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Leadership, social capital and incentives promote successful fisheries

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One billion people depend on seafood as their primary source of protein and 25% of the world's total animal protein comes from fisheries[1]. Yet a third of fish stocks worldwide are overexploited or depleted[1,2]. Using individual case studies, many have argued that community-based co-management[3] should prevent the tragedy of the commons[4] because cooperative management by fishers, managers and scientists often results in sustainable fisheries[3,5,6]. However, general and multidisciplinary evaluations of co-management regimes and the conditions for social, economic and ecological success within such regimes are lacking. Here we examine 130 co-managed fisheries in a wide range of countries with different degrees of development, ecosystems, fishing sectors and type of resources. We identified strong leadership as the most important attribute contributing to success, followed by individual or community quotas, social cohesion and protected areas. Less important conditions included enforcement mechanisms, long-term management policies and life history of the resources. Fisheries were most successful when at least eight co-management attributes were present, showing a strong positive relationship between the number of these attributes and success, owing to redundancy in management regulations. Our results demonstrate the critical importance of prominent community leaders and robust social capital[7], combined with clear incentives through catch shares and conservation benefits derived from protected areas, for successfully managing aquatic resources and securing the livelihoods of communities depending on them. Our study offers hope that co-management, the only realistic solution for the majority of the world's fisheries, can solve many of the problems facing global fisheries.

Fish are a critical natural resource, yet global catches have peaked while human populations and demand for seafood continue to rise[1]. This increasing pressure has coincided with most fisheries worldwide being fully exploited or requiring rebuilding[2]. In the past several decades, researchers have examined the circumstances under which common pool resources, and fisheries in particular, can be successfully managed[3,5]. The dominant theme in fisheries management has been that privatization is necessary to avoid Hardin's tragedy of the commons[4], whereas Ostrom and others[6–9] have argued that community-based co-management can often achieve sustainability.

Community-based co-management (hereafter co-management) occurs when fishers and managers work together to improve the regulatory process. Advantages of co-management include: enhanced sense of ownership encouraging responsible fishing; greater sensitivity to local socioeconomic and ecological restraints; improved management through use of local knowledge; collective ownership by users in decision making; increased compliance with regulations through peer pressure; and better monitoring, control and surveillance by fishers[9,10].

Despite the increasingly widespread adoption of co-management for solving governance issues[11,12], few attempts have been made to synthesize individual case studies into a general fisheries co-management model. There are qualitative case studies, comparative analyses and a few localized quantitative reviews on the subject[12,13], but no comprehensive evaluations to support the hypothesis that co-management improves fisheries' governance systems and performance indicators[14]. Here, we tested whether co-management improves fisheries' social, economic and ecological success, identified relevant attributes generated by isolated study cases in diverse disciplines (such as ecology and social sciences) and evaluated the relative merits of different co-management attributes across fisheries.

We assembled worldwide data from the peer-reviewed literature, government and non-governmental organization (NGO) reports and from interviews of experts on co-managed fisheries. We identified 130 co-managed fisheries in 44 countries (Fig. 1 and Supplementary Table 1) covering artisanal and industrial sectors, and a variety of ecosystem types, degrees of human development (Human Development Index (HDI)[15]), and social, economic and political settings (Supplementary Table 2). We extracted 19 variables relating co-management attributes under five categories suggested by Ostrom[16] for analysing social–ecological systems (Table 1 and Supplementary Table 2). These were used to predict eight binary measures of success grouped into ecological (for example, increase in stock abundance), social (for example, increase in social welfare) and economic (for example, increase in unit price) indicators and summed them to obtain a single holistic success score that captures natural and human dimensions of fisheries[17].

Statistically demonstrating a causal connection between co-management attributes and successful fisheries is challenging, because we are mostly dealing with non-experimental and observational studies in which random treatments and control groups are not present.

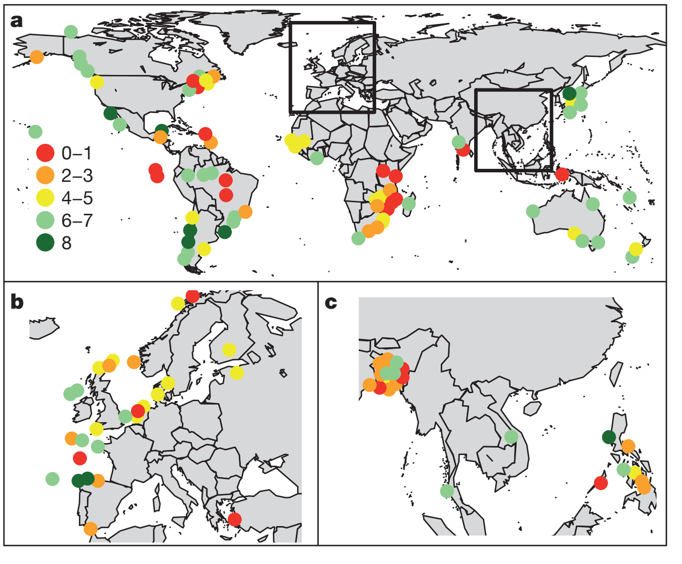

Figure 1 | Location and success score for all study cases of fisheries co-management. a–c, Success was grouped in five categories according to number of social, ecological and economic outcomes achieved. **a**, Global map. Insets are Europe (**b**) and Southeast Asia (**c**). $n = 130$.

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Table 1 | Fisheries co-management attributes and outcomes.

Group	Variable name	Frequency (%)
Co-management	Type (consultative, cooperative, delegated)	-
	Phase (pre-, implementation, post-)	-
	Time frame	-
Resource system	HDI (low, medium, high, very high)	-
	Governance Index	-
	Corruption Perceptions Index	-
	Resource type (single*, multi-species)	-
	Ecosystem (inland, coastal, offshore)	-
	Fishing sector (artisanal, industrial, sequential)	-
	Defined geographic boundaries	52
Resource unit	Sedentary/low mobility resources	38
Governance system	Central government support (local)	93
	Scientific advice	92
	Minimum size restrictions	76
	Long-term management policy	71
	Global catch quotas	52
	Monitoring, control and surveillance	47
	Protected areas	39
	Spatially explicit management	37
	Individual or community quotas	33
	Co-management in law (national)	32
	Seeding or restocking programs	19
	TURF	18
Users system	Social cohesion	78
	Self-enforcement mechanisms	71
	Leadership	62
	Tradition in self-organization	55
	Influence in local market	28
Outcomes	Community empowerment	85
	Fishery status (under or fully, over-exploited)	67
	Sustainable catches	62
	Increase in social welfare	61
	Increase in catch per unit of effort	54
	Add-on conservation benefits	45
	Increase in abundance	38
	Increase in unit prices	30

All attributes were grouped according to the classification of Ostrom[16]. Values in the frequency column denote percentage of co-management attributes reported as present within the co-management systems. For complete variable descriptions see Supplementary Table 2.
* Benthic, demersal, pelagic, mammal.

