designated, and total size of large MPAs used in this study, (see S1 for complete list of LMPAs).

2.3. 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.

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 < 1000; medium 1001–9999; high > 10,000). (For interpretation of the references to color in this table, the reader is referred to the web version of this article.)

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

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

For each case, we evaluated three outcome variables from across the social-ecological system. These were: 1) trend in the condition of the ecosystem health proxy, which included proxies such as the change in coral cover (options are: decreased, remained the same, or increased); 2) trend in the condition of the fished species, which included proxies such as stock assessment estimates (options are: decreased, remained the same, or increased); 3) trend in the wellbeing of the user group dependent on the fishery, which included proxies such as monetary income or access to education (options are: declined, remained the same, or improved). See S3 for the proxies coded in each case. 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 MPAs or common pool resources as suggested 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 I: ecological and economic attributes of the species or ecosystem

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.

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	Hypothesized fisheries trend	Evidence	Hypothesized wellbeing trend	Evidence	Hypothesized ecosystem health trend	Evidence
I	Low productivity	↓	✓		○	↓	
	High ecological resilience	↑			○	↑	
	High mobility of the commons	↓	✓			↓	
	High market value	↓	✓		○	↓	
	Close proximity to market	↓	○			↓	
II	High compliance and enforcement	↑	✓			↑	
	Older MPA	↑	✓				
	Larger spatial extent	↑					
	Larger proportion no-take areas	↑					
	Greater isolation	↑					
	Explicit inclusion of MPA design criteria	↑				↑	
III	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	↑	○	↑	✓	↑	
IV	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	↑		↑	✓	↑	

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). 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).

3.2. Thematic hypothesis II: attributes of the MPA

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

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. (For interpretation of the references to color in this table, the reader is referred to the web version of this article.)

Thematic Hypothesis	Outcomes		
	Fisheries	Wellbeing	Ecosystem health
I: Ecological & economic attributes	Low productivity; High economic value; Distance to market > 1000km; High mobility	Intermediate productivity; Intermediate economic value	
II: Attributes of MPAs	Older; High enforcement		
III: Institutional design principles	Moderate external recognition; Intermediate participation; Intermediate environmental monitoring; Total outsider exclusion	High compliance; Proportionality of costs & benefits; Intermediate social-ecological fit Some compliance; No proportionality of costs & 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
IV: Participation	Intermediate participation in: siting; rulemaking; environmental monitoring	High participation in: zoning; social monitoring; siting; rulemaking; environmental monitoring	

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 III: the institutional design principles

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 costs 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 costs 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 costs 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). None of the other design principles were correlated with outcomes.

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 tag-recapture 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 I). 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 costs 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, 2015) 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 IV: participation

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.

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 hypotheses are 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 institutional design principles to large-scale environmental governance has been questioned (Young, 2002; Araral 2014). Although our results provide partial support for the institutional 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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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.gloenvcha.2017.01.003.

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