Supplementary Methods

1 Analytical framework and indicators

The Convention on Biological Diversity Aichi Target 11 calls for countries to "effectively and equitably" manage 10% of their coastal and marine areas by 2020 within marine protected areas and "other effective area-based conservation measures" (hereafter MPAs) [1]. Effective and equitable management of conservation interventions relates not only to how the site is governed and managed (procedural efficacy and equity), but also the resulting (substantive) social and ecological impacts [2].

Here *procedural efficacy* refers to the adequacy of management activities and capacities towards achieving predefined management objectives (e.g. adequate monitoring and enforcement systems, development of a management plan to guide management activities, adequate staff capacity) [3,4]. *Procedural equity* refers to the fairness or justness of management. This includes the fair and effective participation in decision making processes and management by all actors affected by the conservation intervention [5]. In this study we drew upon social and ecological theories [4,6–9] to identify ten indicators of procedural efficacy and equity of protected area management and governance using data from widely used management datasets and instruments (Extended Data Fig.1 and Supplementary Table 1).

Substantive efficacy speaks to whether the direction and magnitude of the realized impacts (intended and unintended) from a conservation intervention align with its predetermined goals and objectives (e.g. biodiversity threats abated, population recovery, improved human well-being [3]. *Substantive equity* is the fair distribution of the resulting costs and benefits of impacts among individuals and groups. Here resource access rights, allotment of land or sea area, financial benefits, etc. are appropriately distributed to individuals or groups regardless of class, gender, or ethnicity [10]. In assessing the substantive efficacy of MPAs as it relates to ecological impacts, we apply an impact evaluation framework to compare observed fish population outcomes (total fish biomass per unit area) to counterfactual conditions [11]. The dearth of available social outcome data from MPAs prevented us from assessing the social elements of substantive efficacy and equity.

2 MPA spatial data sources

We initially sourced data on MPA boundaries and attributes from the October 2015 version of the World Database of Protected Areas (WDPA) geospatial datasets. These data consist of polygons representing the locations and boundaries of MPAs (and points where only the general location is known) submitted by the governments of the 193 United Nations member states [12]. As such, the currency and quality of the data in the WDPA are dependent on numerous data providers, many of whom have limited capacity to provide current and accurate spatial data on all the protected areas within their national boundaries. Further, as the WDPA consists of only nationally and internationally recognized MPAs, many Locally Managed Marine Areas (LMMAs), de-facto MPAs and privately-owned MPAs may not be included in this dataset [12]. To overcome some of these challenges in our analysis, we sourced additional MPA geospatial datasets for the various geographies of interest. For the Caribbean, we used geospatial datasets created by The Nature Conservancy[13] (insular Caribbean), NOAA[14] (MPA inventory: U.S. Caribbean) and the Healthy Reefs Initiative[15] (Meso-American Barrier Reef, Central America) to supplement and validate the MPA data in the WDPA. For locations outside of the Caribbean, we used other datasets including the Collaborative Australian Protected Areas Database[16]

(Australia), MPA Atlas[17], and the NOAA MPA inventory[14] (U.S. Pacific territories). In some cases, we validated or digitized MPA polygons from other official sources.

3 MPA management data

3.1 MPA management data compilation

Detailed data on MPA management processes were sourced from three management assessment tools: the Management Effectiveness Tracking Tool (METT) [18], the World Bank MPA Score Card [19], and the NOAA Coral Reef Conservation Program's (CRCP) MPA Management Assessment Checklist [20] (Supplementary Table 2). The METT is a management assessment tool implemented in all protected areas funded by the Global Environment Facility (GEF) and similar donors [21]. As such, it is the largest source of protected area management data, with 4,046 assessments conducted in 2,045 protected areas [21]. The MPA Scorecard represents a marine adaptation to the METT and is also widely used by donor agencies [19]. The NOAA CRCP MPA Checklist is a tool that was developed to assess the management of MPAs in priority coral reef sites in U.S. jurisdictions and internationally in areas important to the CRCP and jurisdictional partners [20].

Most of the METT data were sourced from the Global Database for Protected Area Management Effectiveness (GD-PAME[21]). The GD-PAME data were supplemented with additional assessments collected by Conservation International. The majority of the World Bank MPA Scorecard data were sourced from a Conservation International working database, and a WWF database for MPAs across the Birds Head Seascape, Indonesia. The NOAA CRCP MPA Checklist data were sourced from the NOAA Coral Reef Conservation Program.

3.1.1 Identifying MPAs in management datasets

While the MPA Scorecard and NOAA CRCP MPA Checklist assessments targeted MPAs only, the METT database does not specify whether an assessed site was terrestrial or marine. According to the IUCN, an MPA is "*any (protected) area of intertidal or sub-tidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features*" [22]. For the purpose of this study, we focused our selection of protected areas on those that encompass marine habitats (e.g. coral reefs, seagrass beds, intertidal wetlands) and/or are capable of supporting marine (namely fish) populations. Where no such ecological data were available, we identified MPAs from the geographies where we have a strong working knowledge. Additional MPAs were identified through a series of subsequent steps. First, the protected area name and/or designation fields were searched for indicative keywords. Examples include: marin*, sea, reef; examples identified: Locally Managed Marine Area, Parque Nacional Marinho, Marine Fish Sanctuary. Second, those protected areas (PAs) that were identifiable within the WDPA and classified as "coastal" or "marine" were individually inspected to confirm that the PA boundaries extended noticeably beyond the coast and/or included marine or intertidal wetland habitat [23]. Thirdly, in cases where it was not completely clear that a potential protected area was marine from the name, designation, or maps, we used supplementary information from within the assessment (e.g. location description, PA objectives, reasons for designation and threats) to assist in the identification process.

4 Ecological data (fish biomass)

4.1 Identifying proximate MPAs

Most datasets (Supplementary Table 2) indicated which surveys were conducted inside an MPA, along with the name of the MPA. For the AGRRA, NOAA CREP datasets, and some of the RLS data, MPA survey sites were not explicitly identified, therefore surveys conducted inside an MPA were identified by importing the survey sites into ESRI ArcGIS 10.2.2 using the provided site coordinates. These points were then overlaid onto maps with MPA polygons (sources described in Section 2). Data were either maintained in, or transformed to, the WGS84 coordinate system as it is the native GCS of most handheld GPS units commonly used in field data collection. In addition, survey sites that were located within 500 m of an MPA boundary were considered inside the MPA. This decision was made after a few survey sites known to be inside an MPA were found just outside of the MPA shapefile boundary, including several that fell on land. Where possible, these points were validated with data from other sources and this adjustment appeared to account for most of these misplaced points. It is recognized that this could lead to some control (outside) sites being misidentified as treatment (MPA) sites; however, such a misidentification will likely reduce rather than amplify the overall estimate of MPA effects. Further, it is likely that many of these survey sites will likely be subject to MPA effects due to spillover [24]. All distances were calculated using the Near tool in ArcGIS 10.2.2 using geodesic distances, which accounts for the curvature of the earth's surface, overcoming the distance errors that occur when calculating planar distances on projected data that are globally distributed [25]. For cases where no MPA boundary data were available, we created convex hull polygons of all survey sites known to be inside a particular MPA.