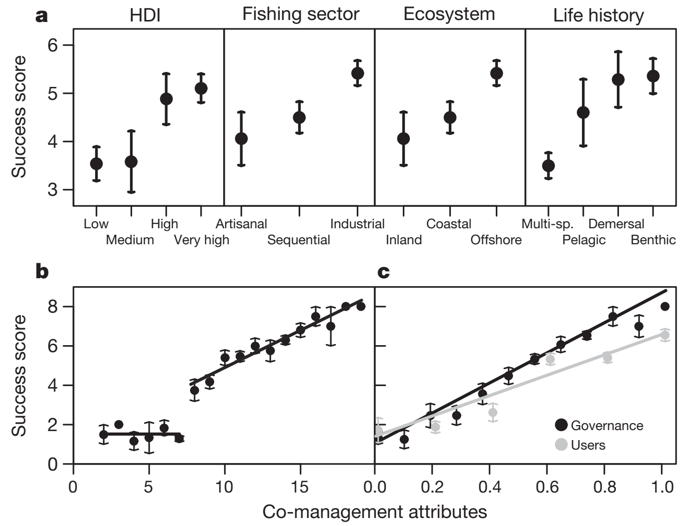

Figure 2 | Fisheries co-management performance. **a**, Success score discriminated by the HDI, fishing sector, ecosystem and life history. Multi-sp., multi-species. **b**, Success score correlated with the number of all co-management attributes present in the fishery. **c**, Success score correlated with proportion of governance and users' attributes separately (relative *x*-axis is shown for comparison purposes). Grouping variables are explained in Supplementary Table 2. All data are shown as mean ± s.e.m.

However, the large number of fisheries involved in our study, covering a wide spectrum of social, ecological and political settings, and the detailed information contained in the reviewed documents, provided the basis to assess causality through several criteria: (1) strength of association between co-management attributes and success measured by robust statistical methods; (2) consistency of association in various conditions across ecosystems, fishing sectors and degrees of human development; (3) plausibility of causal explanations; (4) coherence with co-management theories and knowledge of each fishery; and (5) temporality, where presence of attributes preceded success[18]. Furthermore, although comparison to top-down management would be of interest, the objective of this study was to identify and quantify the co-management attributes determining successful fisheries, and not explicitly to compare its performance with top-down centralized management.

We tested whether success scores differed among socio-economic conditions (HDI, fishing sector) and ecological settings (ecosystems, life history of exploited resources) and we identified specific attributes associated with their success (see Supplementary Information). Countries with high and very high HDIs were more successful than low and medium HDI countries, owing to higher redundancy in management tactics and stronger central governance structures. Industrial fisheries scored higher than artisanal fisheries mainly because of stronger enforcement mechanisms, whereas inland fisheries were less successful than coastal and offshore fisheries owing mostly to weaker social capital and short-term co-management arrangements. Co-management systems thrived in benthic and demersal fisheries, especially when accompanied by protected areas, territorial user rights for fishing (TURFs) and community or individual quotas allocated to well-defined groups of fishers. In contrast, less successful co-management observed in multi-species fisheries could be related to a mismatch between scales of distribution and mobility of stocks and the area of influence of the fishing process and the management system (Fig. 2a, Supplementary Fig. 3 and Supplementary Table 4).

There was a distinctive two-step pattern between success scores and the total number of attributes in each fishery. If fewer than eight attributes were present, the success score was close to zero, whereas above this threshold there was a strong positive relationship, with increasing attributes leading to higher success scores (Fig. 2b). Success scores were also more strongly correlated with the number of governance attributes present than with the number of users/community attributes (Fig. 2c and Supplementary Table 4). This indicates that even though co-management is enhanced by strong central governance systems, local community attributes were also necessary for success. These results demonstrate that the likelihood of co-management success increases when more management tools are added, providing redundancy in management regulations[19,20]. Further, no significant relationship ($P > 0.05$) was found between success and time frames of co-management regimes (omitting pre-implementation phase; mean ± standard deviation = 15.9 ± 9.8 years), indicating that failure or success is independent of the number of years the regime has been in place.

Using regression trees and random forests[21], we found that the most important co-management conditions necessary for successful management of fisheries are presence of community leaders, strong social cohesion, individual or community quotas, and community-based protected areas (Fig. 3a, b and Supplementary Table 2). Additional key attributes were enforcement mechanisms, long-term management policies and influence of fishers in local markets. Considering governance and users' attributes independently in the regression tree showed little differences in predictive accuracy compared to the joint tree (<4%) and between governance and users' trees (<5%). When analysed separately, community quotas were the most important management attribute followed by long-term management policies and protected areas, whereas leadership was by far the most significant users' attribute (Supplementary Fig. 4).These findings reinforce the notion that fisheries are complex social–ecological systems that need to be managed by addressing problems related not only to the resources themselves but to the people targeting them[22].