Size data were missing from 51 of the NOAA NCRMP fish records and as such, the total biomass values may be underestimated for those survey sites (48 of 8047 survey sites or 0.6% of the dataset with data missing for one or two individual fish).

4.2 Covariate matching variables and sources

Based on existing literature on MPA site-selection biases and factors affecting variation in fish populations, Supplementary Table 5 and the following sections describe the covariates compiled for each of the 15,978 UVC survey sites and used in the statistical matching procedures.

4.2.1 Depth

Depth data (meters) were available for each survey site with the exception of a few NOAA NCRMP survey sites. For the NOAA NCRMP sites with no depth data (approximately 20% of the NOAA data), bathymetric raster maps were sourced for the Puerto Rico [26], the US Virgin Islands [27] and Hawaii [28] sites. Depth values were then extracted from these raster maps at the survey points. For survey sites where no bathymetric data were available (e.g. sites that fell on land due to geospatial mismatches), the missing values were replaced with the depth mean (9.77m) and an additional field was created to identify these survey sites in the matching process (n=153 sites). By including this field as a matching variable, it helps to controls for unobserved factors that may cause data to be missing at some sites and not others [29]; in this case, proximity to land.

4.2.2 Habitat

Detailed benthic habitat information was provided in the AGRRA, BHS and NOAA CREP datasets where survey sites were matched by reef type (e.g. fringing, barrier, patch reef). Surveys conducted in rare habitats (e.g. pinnacles, ridges, back reefs) were removed from the dataset (n=13 survey sites) as these habitats were rarely surveyed within those datasets and were unlikely to have an appropriate match. In the WCS data, researchers classified the benthic habitats as sheltered reefs and exposed reefs.

NOAA benthic habitat maps for the U.S. Caribbean and Hawaii [30] were used to supplement the habitat information for the NOAA NCRMP survey sites where the habitat categories were inconsistently applied across sites (or absent). Nevertheless, habitat categories from the benthic habitat maps also varied greatly between locations. Consequently, we placed habitat types in the following broad categories: coral reef and colonized hardbottom; uncolonized hardbottom; mangrove; seagrass; unconsolidated sediments; unknown hardbottom; and unknown. Survey sites where the habitat was unknown were removed from the analysis (n=942 survey sites). For the WCS data, habitat delineation took the form of exposed vs sheltered reef habitats. For the RLS data, no comprehensive, high-resolution benthic habitat dataset was available as these survey sites were globally distributed. Further, as this dataset consists of coral and rocky reef locations, it was necessary to separate the data by these two unique habitat types. To accomplish this, we used the WCMC-008 Global Distribution of Coral Reefs [31] data layer to identify marine ecoregions [32] that contain coral reefs. The RLS survey sites within coral ecoregions were then designated as coral habitat and the others as rocky or non-coral habitat. After specifically assessing a few locations in sub-tropical areas, it appears that this habitat categorization was reasonably effective and modifications were made in cases where it was incorrect.

The resulting benthic habitat categories vary greatly between datasets, leading to some survey sites being more precisely matched than others. Nevertheless, given the scale of the data, we believe that this represents the highest resolution of habitat data that can be applied to each dataset. Further, the additional process of matching by location, depth and wave exposure helped to reduce inappropriately matching survey sites with very dissimilar habitats.

4.2.3 Minimum sea surface temperature, Chlorophyll-a

Data on sea surface temperatures and chlorophyll-a concentrations were derived from Bio-ORACLE [33]. These values represent the monthly average values for the years 2002-2009. Given the imprecision of some survey site locations, the chlorophyll and temperature rasters were converted to points and the biophysical data were spatially joined to the proximate survey site.

4.2.4 Neighboring coastal population

Coastal population values represent the total human population within 100 km radius of each survey site, calculated in ArcGIS using the Socioeconomic Data and Application Centre (SEDAC) Gridded Population Of The World database [34] for the year 2000. This was done by converting the adjusted population count raster to points, and summing the point values within a 100 km buffer.

4.2.5 Distances to market and shore

In this study, distance to provincial capital, a proxy for distance to market and thus fishing intensity [35] represents the shortest geodesic distance of each survey site to the nearest provincial or national capital using the Near tool in ArcGIS 10.2.2. These data were sourced from the World Cities base map layer provided by ESRI [36] (Version 10.1), which also includes major population centers and landmark cities. Distance to shore represents the shortest geodesic distance to land, using the full resolution shoreline layer of the Global Self-consistent, Hierarchical, High-resolution Geography (GSHHG) v2.3.3 global shoreline dataset [37].

4.2.6 Ecoregion, country

We used the WWF Marine Ecosystems of the World GIS layer [32] to identify ecoregions if not already identified in the dataset. Country names were already identified in each dataset.

4.2.7 Wave exposure

Wind-wave exposure E_w was calculated based on average wave power values near each site:

$$E_w = \sum_{n=1}^{16} P_n O_n, \quad (1)$$

where P_n is the average power of the top 10% most powerful waves and O_n is the percent of times when waves are travelling in one of the major bearing sector n. The value of the average wave power near each site was computed differently, depending on whether a site was deemed exposed or sheltered. Survey sites were considered to be exposed to the open ocean if more than 60% of the fetch distances F_n have a fetch length greater than 15 km and sheltered if not. Fetch distances F_n were estimated using "waver", an R package developed by Philippe Marchand and a subset of authors [38], for each of the 16 major bearing directions as:

$$F_n = \sum_{j=1}^{9} f_j \cos\theta / 9 \cos\theta \quad (2)$$

where $\theta = 2.5°$, and f_j is the geodesic distance between each survey site and the nearest land mass computed every 2.5° angle.

For each sheltered site, locally generated wave time series were estimated by combining fetch distances and ten years of wind speed information gathered from the nearest WaveWatch III grid point [39], following the wind-wave generation formula proposed by Holthuijsen [40]. For each exposed site, wave characteristics at each nearest WaveWatch III grid point were converted into wave power values. From these time series, wave power was computed following $P = 0.5\,H^2T$ where P= wave power (kW/m) of an observed wave with a wave height (m) H and wave period (seconds) T [40]. Wave power values in sectors that had fetch distances smaller than 15 km were ignored. For more information, see Holthuijsen [40].

For those survey sites where wind or wave statistics were not available within 100km (n=68 survey sites), mean wave exposure was used (26.3 kW/m). Similar to cases of missing depth data, we added an additional field to identify these survey sites in the matching process.

4.2.8 Spatial and temporal variation

To reduce the effects of spatial and temporal variability on the analysis, we matched control and treatment sites by site coordinates (to reduce distance between survey sites) and applied a year caliper (matching restriction) to ensure that the matched survey sites were assessed within three years of each other.