Leadership was critical for successful co-management of fisheries. Presence of at least one singular individual with entrepreneurial skills, highly motivated, respected as a local leader and making a personal

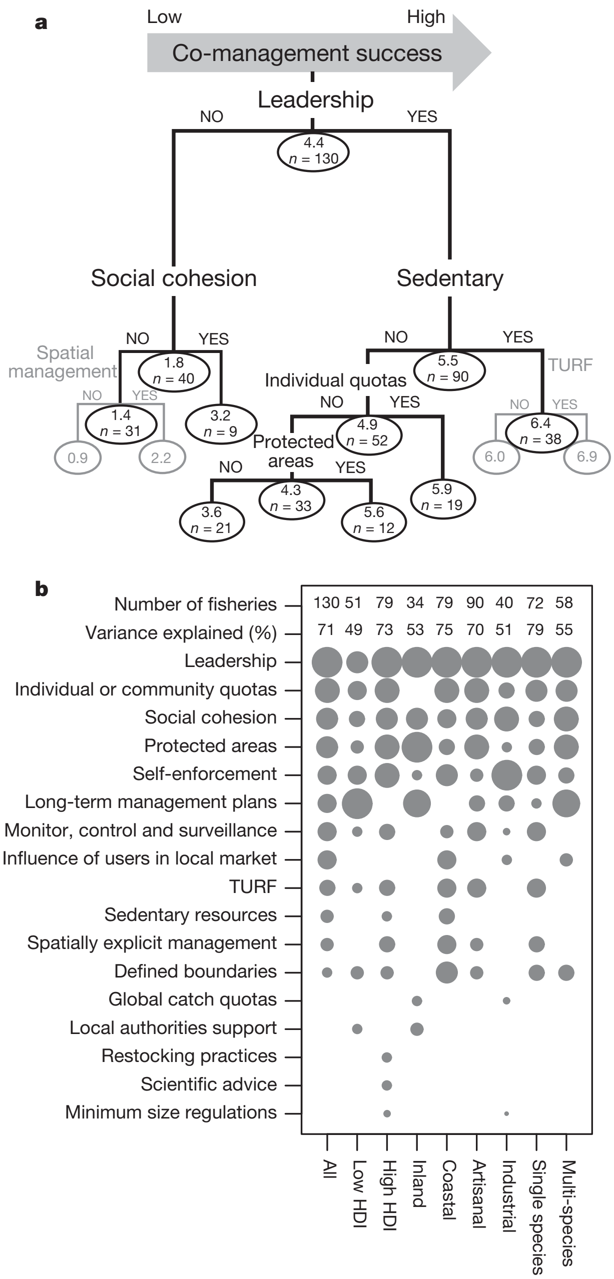

Figure 3 | Key co-management attributes for fisheries success. a, Regression tree showing the most important factors determining success. Higher branches offer greater explanatory power. Average success score and number of fisheries are listed at each node. The optimal tree explained 69% of the total deviance, and the vertical depth of each split is proportional to the variation explained by each attribute. **b**, Importance of individual attributes (rank proportional to circle size) for the full data set and for selected subsets of the data determined by random forests. The number of fisheries and variance explained are also indicated. Variables descriptions are given in Supplementary Table 2.

commitment to the co-management implementation process, was essential. Legitimate community leaders, when guided by collective interests and not self-benefits, give resilience to changes in governance, influence users' compliance to regulations and enhance conflict resolutions in quota allocations[23]. Community cohesion founded on norms, trust, communication, and connectedness in networks and groups was also an important global attribute leading to successful fisheries co-management. This robust social capital[7,24] serves as a buffer against changes in institutional arrangements, economic crises and resource overexploitation, and fosters sustainable co-management systems[3,25]. Our results show that additional resources should be spent on efforts to identify community leaders and build social capital rather than only imposing management tactics without users' involvement.

Catch shares, both by individual or community quotas and by TURFs, were a key management condition towards co-management success. Well-designed and implemented catch shares have helped to prevent overfishing[26], promote stability[27] and ecological stewardship[28]. However, previous analyses of catch share programs have focused mainly on industrial fisheries in developed countries. We highlight the importance of users' security over catch or space in attaining social, economic and ecological success across all co-managed fisheries.

The effects of protected areas in achieving co-management success reaffirmed their strong link to social–ecological dynamics and the role of local communities in their successful implementation[29]. Their potential value for improving fisheries management depends on proper incentives, decentralized institutional arrangements and cohesive social organizations, all of which are more likely to happen under well-established co-management regimes. Spatial considerations, through clearly defined geographic boundaries (such as lake or enclosed bay) and sedentary life history of the resources contributed to co-management success by confining the number of users, lowering associated costs of information gathering, monitoring and enforcement, and restricting the spatial dynamics of fishing effort to well-defined areas.

Self-enforcing mechanisms contributed significantly to co-management success when guided by self-interests[24] (for example, through systems of penalties imposed by strong operational rules designed, enforced and controlled by local fishers). Influence of fishers in local markets characterized most accomplished co-management regimes, by allowing for specific marketing tactics, improved product quality, shorter intermediaries' chains, market timing coordination and eco-labelling strategies. This influence of users in local markets may result in multiple benefits to local communities, minimizing the probability of overexploitation and enhancing economic revenues by higher income per unit of effort[12].

Our study is, to our knowledge, the first comprehensive global assessment of social, economic and ecological attributes contributing to fisheries co-management success. Our synthesis shows that co-management holds great promise for successful and sustainable fisheries worldwide. However, there is an urgent need to gather long-term ecological, economic and social data from a variety of fisheries in a multi-disciplinary context in order to compare empirically different degrees of users' involvement in management decisions and to better understand and improve fisheries co-management[30].

METHODS SUMMARY

We conducted a systematic search of the peer-reviewed and grey literature ($n = 1,168$ documents) to identify quantitative and qualitative evidences of the impacts of fisheries co-management practices around the world. We used the term community-based co-management to cover the whole spectrum of co-management arrangements (from formal consultation mechanisms between government and users to self-governance). The presence of well-established local co-management institutions with decision power in fisheries management was also used as compulsory criterion to classify a fishery as co-managed. Fisheries without sufficient or consistent information as well as co-management regimes in a pre-implementation phase were excluded from the analyses. For 130 fisheries (out of a total of 218 study cases; Supplementary Table 1) we compiled a database of 9 grouping or contextual variables including co-management type, co-management phase, duration of the management regime, HDI, Corruption Perception Index, Governance Index, ecosystem, fishing sector and resource type and 19 co-management attributes (Table 1 and Supplementary Table 2). We used aggregated social, economic and ecological binary outcomes to represent co-management success (success score; Supplementary Table 2). We built a regression tree model that graphically depicts quantitative relationships between predictor attributes and co-management success. Missing values were filled in using surrogate splits inside the regression model. A random forest model of 10,000 trees was used to estimate the relative importance of selected attributes in determining co-management success. The importance of contextual variables (for example, fishing sector) was also investigated by grouping them in the random forest models and by running independent models for each category (for example, artisanal, industrial). Model accuracy for trees and random forests were quantified using standard metrics, and model selection was performed by backwards stepwise elimination of non-significant predictors (see Supplementary Information).

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Supplementary Information is linked to the online version of the paper at www.nature.com/nature.