5 Management and ecological data analysis

We used a portfolio of statistical approaches to examine the relationships between MPA management processes and ecological impacts. In addition to exploring the correlative (Extended Data Fig. 7) and bivariate relationships (Extended Data Fig. 5) between ecological impacts, management predictors and other variables, we also employ random forests and linear mixed effects models. In these models we used the management indicator scores (not thresholds) as predictors, and ecological impact (natural log of fish biomass response ratios, or lnRR) as the response variable to indicate conservation performance. The unit of analysis was an MPA, and we used a sample of 62 MPAs where both management and ecological data were available. The following steps outline the modeling procedures used.

5.1 Accounting for non-management factors

To identify the effects of management processes on ecological impacts, we first sought to account for the explanatory and interacting effects of other non-management factors. The non-management factors we investigated were derived from: 1) literature on important explanatory variables for MPA ecological outcomes[41–43] and; 2) variables identified as important to explaining variation in fish populations, some of which were used in the statistical matching procedure (see Supplementary Table 4 for the list of predictors). Although matching can control for site variability between control (non-MPA) and treatment (MPA) survey sites[44], some MPA-level variability may still exist (e.g., offshore MPAs perform differently from those in the nearshore).

5.2 Random forest models

In this study we employ random forests with conditional inference trees (also known as conditional inference forests (CIFs)) to examine the relative importance of the management indicators in explaining the variation in ecological impacts. We used the "party" package version 1.0-25 [45] in the R statistical software [46].

Random forests are an ensemble of regression or classification trees that recursively partition the n-dimensional parameter space into regions of similar response values [47]. Random forests, particularly CIFs, are useful and increasingly utilized for handling "small n, large p" problems [47]. They have been shown to perform well in situations with heterogeneous and unscaled predictors, and even with correlated predictors (at times better than their parametric equivalents), particularly in situations where there are higher order interactions or the functional forms are not known [47–50]. CIFs implemented within the R 'party' package also employ a variety of mechanisms to deal with missing values, both within the tree-building process (e.g., using surrogate variables[47,48]) and in the calculation of the variable importance scores[50]. For example, when data are missing, the 'varimp' function employs a procedure developed by Hapfelmeier et al. [50]. In this procedure, when a split occurs based on a predictor with missing values, rather than permuting the values of the predictor to 'break' the predictor-response relationship, the observations are randomly allocated into the child nodes (new branches) [50]. This procedure has been shown to perform well with simulated and real datasets, even in cases where variables are not missing at random [50]. In other simulation studies, conditional inference forests perform similarly to other imputation methods with regard to missing values [51]. CIFs also avoid the artificial bias selection towards predictors with missing data that can occur in random forests when variable selection is based on other measures [52]. See Strobl et al.[47] for more information on random forests and conditional inference forests and Hothorn et al.[45] for more details on the 'party' R package.

We estimated the random forest models using the "cforest" function in the "party" package [45]. Five predictor variables were randomly selected from the full set of predictors at each node (which performed similarly when four or six variables were selected) and we created 10,000 trees in each forest to ensure stability in the model results. We determined the relative variable importance measures using the 'varimp' function in the 'party' package. Variable importance in CIFs (as shown in Fig. 3a) was measured by the mean decrease in accuracy when a predictor variable of interest is randomly permuted [45]. This process 'breaks' the predictor-response relationship for that variable and should result in lower predictive accuracy if a relationship existed [50]. This difference in accuracy is averaged across all trees in the forest. This method is more robust against biased variable selection than other importance measures, such as those that rely on Gini indices [52].This process 'breaks' the relationship between the predictor variable and the response and should result in lower predictive accuracy if a relationship exists [50]. This difference in accuracy is averaged across all trees in the forest. This method is more robust against biased variable selection than other importance measures, such as those that rely on Gini indices [52].

We calculated the unconditional variable importance measures due to missing data in some of the predictors (Fig 3a). Conditional variable importance procedures apply a more rigorous procedure to deal with correlated predictors, however require that there are no missing data [53]. To ensure that our results were not biased by correlated predictors, we re-ran the models without variables that were highly correlated (variance inflation factors >5 in a generalized linear model [54]; management plan, country, ecoregion) and without those with many missing values (i.e., budget capacity and legal status) (Extended Data Figure 9b). The model returned similar relative importance measures to the original model with all the variables included (Extended Data Figure 9b and 9a respectively).

5.3 Mixed effects models

We investigated the linear relationship between the management indicators and ecological outcomes while holding other important non-management factors constant (see Supplementary Table 4 for list of predictors). All linear models were implemented using the R "nlme" package version 3.1-128 [55]. We first identified the important non-management variables to include in the models using those identified as important in the conditional inference forest models (mean chlorophyll, mean shore distance, mean MPA age, and MPA size; see Fig. 3a). We also included the variable "proportion no fishing" given previous evidence of the importance of fishing regulations in explaining ecological outcomes [42,43] and given the differences we observed in fish biomass between multi-use and prohibited fishing areas (Extended Data Fig. 4). This variable represents the proportion of survey sites for an MPA sampled from within a prohibited-fishing (no-take) zone.

Mixed effects models allow us to effectively explore the predictor-response relationships where spatial or other nested hierarchy may exist in the data structure[56]. We chose to include a random intercept for country to account for potential non-independence in the results between MPAs in the same country (e.g., MPAs managed by the same national agency). This random intercept performed similarly to other random effect structures that account for spatial hierarchy (see Supplementary Table 8) when testing it with a 'beyond optimal' fixed effects structure using all the fixed effects variables [57]. For all the models, we examined the fitted model residuals (e.g., using quantile-quantile plots [57]) to ensure model fit and distribution were acceptable.

We only included one management predictor in each model due to strong correlation amongst some of the predictor variables (Extended Data Fig. 6) and missing data in predictor variables for some MPAs. The resulting models are shown in Supplementary Table 9. The management variables that are identified as important are similar to those identified in the random forest models (Fig 3a).

6 Data Limitations

6.1 MPA spatial and attribute data

MPA data (i.e., age, area, boundaries, fishing regulations) were primarily sourced from global, regional and national MPA geospatial datasets (see Section 2) and supplemented with data from scientific publications, reports, GIS data and websites from official government and NGO sources, as well as local expert knowledge. These sources were also used to validate which fish survey sites were located inside each MPA. We attempted to identify at least two sources to confirm each MPA attribute, even if the data were provided in the survey dataset (e.g., whether or not a survey site was located inside a specified MPA). Nonetheless, attribute data were only available from one source for some MPAs, and in a few cases the MPA boundaries were not known. Some fish survey sites could therefore have been categorized as being outside of an MPA but actually be inside an MPA that is not officially recognized. This will only serve to reduce rather than amplify our estimates of MPA effects, leading to more conservative results.

In addition to the MPA attribute data, we identified which surveys were located inside of zones where fishing is prohibited (‘no-take’) within an MPA as well as the attributes of these zones. For the purpose of this study, “fishing prohibited” refers to an MPA or zone within an MPA that prohibits any type of fishing activity, including subsistence and recreational fishing. Information on these no fishing zones within MPAs was more difficult to source than information for the entire MPA, and in some cases, only MPA-level data were available (e.g., date of establishment and area). Changes in the MPA boundaries and zonation recently before or after UVC data were collected can also affect the accuracy of the MPA/zonal attribute data used in the analysis. Nevertheless, with recent efforts to update and improve global MPA datasets (e.g. WDPA) and the meticulous process we used to validate the data, we have identified to the maximum practical extent the survey sites that fall within MPA/zone boundaries as well as the attributes of those MPAs and/or zones. Where there was high uncertainty or ambiguity regarding a site location or fishing regulations in the area (e.g. some whale sanctuaries), we removed those survey sites from the analysis (n=148 survey sites).

6.2 Management and ecological data limitations

There were other METT and World Bank MPA Scorecard indicators relevant to our indicator framework (Extended Data Fig. 1; e.g. involvement of indigenous people, protected area design, stakeholder influence into management plans) that could not be included in the analysis as they were not available in the NOAA CRCP MPA Checklist. Conversely, we could not assess conflict-resolution mechanisms as such information was only available in the NOAA CRCP MPA Checklist. We were also limited in our ability to measure equity. Equity is multi-dimensional [58], and even within procedural equity, devolution (non-state or shared management) and stakeholder involvement are not precise metrics, as they only capture whether or not other stakeholders were included and not which ones. Despite the limitations of these metrics, having multiple interests represented in the decision making process (through inclusive decision making and/or devolved management) reduces the risks of select user groups appropriating unequal shares of the MPA costs or benefits, and can facilitate the inclusion of local knowledge to improve the contextual fit of management [7].

It is recognized that there are many observed and potential biases associated with using management assessments such as the METT and MPA Scorecard [59]. Geopolitical biases are apparent, with most assessments carried out in developing countries where Global Environment Facility (GEF) and World Bank funding are targeted [60]. Similar geographic biases were observed with the ecological data, where most underwater visual census data were carried out on warm-water coral reefs. Specific categories of protected areas are also over-represented in some assessment databases (e.g., IUCN category II and Ia) [60,61]. Despite the geographic biases in the ecological and management datasets, the combination of both datasets provides a broader view of MPA performance around the world. For example, while it is true that we had strong ecological data coverage in North and Central America and Australia, the management data covered other parts of the globe including Europe, Africa and Asia (e.g., Fig. 4).

It is acknowledged that the management assessment responses are subjective, and given that the assessment data are usually self-reported, respondents may have perverse incentives to report higher (e.g., protect credibility) or lower scores (e.g., to receive additional funding) [59]. Nevertheless, some studies indicate that subjective and reporting biases may not be as prevalent as assumed, and that responses to these assessments may fairly accurately represent local conditions [61–63]. Further, not all management data included here are self-reported, given that the NOAA CRCP MPA Checklist is usually collected by independent assessors in some areas.

Supplementary Table 1 | Key domains along with illustrative indicators and thresholds for assessing management efficacy and equity.

Domain	Indicator categories	Indicator	Indicator thresholds	Definition for measurement	Hypotheses and rationale for inclusion	Sources
Procedural efficacy	Management capacity[iii,v]	Budget capacity	Acceptable budget capacity	Adequacy of budget to meet management needs	Management capacity includes the human, financial, physical, information and other resources without which, management will not be able to achieve its pre-determined objectives. Lack of resources has been cited as a key reason for management failure [64,65]	a,b
		Staff capacity and/or presence	Adequate staff capacity/presence	Adequacy of (on-site) staff capacity/numbers to carry out management activities (including designated community staff)		a,b,c
	Implementation of management activities[iii,v]	Implementation of management activities	Active implementation of pre-determined management activities	Existence and implementation of a management plan to guide management activities	MPAs are more likely to achieve their objectives if a management plan is in place and being implemented [4,9]	a,b,c
	Monitoring and enforcement systems[i,ii,iv]	Degree of monitoring of management, users, and/ or resource conditions	Monitoring of management, users, and/or resource conditions informs management activities	Monitoring of MPA management and/or MPA conditions (biophysical, socioeconomic) where information is used to inform management	Monitoring of resource conditions and resource users facilitates adaptive management, allowing management to be more responsive to dynamic social and ecological processes within an MPA [3]	a,b,c
		Level of enforcement	Adequate enforcement capacity and/or consistency	Capacity for and/or consistency of the enforcement of MPA legislation and regulations	Surveillance of resource use activities creates disincentives for non-compliance with MPA rules and regulations [7]	a,b,c
	Resource use rights [i,ii,iv]	Delineation of MPA boundaries	Clearly defined boundaries	MPA boundaries are clearly defined/demarcated and well known to local stakeholders	If resource use rules are clearly defined and known to all users (e.g. no-take boundaries demarcated), they increase the likelihood of conservation meeting its policy objectives [6]. Ambiguous and unstable resource use rights and boundaries can create uncertainty regarding the effectiveness of management to conserve resources, affecting its legitimacy, and can lead to conflicts amongst user groups [6,7]	a,b,c
		Appropriateness of regulations controlling use	Appropriate MPA regulations controlling use	Appropriate regulations to control use/unsustainable activities are defined and in place		a,c
		Level of legislative support	Strong legislative support (MPA legally gazetted)	Legal status of the MPA	MPA gazettement provides legislative support for these rules and regulations and can increase legitimacy	a,b
Procedural equity	Decision making arrangements [i,ii,iv]	Degree of stakeholder involvement in decision making	Inclusive decision making: stakeholders directly involved in decision making	Contribution of local communities/ stakeholders to management decision making, including planning and implementation	Including a diversity of stakeholders increases the likelihood that management will be better suited to the local social and ecological context, and enhances the perceived legitimacy of the protected area and compliance [6,7]	a,b,c
		Degree of devolution of mgmt. authority	Devolution of management to non-state actors	The devolution of management from state to non-state actors or shared management	Devolved management could provide enabling conditions for multiple stakeholders to be involved in decision making	a,b,c

	Conflict resolution mechanisms (not included in this study)[i,ii,]	Accessibility of conflict resolution mechanisms	Accessible (and low cost) conflict resolution mechanisms	Cost and accessibility of conflict resolution mechanisms	Having accessible conflict resolution mechanisms can mitigate conflicts arising within the MPA and can also give voice to marginalized groups [7]	c
Substantive Efficacy	Resource condition	Status or change in species or habitat condition	Biodiversity/habitat maintenance or recovery (e.g. increased biomass)	Change in biodiversity/habitat conditions relative to non-MPA areas (improvements, no change, or moderated declines relative to non-MPA areas). In this study, we used fish biomass as the indicator	Management of human activity can results in improvements in fish sizes and abundance in MPAs relative to corresponding non-MPA areas or pre-MPA conditions [66]	d
	Environmental threats (not included in this study)	Status or change in threats to resource conditions (e.g. overharvesting)	Reduction or moderation in the level of environmental threats	Change in environmental threats relative to non-MPA areas (reduced threats, no change, or moderated increases relative to non-MPA areas)	The appropriate application of MPA rules and regulations can reduce negative human impacts on marine resources	Not available
	Human well-being (not included in this study)	Status or change in well-being of affected communities (e.g. income, health, democratic participation, etc.)	Improvement or moderation of change in human well-being	Change in level of human well-being relative to non-MPA areas (improvements, no change, or moderated declines relative to non-MPA areas)	MPAs can provide increased income, food security, health, political empowerment and overall community development [67–69]	Not available
	Social conflict (not included in this study)	Status or change in social conflict relating to resource use	Reduction or moderation in the level of social conflict	Changes in social conflict relative to non-MPA areas (reduced conflict, no change, or moderated increases relative to non-MPA areas)	Equitable management processes and accessible conflict resolution mechanisms can facilitate a reduction social conflicts relating to MPA use [7]	Not available
Substantive equity	Distributive equity (not included in this study)	Relative distribution of MPA costs (e.g. reduction in access) and benefits (e.g. fishing quotas)	Equitable distribution of MPA costs and benefits	The fairness/justness of the distribution of MPA management outcomes and impacts both social and ecological across societal or resource groups, time, or locations	Equitable management can promote social justice, cohesion and the rights of marginalized groups, providing overall societal benefits [5]	Not available