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Author Contributions N.L.G. designed the study, compiled and analysed the data and performed the statistical analyses; O.D. compiled and analysed the data. All authors discussed the results and jointly wrote the manuscript.

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Overview

Fig. S1 presents an overview of the literature review, data compilation, statistical analyses and main results.

Supplementary Methods

Literature search

We conducted a systematic search of the scientific and gray literature to identify quantitative and qualitative evidence of the impacts of fisheries co-management practices worldwide (Fig. S1). Co-management studies published prior to January 2010 were identified using (i) journal search tools (Web of Science, EBSCO, JSTOR); (ii) Governmental and Non-Governmental Organizations websites (fisheries management agencies, WorldFish/ICLARM, FAO, IUCN, IMCS, World Bank, etc.); (iii) academic databases (Digital Library of the Commons, UW WorldCat); (iv) list of references from most relevant documents; and (v) personal knowledge and direct communication with the authors of studies and/or managers.

In order to identify peer-reviewed studies (e.g., using ISI Web of Knowledge) we performed a search with no restriction on publication year, using the following search term combinations: [("community-based" OR "co-management" OR "self-governance") AND (fisheries)]. We used the 'Refine Results' option in order to identify areas of interest and discard out-of-scope documents. This resulted in 389 references. We examined each of these references to assess their potential for meeting the selection criteria for inclusion in the review.

Considerable amounts of co-management documentation on data collection, analysis and results exist outside of the peer-reviewed literature. To incorporate information from workshops, conference proceedings, technical reports, theses, we performed a hierarchical search of study cases by co-management systems/regions/fisheries and by species and finally by Principal Investigators and by species. By including analysis of gray literature and unpublished documents, our literature search method reduces selection bias resulting from a possible over-representation of only positive co-management success analyses in peer-reviewed literature. Manuscripts in different languages (i.e., English, Spanish, French, and Portuguese) were also assessed and processed.

Initial screening in the literature review involved the description of a co-management regime and its consequent evaluation considering biological, social, and economic indicators (Fig. S1). We included all co-management regimes within the spectrum of arrangements, based on the level of involvement and mode of communication between government and fishers (i.e., from consultative to self-governance). The study cases were classified by co-management type (consultative, cooperative, and delegated)[1] and phase (pre-implementation, implementation, and post-implementation). Although we recognize our definition of co-management may be too broad, we also used well established co-management organizations and/or institutions with decision power in local fisheries management as compulsory criteria to classify a fishery as co-managed. Further, considering that fisheries management systems in almost all developed countries involve some form of user involvement through participation of stakeholders on the decision making bodies (e.g., through consultative committees), those cases where the importance of the legal and political systems dominates the co-management aspects of the fisheries were not included in our analyses.

For each identified co-managed fishery, manuscripts were assessed in detail in order to extract information on co-management attributes and measures of performance. When possible, we verified data and analyses by directly contacting PI or fisheries managers. The number of study cases (i.e., fisheries) including relevant information was 218 (Table S1). However, in order to eliminate data gaps, an additional bibliographic search for each fishery was performed (Fig. S1). The final search for these 218 case studies encompassed 1,168 documents, where 461 referred to general co-management theory and 707 to individual or multiple study cases. From those references, 306 were peer-reviewed and 401 considered gray literature.

Data extraction and variable coding

In order to understand co-management dynamics, complex fishery social-ecological systems (SESs) need to be decomposed into groups and sub-groups of variables that can be analyzed, tracked, and objectively compared[2]. Following the rationale of Institutional Analysis and Design[3,4] (IAD), a series of explanatory variables describing interdisciplinary attributes of fisheries co-management and measures of their performance were identified. This framework provided an appropriate basis for identifying relevant co-management attributes, their outcomes, and formulating hypotheses concerning the relationships among them. These variables were classified in 5 different sub-groups[1,2]: (i) resource system; (ii) resource unit; (iii) governance system; (iv) users system; and (v) outcomes. A large and extensive list of explanatory co-management attributes has been used in previous studies of common pool resources[5-7] and fisheries co-management[8,9]. These variables reflect the need to provide alternative indicators to describe a vast range of different fishery types, ecosystems, fishing sectors, management institutions, and social, economic and political settings. We selected a smaller subset of variables to: (i) minimize the problem of missing data; (ii) ensure variables were applicable to most study cases; (iii) minimize variables that can only be assessed subjectively; and (iv) reduce attributes that display high collinearity. We used 9 study case key identifiers or grouping variables related to the resource system, 19 variables describing fisheries co-management attributes and 8 outcomes or measures of social, economic and ecological performance (Table S2).

Co-management attributes and outcomes were defined on a binary scale denoting presence or absence (1-0). Even though this dichotomous coding schema may be not realistic, including values that exhaust all possibilities (e.g., low, medium, high degree of cohesion) or quantifying these factors in an ordinal scale was impossible for all selected study cases, due to: i) the qualitative character of most studies; or ii) the mutually exclusive nature of the selected variables. Thus, most attributes reported by the published studies were considered to be positively related to the successful fisheries. Simplicity, both related to the number of variables included in the analysis and the binary structure of the data was needed to identify the most important causal mechanisms and/or attributes and take general conclusions from the available information.

A compounded success score was built by adding each of the 8 individual outcomes and used as a proxy for co-management performance (i.e., 0 means total failure and 8 total success). This success score was used as the response variable in all subsequent statistical analyses (Fig. S1). Although these performance indicators do not cover all aspects of the fishery's functioning, they represent its social, ecological, and economic performance.

Since correlation may or not may imply causality, this condition was assessed and verified during the variable coding through several criteria[10,11]: (i) strength of association through statistical methods (a causal attribute must be correlated with co-management success and have explanatory power); (ii) consistency (a causal attribute must be associated with success in various conditions); (iii) plausibility of causal explanation; (iv) coherence (a causal explanation should be consistent with the current body of knowledge of both co-management theory and the specific fisheries); (v) temporality (a causal factor has to precede measures of success; most studies present qualitative, and quantitative in less extent, baseline evidence for this criteria).