More theoretical background information can be found in: i [6],ii [7],iii [4],iv [8], and v [9]. Data sources for indicators include the Management Effectiveness Tracking Tool (METT)[a], World Bank MPA Scorecard[b], NOAA CRCP MPA Management Assessment Checklist[c], and six underwater visual census datasets and a meta-analysis of MPA ecological impacts[43,66] (Supplementary Table 2)[d].

Supplementary Table 2 | Sources and description of MPA management assessment and fish population data.

Dataset/ management assessment tool	Geographic coverage/habitat	Date range	Number of survey sites	Data type	Data source
Management data					
Management Effectiveness Tracking Tool (METT)	Global; mostly developing countries	2000-2014	533*	Likert-scaled management assessments	Global Database for Protected Area Management Effectiveness [21]; Conservation International
World Bank MPA Scorecard	Global; mostly in developing countries	2011-2015	166*	Likert-scaled management assessments	Conservation International; WWF Birds Head Seascape project
NOAA CRCP MPA Management Assessment Checklist (NOAA CRCP MPA Checklist)	US Caribbean and Pacific as well as other Caribbean MPAs	2011	51*	Likert-scaled management assessments	NOAA Coral Reef Conservation Program
Ecological data					
Atlantic Gulf Rapid Reef Assessment (AGRRA)	Wider Caribbean; coral reefs	1997-2012	1,394	UVC surveys (ecologically and commercially important species)	www.agrra.org
NOAA National Coral Reef Monitoring Program (NOAA NCRMP)**	US Caribbean and Pacific (Hawaii, Guam, Tutuila); coral reefs and associated ecosystems	2000-2014	8,534	UVC surveys	www8.nos.noaa.gov/bpdmWeb/queryMain.aspx; www.pifsc.noaa.gov/cred
Lester et al.	Global; broad spectra of marine habitats	NA	40*	Meta-analysis	Lester et al [41,42]
Reef Life Surveys (RLS)	Global; rocky and coral reefs	2006-2013	5,760	UVC surveys	www.reeflifesurvey.com
Wildlife Conservation Society (WCS)	East Africa coral reefs (Madagascar and Mozambique)	2007-2015	103*	UVC surveys (fishable biomass: >10 cm excluding non-target species)	Wildlife Conservation Society
WWF Bird's Head Seascape Ecological Impact Evaluation programme	Indonesia coral reefs	2011-2014	200	UVC surveys (major fish families)	World Wildlife Fund

*MPA level survey data. **NOAA NCRMP comprised data from the online NCRMP dataset as well as data made available from the NOAA Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Program (CREP). Survey sites refer to spatially explicit sampling events.

Supplementary Table 3 | Indicators, thresholds and scores from the three management assessments used in this study.

Management indicator	Threshold (dashed blue line)	Adjusted Score	Indicator score descriptions: Management Effectiveness Tracking Tool	World Bank MPA Scorecard (and variants)	NOAA CRCP MPA Checklist
Budget capacity	Acceptable budget capacity	1	There is no budget	There is no budget for the marine protected area	
			The available budget is inadequate for basic management needs	The available budget is inadequate for basic management needs and presents a serious constraint to the capacity to manage	
		2	The available budget is acceptable but could be further improved	The available budget is acceptable, but could be further improved to fully achieve effective management	
		3	The available budget is sufficient	The available budget is sufficient and meets the full management needs of the protected area	
Staff capacity and/or presence	Adequate staff capacity/presence	1	There are no staff	There are no staff	No management personnel assigned to site and/or little or no formalized community oversight
		2	Staff numbers are inadequate	Staff numbers are inadequate for critical management activities	Some management personnel assigned to site or some formalized community oversight
			Staff numbers are below optimum	Staff numbers are below optimum level for critical management activities	
		3	Staff numbers are adequate	Staff numbers are adequate for the management needs of the site	Full-time site manager and programmatic personnel assigned to site or local community based management leader in place that has been formally designated and accepted and is able to dedicate sufficient time to the management of the site
Implementation of management activities	Active implementation of pre-determined management activities	1	There is no management plan	There is no management plan for the marine protected area	Some management activity being implemented, but no management plan in place
			A management plan is being prepared or has been prepared but is not being implemented	A management plan is being prepared or has been prepared but is not being implemented	
		2	Management plans is partially implemented	An approved management plan exists but it is only being partially implemented	Some management activity being implemented and management plan developed
		3	A management plan exists and is being implemented	approved management plan exists and is being implemented	Approved management plan that is being implemented
Degree of monitoring of management, users, and/ or resource conditions	Monitoring informing management activities	1	There is no monitoring and evaluation	There is no monitoring and evaluation the biophysical, socioeconomic and governance context of the MPA	Little or no existing biophysical monitoring activity
			There is some ad hoc monitoring and evaluation, but no overall strategy	There is some ad hoc monitoring and evaluation, but no overall strategy and/or no regular collection of results	Little or no existing socioeconomic monitoring activity Little or no evaluation of MPA effectiveness
		2	There is an agreed and implemented monitoring and evaluation system but results do not feed back into management	There is an agreed and implemented monitoring and evaluation system but results are not systematically used for management	Existing biophysical monitoring program Existing socioeconomic monitoring program MPA effectiveness evaluated but no ongoing effectiveness monitoring and evaluation program in place
		3	A good monitoring and evaluation system exists, and is well implemented and used in adaptive management	A good monitoring and evaluation system exists, is well implemented and used in adaptive management	Data produced from biophysical monitoring program being evaluated and used to inform management decisions Data produced from socioeconomic monitoring program being evaluated and used to inform management decisions