To minimize bias in extracting and processing the information and to overcome inconsistencies in variable coding, two independent readers (NLG and OD) analyzed key references for each study. A random sample of 25% of the study cases was also re-coded as a reliability test, revealing no systematic bias. Those cases not providing a thorough description of the co-management process were eliminated, together with those presenting contradictory or lack of information on the selected variables (*n* = 68). Since co-management effects evolve over time, we excluded regimes at the pre-implementation stage (*n* = 20). The final screening reduced our dataset to 130 fisheries in 44 countries, a comprehensive and representative set of community-based co-management fisheries from different countries, degrees of human development, ecosystems, fishing sectors and types of resources (and not a complete global census of co-managed fisheries). For these fisheries, our data came from 4.06 documents on average (s.d. 1.73) (Table S1).

We recognize that individual fisheries may have idiosyncratic features (e.g. cultural, political, or economic factors) that may affect their success. Here, we expanded beyond these contextual characteristics in order to consider the characteristics of the co-management systems, by controlling for Human Development Index[12], Governance Index[13], Corruption Perceptions Index[14], continent, fishing sector, and type of resource (Table S2) and to determine whether a non-randomized co-management regime causes a particular outcome. Although it is nearly impossible to select case studies completely at random from all co-managed fisheries, our study comprises the most comprehensive sample of fisheries co-management assembled to date, including a full range of social, ecological, cultural and political settings.

We addressed potential biases in selecting the study cases and in coding all variables: (i) several search methods and databases were used in locating and selecting relevant documents; (ii) published and unpublished documents from very different sources (ISI journals, technical reports, conference proceedings, books chapters), various languages (English, Spanish, and French), a variety of disciplines (fisheries, ecology, social and environmental sciences, policy, etc.), and institutions (academia, management agencies, NGOs, etc.) were analyzed; (iii) two independent reviewers extracted the information needed for variable coding and checked for inconsistencies; (iv) external review was considered in some cases *via* email to Principal Investigator or fisheries managers; and (v) missing data categories were assigned in those cases were coding variables where inconsistent or causality uncertain.

Statistical analyses

The final data set was analyzed using R[15]. Correlation matrices of selected attributes and performance indicators (outcomes) were constructed to detect attribute redundancies (Table S3), as well as their frequency distributions to paint a picture of attributes and outcomes most often present in fisheries co-management systems across all fisheries (Fig. S2) and by categories of grouping variables (Fig. S3).

An orthogonal, multifactorial design was not possible due to absence of some treatments within factors (e.g., industrial fisheries are absent in inland ecosystems). Thus, we used one-way analyses of covariance (ANCOVAs) to test for differences in success score between ecosystems, fishing sectors and resource types, using the number of management attributes as the covariate. When significant differences were detected, multiple comparisons were conducted through a Fisher least significant difference (LSD) test ($\alpha = 0.05$). Relationships between success scores and number of attributes, both aggregated and by group (i.e., governmental attributes and users attributes), were also examined through linear models and ANCOVAs. A Bartlett test was performed prior to all analyses in order to test the assumption of homogeneity of variances among treatments. When data were heteroscedastic, the necessary transformations were carried out. Homogeneity of slopes (parallelism test) of dependent variable – covariate relationship was also tested. Results are presented in Table S4.

Decision trees were used to identify key social, ecological, and economic attributes of co-management and to determine the way in which these variables would influence outcomes. Decision trees produce a hierarchical map of binary choices showing which attributes best partition the data according to the success score. Previous analyses[8,9,16,17] used mostly logistic regressions, generalized linear models or neural networks, but decision trees offer substantial advantages over these methods when analyzing complex social-ecological datasets and in particular when modeling nonlinear data containing multiple interacting variables[18-21]: (1) flexibility to handle a broad range of explanatory variables (e.g., categorical, interval, and continuous) and to deal with high dimensionality (large number of explanatory variables with relatively small data sets); (2) ability to deal with missing values in the explanatory variables; (3) invariance under monotonic transformations of the explanatory variables; and (4) easy and robust construction and visualization. Here, we fit regression trees for the whole set of co-management attributes (Fig. 3a) and also to government and users' attributes independently, in order to explore the degree to which each group separately explained co-management success (Fig. S4). In constructing the regression trees, the following steps were implemented:

(1) **Growing the tree, splitting criteria and missing data**. The regression tree algorithm in *rpart*[22] package in R builds trees by iteratively partitioning the dataset into a

nested series of mutually exclusive groups according to a "splitting rule" (e.g., are there protected areas within the co-management regime of a particular fishery present or absent?) and a "goodness of split criterion" (i.e., by maximizing groups homogeneity or minimizing their impurity with respect to co-management success). Missing data of co-management attributes (mean percentage of missing data per variable ± s.d. = 4.5 ± 0.6; <10% of the total database) were treated by multiple imputation and by using surrogates as proxy variables for the main splitting variable. Comparisons of trees for both methods showed that surrogates splits performed slightly better in terms of predictive accuracy (% deviance explained) than multiple imputation, corroborating prior regression tree simulation analysis by Feelders[23].

(2) **Pruning and selecting the tree.** After generating a large tree, lower branches were pruned to produce an optimal tree, balancing complexity (i.e., number of terminal nodes) with prediction accuracy. For description and visualization purposes a single tree was selected by running a set of 50 10-fold cross-validations in order to assess the degree of variation in the size of the best tree, and to ensure the chosen tree was not atypical[21]. We then selected the tree size from each cross-validation of the series according to the 1-SE[24] rule to avoid over-fitting of the data (Fig. S5). The final tree also coincided with the most frequently occurring (modal) size from the distribution of optimal tree sizes (6 leaves; Table S5; Fig. 3a). Residuals analyses were performed for all trees (Q-Q plots, residuals vs. predicted).

Under certain conditions, and in particular when dealing with missing values, regression trees can be unstable to small changes in the data with significant differences in the variables used in the splits and the overall tree shape. To overcome this problem, we used random forests (package *randomForest*[25]), an extension of the regression tree method based on the generation and averaging of an ensemble of trees[18,24]. Random forest models cope well with high dimensional data sets and multiclass problems and, more importantly, also provide insights into the structure of the data under study by quantifying the confidence in regression and by indicating the importance of each variable for the regression task[25]. Considering that high correlation among explanatory variables can lead to bias in computing variable importance[26,27], we checked for multicollinearity by using the variance inflation factor[28]. In random forests, rather than using all explanatory variables or attributes and all study cases to make a single tree, we created a forest of many trees, each one based on a random (bootstrapped) selection of co-management attributes and fisheries in the following manner:

(1) **Growing and assessing the performance of the random forest.** From the complete data set, a bootstrap sample (without replacement) was taken in order to grow each tree with the following modifications[29]: at each node, the best split was chosen among a randomly selected subset of explanatory variables (*mtry*). The tree was grown to a pre-specify

number of nodes (*nodesize*) and not pruned back. These steps were repeated until a sufficiently large number of trees (*ntree*) were grown.