					MPA effectiveness evaluated and effectiveness monitoring and evaluation program in place with findings being applied to adapt management strategies
Level of enforcement	Adequate enforcement capacity and/or consistency	1	No effective capacity/resources to enforce protected area legislation and regulations	The staff have no effective capacity/resources to enforce marine protected area legislation and regulations	Few or no established rules and regulations exist or there is little or no enforcement of existing rules and regulations
			There are major deficiencies in staff capacity/resources to enforce protected area legislation and regulations (e.g. lack of skills, no patrol budget, lack of institutional support)	There are major deficiencies in staff capacity/resources to enforce marine protected area legislation and regulations (e.g. lack of skills no patrol budget)	Inconsistent enforcement of rules and regulations
		2	The staff have acceptable capacity/resources to enforce protected area legislation and regulations	The staff have acceptable capacity/resources to enforce marine protected area legislation and regulations but some deficiencies remain	Active and consistent enforcement of rules and regulations
			The staff have excellent capacity/resources to enforce protected area legislation and regulations	The staff have excellent capacity/resources to enforce marine protected area legislation and regulations	
Delineation of PA boundaries	Clearly defined boundaries	1	The boundary of the protected area is not known	The boundaries of the marine protected area are not known by the management authority or other stakeholders	Lack of clearly defined boundaries and/or zones
		2	The boundary of the protected area is known by the management authority but is not known by local residents	The boundary of the marine protected area is known by authority but is not known by other stakeholders	Clearly defined boundaries and/or zones
			The boundary of the protected area is known but is not demarcated	The boundary of the marine protected area is known by both the management authority and others but is not appropriately demarcated	
		3	The boundary of the protected area is known and is appropriately demarcated	The boundary of the marine protected area is known by the management authority and stakeholders and is appropriately demarcated	Clearly defined boundaries and zones and information on boundary locations and permitted activities in various zones (if applicable) provided to public and MPA stakeholders
Appropriateness of regulations controlling use	Appropriate MPA regulations in place controlling use	1	There are no regulations Regulations with major weaknesses		Site has been legally established or is under equivalent customary tenure or other form of community-based protection status, but there are few or no official or community based rules and regulations in place supporting the MPA and its management plan
		2	Regulations with some weaknesses or gaps		Laws or customary instruments for the establishment of the MPA are in place, and official or community based rules or regulations governing some specific activities within the MPA are also in place
		3	Regulations provide an excellent basis for management		Clearly defined laws or customary instruments and official or community based rules and regulations governing all specific activities included in the objectives of the site management plan are in place
Level of legislative support	Strong legislative support (MPA legally gazetted)	1	The protected area is not gazetted/covenanted	The marine protected area is not gazetted	
			There is agreement that the protected area should be gazetted/covenanted but the process has not yet begun	The government has agreed that the marine protected area should be gazetted but the process has not yet begun	
		2	The protected area is in the process of being gazetted/covenanted but the process is still incomplete	The marine protected area is in the process of being gazetted but the process is still incomplete.	
		3	The protected area has been formally gazetted/covenanted	The marine protected area has been legally gazetted (or in the case of private reserves is owned by a trust or similar)	

Degree of stakeholder involvement in decision making	Inclusive decision making	1	Local communities have no input into decisions	Stakeholders have no input into decisions relating to the management of the protected area	Little or no community and stakeholder engagement in management planning
			Local communities have some input into discussions	Stakeholders have some input into discussions relating to management but no direct involvement in the resulting decisions	
		2	Local communities directly contribute to some relevant decisions	Stakeholders directly contribute to some decisions management	Community and stakeholder engagement in management planning
			Local communities directly participate in all relevant decisions	Stakeholders directly participate in making decisions relating to management	Community and stakeholder engagement in management planning and implementation of site management efforts
Degree of devolution of mgmt. authority	Shared/non-state management	1	State managed	State managed	State managed
		2	Shared management	Shared management	Shared management
		3	Non-state management	Non-state management	Non-state management

Management Effectiveness Tracking Tool [18] (METT), the World Bank MPA Scorecard[19] (and variants), and the NOAA CRCP MPA Checklist [20]. Blue dotted line indicates the threshold levels for each indicator.

Supplementary Table 4 | Variables used in this study.

Variable	Variable type	Category	Data Type	Spatial Scale	Variable Description	Source/Dataset
Fish biomass response ratios	Response	E	Cont	MPA	The MPA-averaged logged ratio of fish biomass (lnRR) inside the MPA relative to non-MPA locations (outside MPA and/or before MPA establishment)	Calculated from transect/site level underwater visual census data (see Supplementary Table 2) as well as ratios from Lester et al [41,42]
Age	Predictor	C	Cont	MPA	Mean age of the MPA at the time of the survey (years)	Calculated from MPA establishment data from official government/NGO sources and/or WDPA[70] (October 2015 release)
Size	Predictor	C	Cont	MPA	MPA size (km^2)	Based on data from official government/NGO sources and/or WDPA (October 2015 release); Some values calculated from geospatial data
Fishing prohibited	Predictor	C	Cont	MPA	Proportion of MPA survey sites sampled within a prohibited fishing (no-take) zone of the MPA where 1= all prohibited fishing and 0 = all multi-use fishing area.	Based on data from ecological data providers, official government/NGO sources and/or WDPA (October 2015 release)
Acceptable budget	Predictor	M	Ord	MPA	Adequacy of budget to meet management needs	METT; MPA Scorecard
Adequate staff capacity/presence	Predictor	M	Ord	MPA	Adequacy of (on-site) staff capacity/numbers to carry out management activities (including designated community staff)	METT; MPA Scorecard; NOAA CRCP MPA Checklist
Implementing management plan	Predictor	M	Ord	MPA	Existence and implementation of a management plan to guide management activities	METT; MPA Scorecard; NOAA CRCP MPA Checklist
Monitoring informs management activities	Predictor	M	Ord	MPA	Monitoring of MPA management, users and/or MPA conditions (ecological, socioeconomic) where information is used to inform management	METT; MPA Scorecard; NOAA CRCP MPA Checklist
Adequate enforcement	Predictor	M	Bin	MPA	Capacity for and/or consistency of the enforcement of MPA legislation and regulations	METT; MPA Scorecard; NOAA CRCP MPA Checklist
Clearly defined boundaries	Predictor	M	Ord	MPA	MPA boundaries are clearly defined/demarcated and well known to local stakeholders	METT; MPA Scorecard; NOAA CRCP MPA Checklist
Appropriate MPA regulations in place	Predictor	M	Ord	MPA	Appropriate regulations to control use/unsustainable activities are defined and in place	METT; NOAA CRCP MPA Checklist
Legally gazetted	Predictor	M	Ord	MPA	Strong legislative support (MPA gazetted/covenanted)	METT; MPA Scorecard
Inclusive decision making	Predictor	M	Bin	MPA	Local communities/ stakeholders directly contribute to management decision making, including planning and implementation	METT; MPA Scorecard; NOAA CRCP MPA Checklist
Shared/non-state management	Predictor	M	Ord	MPA	The devolution of management from state to non-state actors or shared management	METT; MPA Scorecard; NOAA CRCP MPA Checklist; WDPA and other official government/NGO sources
Latitude/longitude	Matching covariate	C	Cont	Survey	Location of fish survey site	Fish survey data
Country	Matching covariate; predictor	C	Cat	Survey; MPA	Location of fish survey site /MPA	Fish survey data
Habitat	Matching covariate	C	Cat	Survey	Marine habitat at fish survey site (e.g. patch coral reef, rocky reef)	Fish survey data; benthic NOAA habitat maps [30]; WCMC Global Distribution of Coral Reefs [31]
Minimum sea surface temperature	Matching covariate; predictor	C	Cont	Survey; MPA	Minimum sea surface temperature (2002-2009; ºC)	Bio-ORACLE [33]