(2) **Tuning parameters**. We tested the sensitivity of the random forest performance to different values of *mtry*, with little changes over a wide range of values (Fig. S6a). To be consistent with the model selection backward step-wise procedure described later, we chose *mtry*=2. In addition, the number of trees was chosen to be sufficiently large so that the mean square error has stabilized. In our case, 5,000 trees were sufficient (Fig. S6b), although we chose *ntree*=10,000 since computational time was not an issue. Lastly, we tested the sensitivity of the random forest to different values of *nodesize*, which determines the tree depth or minimum size of nodes below which no split will be attempted. Since no considerable changes in performance were observed, we used the default value of 5 (Fig. S6c).

(3) **Co-management attributes importance.** We used the unnormalized decrease in accuracy (i.e., increase in mean square error) as a measure of variable importance[29,30] (Fig. 3b). For model selection purposes and to exclude noisy explanatory variables we used a backward step-wise procedure[31]. Variable importances were not re-calculated in order to avoid over-fitting[32] and the model with the smallest number of attributes whose error rate was within 1 standard deviation of the minimum error rate of all forests was selected[33] (similar rational to the 1-SE rule used in tree pruning).

(4) **Effect of grouping variables**. In order to assess the effect of grouping variables in co-management success, we used three different exploratory approaches: (i) we included all grouping (i.e., contextual) and explanatory variables (i.e., co-management attributes) within the random forest and we followed the above mentioned procedure (Fig. S7); (ii) we split the dataset in categories for the most influential grouping variables (i.e., HDI, ecosystem, fishing sector and targeted resource) and we assessed attributes' importance for each category (Fig 3b); and (iii) we assessed the effect of deleting a particular category from the dataset by using the following algorithm[30]: (a) we ran the random forest model for the dataset omitting each category one at a time (e.g., omitting artisanal fisheries); we computed the Kendall's coefficient of concordance (*W*) of the variables rankings for the dataset as a whole and for the dataset subdivided in categories for each grouping variables. This provided an overall synthetic indication on how much the variables importance rankings are modified by the effect of the grouping variables (Table S6).

Supplementary Results

Out of our 130 study cases, 20% did not use any type of data, 20% used only qualitative methods (e.g., in-depth or semi-structured interviews, Venn diagrams), 15% of the studies used both qualitative information and fishery-dependent data (e.g., CPUE) and 11% used both fishery-dependent and -independent data (e.g. abundance surveys). Only 7% of the study cases used a combination of interviews, fishery-dependent and -independent data in assessing co-management failure or success, while a further 6% used before-after, control-impact, or complete before-after-control-impact (BACI) approach in assessing co-management regimes. Thus, most assessments were treated as perceived trends in the condition of fishery resources but no long-term databases were analyzed to test specific hypotheses.

Most cases (71%) came from countries with high and very high Human Development Index (HDI). Case studies were split between Asia (26%), Europe (21%), Africa (15%), South America (14%), North America and the Caribbean (17%), and Oceania (7%). Coastal ecosystems were the most represented (61%), followed by inland (26%) and offshore (13%). The majority (69%) were artisanal fisheries, while relatively few were industrial (25%) or exploited by both industrial and artisanal fisheries (sequential; 5%). 45% of the fisheries analyzed were multi-specific, 32% targeted on benthic resources and 12% and 11% corresponded to demersal and pelagic/mammal species respectively.

The most frequently reported co-management attributes were local government support, scientific advice (both > 90% of fisheries), minimum size restrictions and community cohesion (both >70% of fisheries) (Fig. S2). The least observed attributes were influence of users in local markets (28%), restocking practices (19%) and Territorial Use Rights for Fisheries (TURFs: 18%).

In terms of performance indicators, community empowerment was by far the most frequently reported outcome (85% of the fisheries), highlighting the importance of these systems in creating social capital. Increase in stock abundance (38%) and in unit prices (30%) were the least frequent reported outcomes. According to the judgment of co-management study authors, 69% of the study cases were classified as successful in achieving the co-management objectives and 31% as failure. However, only 7% (n = 9) of the fisheries showed success on all the 8 social, economic, and ecological performance indicators (Fig. S2).

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Supplementary Table S1. Summary information of total study cases (*n* = 218) of fisheries co-management systems identified from the literature review. Highlighted in grey are the definitive cases included in the final model (*n* = 130) with their most relevant supporting references. Continent: AF= Africa, AS= Asia, OC= Oceania, NAC= North America and the Caribbean, SA= South America, EU= Europe; Human Development Index, HDI: LO= low, ME= medium, HI= high, VG= very high; Fishing Sector: Art= artisanal, Ind= industrial, Seq= sequential; Co-management phase: PreImplem= pre-implementation, Implem= implementation, PostImplem = post-implementation.