Chlorophyll-a	Matching covariate; predictor	C	Cont	Survey; MPA	Proxy for primary productivity at study site (Chlorophyll-a (2002-2009; mg/m^3))	Bio-ORACLE [33]
Depth	Matching covariate; predictor	C	Cont	Survey; MPA	Depth at survey site (m)	Fish survey data; NOAA bathymetric raster maps[26–28]
Exposure	Matching covariate; predictor	C	Cont	Survey; MPA	Wave energy at fish survey site (kW/m)	Calculated using wind/wave data from WAVEWATCH III (WW3)[39] and fetch using the 'waver' R package [38]
Marine ecoregions	Matching covariate; predictor	C	Cat	Survey; MPA	Marine biogeographic regions of the world	WWF Marine Ecosystems of the World GIS layer[32]
Distance to shoreline	Matching covariate; predictor	C	Cont	Survey; MPA	Distance to nearest land (km)	Calculated using the shoreline layer from the Global Self-consistent, Hierarchical, High-resolution Geography (GSHHG) dataset [37]
Human population density	Matching covariate; predictor	C	Cont	Survey; MPA	Coastal population within 100 km radius of fish survey site (# individuals)	Calculated using the Socioeconomic Data and Application Centre (SEDAC) Gridded Population Of The World database [34]
Distance to markets	Matching covariate; predictor	C	Cont	Survey; MPA	Distance to capital or population center, used as a proxy for distance to markets (km) and fishing pressure	Calculated using the World Cities base map layer provided by ESRI (Version 10.1) [36]

Variable types include the response variable (fish biomass response ratios), management and contextual predictors, and covariates used in the matching procedures. Data categories include ecological (E), contextual (C) and management (M) variables, and data types were continuous (Cont), ordinal (Ord) or binary (Bin). Spatial scale refers to the scale applied in the matching or analysis and not the original scale of the data. See Supplementary Table 2 for more details on the management and ecological data sources, Supplementary Table 3 for management indicator scoring levels, and Supplementary Table 5 for more details on the matching data.

Supplementary Table 5 | Covariates used in the matching process used to identify appropriate non-MPA (control) survey sites to pair with MPA (treatment) survey sites

Matching covariates	**Rationale**	**Restrictions in treatment-control matched pairs**	**Restriction comments**
Sampling protocol	Control for differences in sampling methodologies	Same methodology only	-
Habitat type	Control for habitat selection bias in MPA placement [71] and natural variation in fish communities by habitat [72–76]	Similar habitat type only (e.g. coral reefs, rocky reefs, fringing reefs, sea grass, mangroves)	-
Minimum sea surface temperature (2002-2009; ^{o}C)	Temperature affects fish community structure. Low temperatures can act as spatial boundaries for warm water fish species [77], which make up the majority of the sample	Minimize mean difference in treatment and control survey sites	-
Chlorophyll-a (2002-2009; mg/m^3)*	Control for variations in available primary productivity which could affect community composition [78] and subsequently biomass	Minimize mean difference between treatment and control survey sites (maximum difference of 3 standard deviations), except extreme upper outliers (top 5%)	Data right skewed.
Depth (m)	Control for natural variation in community composition by depth [79], which can result in differing levels of biomass	Minimize mean difference (maximum difference: 10 m)	-
Wave exposure (kW/m)*	Wave energy explains some of the variation in marine community structure [73,80,81]. Adverse sea conditions can also be a deterrent for small fishing vessels resulting in lower fishing pressure and likelihood of fishing [82,83]	Minimize mean difference between treatment and control survey sites, except extreme upper outliers (top 5%)	Data bimodal. Coding extreme values essentially separates very exposed vs sheltered survey sites
Marine ecoregions	Control for large-scale biogeographic variation [32]	Same ecoregion	
Distance to shoreline (km)*	All else equal, fishing intensity usually negatively correlated with shore distance [84,85]. Also controls for other human impacts (e.g. pollution, destructive nearshore activities) from neighboring coastal populations	Minimize mean difference in sites <20 km	Data right skewed. Bivariate relationship with biomass asymptotes ~ 10km
Country	Control for variation in national policies and/or resource use patterns between countries [86]	Same country only	
Coastal population (individuals within 100km^2)*	Control for human impacts (e.g. pollution, destructive nearshore activities) from neighboring coastal populations [87,88]	Minimize mean difference in survey sites with <1.5 million individuals	Data right skewed. Bivariate relationship with biomass asymptotes at <1 million
Distance to provincial capital (market) (km)*	Distance to capital used as a proxy for distance to markets, which is commonly negatively correlated with fishing intensity ([35] and [89])	Minimize mean difference in survey sites <1000 km from market	Data right skewed. Bivariate relationship with biomass asymptotes ~ 800km
Sample date (years)	Control for unobserved temporal variation caused by factors such as exogenous shocks (e.g. storm events, algal blooms) and other changes between survey periods	Maximum difference: 3 years	-
Latitude/ longitude	Control for unobserved spatial variation caused by factors such as exogenous shocks (e.g. storm events, algal blooms) and other changes between survey locations. Also, to reduce latitudinal variation	Minimize mean difference. Maximum distance 2 degrees latitude	-

*Extreme outliers recoded as 9999999 to avoid matching with the remaining data. Post-matching statistics are reported in Supplementary Table 6**.**

Supplementary Table 6 | Covariate balance statistics for the unmatched and matched data.

Covariate	Matching stage	Treatment (MPA) mean	Control (non-MPA) mean	Std. mean diff. (%)	Mean eQQ diff.	max eQQ diff.
Wave exposure (kW/m)*	unmatched	504,476.811	475,162.084	1.339	29,095.08	9,999,896
	matched	222,642.367	205,613.79	1.154	29,712.17	9,999,896
Survey year	unmatched	2007.88	2007.817	1.806	0.386	2
	matched	2007.485	2007.455	0.852	0.118	1
Shore distance (km)*	unmatched	530.539	227.88	13.502	303.03	9,999.994
	matched	1.31	3.275	-1.716	1.896	9,999.981
Minimum sea surface temp. (ºC)	unmatched	23.359	22.388	20.932	1.135	9.504
	matched	23.871	23.742	2.724	0.174	1.244
Market distance (km)*	unmatched	48.259	97.063	-7.051	48.501	9,999.055
	matched	24.956	24.951	0.001	0.015	0.085
Longitude	unmatched	-12.18	-21.081	8.281	18.244	109.792
	matched	-21.418	-21.412	-0.006	0.217	4.926
Latitude	unmatched	3.152	0.886	9.713	3.687	22.503
	matched	4.985	5.069	-0.372	0.258	1.924
Human population (million)*	unmatched	1.979	1.43	13.765	0.548	10
	matched	2.23	2.221	0.22	0.009	10
Depth (m)	unmatched	9.937	8.997	13.073	0.97	30.536
	matched	9.557	9.596	-0.617	0.318	8.8
Chlorophyll-a (mg/m^3)*	unmatched	383,111.466	722,424.564	-17.677	339,393.9	9,999,997
	matched	153,222.064	153,222.008	0	0.078	0.492
Approx. exposure dummy var.**	unmatched	0.004	0.007	-4.997	0.003	1
	matched	0.004	0.004	0	0	0
Approx. depth dummy var. **	unmatched	0.011	0.011	-0.075	0	0
	matched	0.013	0.012	1.267	0.001	1

* Extreme outliers recoded as 9999999 to avoid matching with the remaining data; **Dummy variable used to indicate where mean values were used to fill missing data. Treatment and control means before and after matching are provided, along with the standardized mean differences between the groups. Lower standardized mean differences after matching indicates good matching performance for that covariate [90]. The mean (Mean eQQ diff.) and maximum differences (max eQQ diff.) from empirical quantile-quantile plots are also shown.