Case	Continent	Country	HDI	Region	Resource	System	Fishing sector	Co-management phase	References
1	AF	Malawi	LO	Chiuta	MultiSpp	Inland	Seq	PostImplem	S34-S36
2	AF	Malawi	LO	Malombe	MultiSpp	Inland	Seq	Implem	S37-S39
3	AF	Malawi	LO	Chilwa	MultiSpp	Inland	Art	Implem	S40-S42
4	AF	Mozambique	LO	Angoche	Demersal	Coastal	Seq	Implem	
5	AF	Mozambique	LO	Inhassoro	MultiSpp	Coastal	Art	PostImplem	S43-S45
6	AF	Mozambique	LO	Kwirikwidge	MultiSpp	Coastal	Art	PostImplem	S46-S48
7	AF	Zimbabwe	LO	Kariba	MultiSpp	Inland	Art	Implem	S49-S51
8	AF	Zambia	LO	Kariba	MultiSpp	Inland	Art	Implem	S52-S54
9	AF	Zambia	LO	Bangweulu	MultiSpp	Inland	Art	Implem	
10	AF	The Gambia	LO		MultiSpp	Coastal	Seq	Implem	S55-S57
11	AF	The Gambia	LO		Demersal	Inland	Art	Implem	S58
12	AF	Cote D'Ivoire	LO	Aby	MultiSpp	Coastal	Art	Implem	S59-S61
13	AF	Tanzania	ME	Tanga	MultiSpp	Coastal	Art	PreImplem	
14	AF	Tanzania	ME	Victoria	MultiSpp	Inland	Art	Implem	S62-S64
15	AF	Kenya	ME	Victoria	MultiSpp	Inland	Art	Implem	
16	AF	Uganda	ME	Victoria	MultiSpp	Inland	Art	PreImplem	
17	AF	South Africa	ME	Sokhulu	Benthic	Coastal	Art	Implem	S65-S67
18	AF	South Africa	ME	Kosi	MultiSpp	Coastal	Art	Implem	S68-S70
19	AF	South Africa	ME	St Lucia	MultiSpp	Coastal	Art	PostImplem	S67,S71-S72
20	AF	South Africa	ME	Olifants	MultiSpp	Inland	Art	Implem	S73-S75
21	AF	South Africa	ME		Demersal	Offshore	Ind	Implem	S76-S78
22	AF	South Africa	ME	Arniston	MultiSpp	Coastal	Art		
23	AF	Guinea-Bissau	LO	Rio Grande	MultiSpp	Coastal	Art	Implem	S79-S80
24	AF	Madagascar	ME		Benthic	Coastal	Seq	Implem	S81-S83
25	AF	Senegal	LO	Kayar	Demersal	Coastal	Art	Implem	S84-S85
26	AF	Benin	LO	Nokoue	MultiSpp	Inland	Art		
27	AF	Nigeria	ME	Chad	MultiSpp	Inland	Art		
28	AF	Kenya	ME		MultiSpp	Coastal	Art	Implem	
29	AF	Kenya	ME	Diani-Chale	MultiSpp	Coastal	Art	Implem	S86-S88
30	AF	Kenya	ME	Kolongo	MultiSpp	Coastal	Art		
31	AF	Cameroon	ME		MultiSpp	Coastal	Art		

32	AS	Philippines	ME	Malalison Is	Benthic	Coastal	Art	PostImplem	S89-S91
33	AS	Philippines	ME	San Salvador	MultiSpp	Coastal	Art	PostImplem	S92-S94
34	AS	Philippines	ME	San Miguel Bay	MultiSpp	Coastal	Art	PostImplem	S95-S97
35	AS	Philippines	ME	Capiz	MultiSpp	Coastal	Art	PostImplem	S98-S100
36	AS	Philippines	ME	Ulugan Bay	MultiSpp	Coastal	Art		
37	AS	Philippines	ME	San Vicente	MultiSpp	Coastal	Art		
38	AS	Philippines	ME	Ilog Bay	MultiSpp	Coastal	Art	PostImplem	S101-S102
39	AS	Philippines	ME	Cogton Bay	MultiSpp	Coastal	Art	PostImplem	S103-S105
40	AS	Philippines	ME	Sagay	MultiSpp	Coastal	Art	PostImplem	S106-S108
41	AS	Bangladesh	ME		MultiSpp	Inland	Art	Implem	S109-S111
42	AS	Bangladesh	ME	Titas River	MultiSpp	Inland	Art	Implem	S112-S114
43	AS	Bangladesh	ME	Kali Nodi	MultiSpp	Inland	Art	Implem	S115-S117
44	AS	Bangladesh	ME	Moisherkandi	MultiSpp	Inland	Art	Implem	S103,S105,S116
45	AS	Bangladesh	ME	Dhaleswari	MultiSpp	Inland	Art	Implem	S118-S128
46	AS	Bangladesh	ME	Jari Jamuna	MultiSpp	Inland	Art	Implem	S118-S128
47	AS	Bangladesh	ME	Tetulia	MultiSpp	Inland	Art	Implem	S118-S128
48	AS	Bangladesh	ME	Ashurar	MultiSpp	Inland	Art	Implem	S118-S128
49	AS	Bangladesh	ME	Hamil	MultiSpp	Inland	Art	Implem	S125-S128
50	AS	Bangladesh	ME	Ubdakhali	MultiSpp	Inland	Art	Implem	S125-S127
51	AS	Bangladesh	ME	Rajdhola	MultiSpp	Inland	Art	Implem	S126-S127
52	AS	Bangladesh	ME	Digshi	MultiSpp	Inland	Art	Implem	S118-S128
53	AS	Bangladesh	ME	Goakhola	MultiSpp	Inland	Art	Implem	S123-S126
54	AS	Bangladesh	ME	Arial Kha	MultiSpp	Inland	Art	Implem	S122-S128
55	AS	Bangladesh	ME	Dum Nadi	MultiSpp	Inland	Art	Implem	S122-S128
56	AS	Bangladesh	ME	Ruhia Baisa	MultiSpp	Inland	Art	Implem	S122-S128
57	AS	Bangladesh	ME	Krishno	MultiSpp	Inland	Art	Implem	S122-S128
58	AS	Japan	VH	Nishi	Pelagic	Offshore	Ind	PostImplem	S129-S132
59	AS	Japan	VH	Suruga Bay	Demersal	Coastal	Ind	PostImplem	S134-S136
60	AS	Japan	VH	Akita	Pelagic	Coast/Off	Ind	PostImplem	S137-S140
61	AS	Japan	VH	Ise Bay	Pelagic	Coastal	Ind	PostImplem	S141-S142
62	AS	Japan	VH	Fukushima	Demersal	Coastal	Ind	PostImplem	
63	AS	Japan	VH	Kyoto	Benthic	Offshore	Ind	PostImplem	S143-S144
64	AS	Japan	VH	Shiretoko	MultiSpp	Coastal	Seq	PostImplem	
65	AS	Japan	VH	Ibaraki	Benthic	Coastal	Art	PostImplem	
66	AS	Cambodia	ME	Tblong Kla	MultiSpp	Inland	Art	PreImplem	
67	AS	Cambodia	ME	Tonle Sap	MultiSpp	Inland	Art	PreImplem	
68	AS	Lao PDR	ME	Khong	MultiSpp	Inland	Art	PostImplem	S145-S147
69	AS	Vietnam	ME	Thac Ba	MultiSpp	Inland	Art		
70	AS	Vietnam	ME	Tien Hai	MultiSpp	Coastal	Art		
71	AS	Vietnam	ME	Khanh Hoa	MultiSpp	Coastal	Art		
72	AS	Vietnam	ME	Daklak	MultiSpp	Inland	Art	PreImplem	
73	AS	India	ME	Cochin	Demersal	Coastal	Art	PostImplem	S149-S151
74	AS	India	ME	Cochin	MultiSpp	Coastal	Art	PostImplem	S152-S154
75	AS	Indonesia	ME	Semarang	MultiSpp	Inland	Art	PostImplem	
76	AS	Indonesia	ME	N. Sulawesi	MultiSpp	Coastal	Art	PreImplem	