Supplementary Table 7 | Number and proportion of MPAs meeting the management threshold values.

Number of thresholds met	Number of MPAs	Cumulative number of MPAs	Cumulative percent of MPAs (%)
9	5	5	1.8
8	10	15	5.4
7	13	28	10.1
6	29	57	20.6
5	41	98	35.4
4	45	143	51.6
3	42	185	66.8
2	45	230	83
1	25	255	92.1
0	22	277	100

Threshold values are for all management indicators (excluding non-state management) where data were available for all nine indicators; n=277 MPAs

Supplementary Table 8 | Comparison of spatial random effects structures used in linear mixed effects models.

Model	df	AIC	BIC	logLik
1|Country	18	87.080	94.242	-25.540
1|Ecoregion	18	87.077	94.239	-25.538
Ecoregion|Country	19	89.077	96.637	-25.538

Supplementary Table 9 | Parameter estimates of linear mixed effects models examining the relationship between the management indicators and biomass response ratios

Predictor	Model										
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Non-state management		0.018									
		(0.097)									
Inclusive decision making			0.180								
			(0.158)								
Legally gazetted				-0.073							
				(0.158)							
MPA regulations					0.183*						
					(0.099)						
Clear boundaries						0.214*					
						(0.120)					
Enforcement							0.231				
							(0.158)				
Monitoring								0.035			
								(0.089)			
Management plan									0.089		
									(0.084)		
Staff capacity										0.359***	
										(0.095)	
Acceptable budget											0.395***
											(0.130)
MPA age	0.158	0.156	0.149	0.229*	0.169	0.162*	0.115	0.157	0.146	0.138	0.177
	(0.096)	(0.097)	(0.102)	(0.128)	(0.099)	(0.093)	(0.097)	(0.103)	(0.097)	(0.085)	(0.106)
MPA size	-0.036	-0.035	-0.028	-0.068*	-0.021	-0.030	-0.056*	-0.037	-0.032	-0.043	-0.093**
	(0.030)	(0.030)	(0.033)	(0.039)	(0.035)	(0.031)	(0.033)	(0.032)	(0.031)	(0.028)	(0.035)
Prop. no fishing	0.274*	0.267	0.228	0.159	0.298*	0.235	0.203	0.236	0.235	0.177	-0.009
	(0.153)	(0.158)	(0.163)	(0.192)	(0.156)	(0.150)	(0.155)	(0.168)	(0.158)	(0.139)	(0.174)
Chlorophyll	-0.152**	-0.149*	-0.170**	-0.178**	-0.133*	-0.127	-0.156*	-0.129	-0.165**	-0.137*	-0.166**
	(0.074)	(0.077)	(0.081)	(0.083)	(0.078)	(0.076)	(0.078)	(0.088)	(0.076)	(0.069)	(0.077)
Shore distance	0.063**	0.062**	0.052	0.065*	0.056*	0.070**	0.058*	0.059*	0.056*	0.028	0.036
	(0.030)	(0.030)	(0.034)	(0.036)	(0.031)	(0.030)	(0.030)	(0.031)	(0.031)	(0.028)	(0.034)
Constant	-0.118	-0.136	-0.434	0.096	-0.556	-0.615	-0.248	-0.133	-0.284	-0.749*	-0.395
	(0.357)	(0.373)	(0.502)	(0.484)	(0.439)	(0.464)	(0.380)	(0.429)	(0.397)	(0.368)	(0.418)
Observations	62	62	57	43	54	62	62	59	61	62	43

*p<0.1; **p<0.05; ***p<0.01. Coefficients are reported for each parameter estimate (standard errors in parentheses). Models include a random intercept for each country.

Supplementary Table 10. Summary statistics for management, ecological, MPA attribute and contextual variables.

Variable	n (MPAs)	mean	sd	se	median	min	max
Management variables							
Inclusive decision-making	388	1.51	0.50	0.03	2	1	2
Legally gazetted	371	2.68	0.68	0.04	3	1	3
Appropriate MPA regulations	373	1.89	0.71	0.04	2	1	3
Clearly defined boundaries	419	2.20	0.59	0.03	2	1	3
Adequate enforcement	411	1.46	0.50	0.02	1	1	2
Monitoring informing mgmt. activities	395	1.56	0.73	0.04	1	1	3
Implementing existing mgmt. plan	420	1.68	0.74	0.04	2	1	3
Adequate staff capacity/presence	417	1.92	0.51	0.03	2	1	3
Acceptable budget capacity	375	1.36	0.51	0.03	1	1	3
Education and outreach	409	1.92	0.56	0.03	2	1	3
Conflict resolution mechanism	51	2.02	0.93	0.13	2	1	3
Ecological variables							
Mean biomass (lnRR)	218	0.47	0.96	0.06	0.39	-3.76	3.69
Mean density (lnRR)	202	0.21	0.74	0.05	0.19	-2.27	3.21
Mean size (lnRR)	191	0.06	0.27	0.02	0.07	-1.06	0.71
Species richness (lnRR)	185	0.11	0.35	0.03	0.10	-1.49	1.22
MPA attribute and contextual variables							
MPA age (years)	181	17.64	14.31	1.06	13.39	3.00	95.00
MPA size (km^2)	216	612.90	3,448.51	234.64	10.00	0.01	35,373.70
Chlorophyll (mg/m^3)	218	0.72	1.39	0.09	0.33	0.04	10.07
Shore distance (km)	218	2.21	8.07	0.55	0.43	-	95.01
Market distance (km)	218	129.83	190.53	12.90	64.93	1.73	1,151.22
Human Population (Million/100km^2)	218	0.63	1.01	0.07	0.15	-	5.31
Wave exposure (kW/m)*	218	176.78	2,338.31	158.37	2.35	-	34,532.05*
Sea surface temperature (^oC)	218	23.09	5.46	0.37	25.72	8.20	29.54

* Extreme outlier, likely due to an error from wind time series from the Mediterranean (not used in the analysis); median wave exposure value is more representative. Statistics for the MPA attribute and contextual variables are for those MPAs with ecological data only ($n \leq 218$ MPAs) and represent the mean values from all survey sites inside the MPA.

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