77	AS	Indonesia	ME	Maluku	MultiSpp	Coastal	Art	PostImplem	S155-S157
78	AS	Korea	VH		MultiSpp	Coastal	Art	PostImplem	
79	AS	Sri Lanka	ME	Negombo	Demersal	Coastal	Art		
80	AS	Sri Lanka	ME	Egodauyana	MultiSpp	Coastal	Art	PostImplem	
81	AS	Sri Lanka	ME	Chilaw	Demersal	Coastal	Art	PostImplem	
82	AS	Sri Lanka	ME	NW province	MultiSpp	Inland	Art	Implem	
83	AS	Thailand	ME	Phang-nga	MultiSpp	Coastal	Art	PostImplem	S158-S160
84	AS	Thailand	ME	Bang Saphan	MultiSpp	Coastal	Art	Implem	
85	AS	Malasya	HI	Langkawi	MultiSpp	Coastal	Art	PreImplem	
86	AS	Sri Lanka	ME	Victoria	MultiSpp	Inland	Art		
87	AS	Taiwan	VH		MultiSpp	Coastal	Ind	PreImplem	
88	OC	Vanuatu	ME		MultiSpp	Coastal	Art	PostImplem	S161-S163
89	OC	Salomon Is	ME		MultiSpp	Coastal	Art	PreImplem	
90	OC	Fiji	ME		MultiSpp	Coastal	Seq	PostImplem	
91	OC	Samoa	ME		MultiSpp	Coastal	Art	PostImplem	
92	OC	Samoa	ME		Pelagic	Offshore	Ind	Implem	
93	OC	Cook Is	ME		MultiSpp	Coastal	Seq	Implem	
94	OC	New Zealand	VH	Bluff	Benthic	Coastal	Ind	Implem	S164-S166
95	OC	New Zealand	VH	N-M Sound	Benthic	Coastal	Ind	PostImplem	S167-S169
96	OC	New Zealand	VH		Benthic	Offshore	Ind	PreImplem	
97	OC	New Zealand	VH		Benthic	Coastal	Ind	PreImplem	
98	OC	Australia	VH	Spencer Gulf	Demersal	Coastal	Ind	Implem	S170-S174
99	OC	Australia	VH	N. Territory	Benthic	Coastal	Art		S175-S176
100	OC	Australia	VH	Exmouth Gulf	Demersal	Coastal	Ind	Implem	S177-S179
101	OC	Australia	VH	Queensland	Demersal	Offshore	Ind	Implem	S180-S183
102	OC	Australia	VH	Victoria	Benthic	Coastal	Ind	Implem	S184-S186
103	OC	Australia	VH	Sub-Antarctic	Demersal	Offshore	Ind	Implem	
104	OC	Australia	VH	SE Australia	Demersal	Offshore	Ind	Implem	S187-S189
105	OC	Australia	VH	SE Australia	Demersal	Coastal	Ind	PreImplem	
106	NAC	Canada	VH	British Columbia	Benthic	Coastal	Ind	PostImplem	S190-S191
107	NAC	Canada	VH	Nova Scotia 19	Benthic	Coastal	Ind	PostImplem	S192-S195
108	NAC	Canada	VH	Nova Scotia 22	Benthic	Coastal	Ind	PostImplem	S192-S195
109	NAC	Canada	VH	Newfoundland	Benthic	Coastal	Ind	PostImplem	S196-S198
110	NAC	Canada	VH	Vancouver Is	Pelagic	Coastal	Art	PreImplem	
111	NAC	Canada	VH	Fraser River	Pelagic	Coastal	Seq	PreImplem	
112	NAC	Canada	VH	Nova Scotia	Benthic	Coastal	Ind	PreImplem	
113	NAC	Canada	VH	British Columbia	Benthic	Coastal	Ind	Implem	S199-S201
114	NAC	Canada	VH	Georges Bank	Benthic	Offshore	Ind	Implem	S202-S204
115	NAC	Canada	VH	Nova Scotia	Demersal	Offshore	Ind	Implem	
116	NAC	Canada	VH	British Columbia	Demersal	Offshore	Ind	Implem	S205-S207
117	NAC	Canada	VH	Kyuquot	Benthic	Coastal	Art	PostImplem	S208-S209
118	NAC	Canada	VH	Scotia-Fundy	Pelagic	Coast/Off	Seq	PostImplem	S210-S215
119	NAC	Canada	VH	Scotia-Fundy	Demersal	Coastal	Art	PostImplem	S196, S216
120	NAC	Canada	VH	NE Canada	MultiSpp	Coastal	Art	PostImplem	S196, S217-S222

121	NAC	Canada	VH	NE Canada	Pelagic	Coastal	Art	PostImplem	S196, S223-S227
122	NAC	Canada	VH	Beaufort Sea	Mammal	Coastal	Art	PostImplem	
123	NAC	USA	VH	Maine	Benthic	Coastal	Ind	PostImplem	S228-S230
124	NAC	USA	VH	West Hawaii	Benthic	Coastal	Art	Implem	S231-S233
125	NAC	USA	VH	Pacific NW	Pelagic	Coastal	Seq	PostImplem	S234-S236
126	NAC	USA	VH	Pacific NW	Pelagic	Coastal	Seq	Implem	
127	NAC	USA	VH	Chignik-Alaska	Pelagic	Coastal	Seq	PreImplem	
128	NAC	USA	VH	Cook- Alaska	Mammal	Coastal	Art	PostImplem	
129	SA	Brazil	HI	Santa Catarina	Benthic	Inland	Art	Implem	S237-S239
130	SA	Brazil	HI	Patos Lagoon	MultiSpp	Coastal	Seq	PreImplem	
131	SA	Brazil	HI	NorthEast	MultiSpp	Inland	Art	PreImplem	
132	SA	Brazil	HI	Amazon Atlantic	MultiSpp	Coastal	Art	PreImplem	
133	SA	Brazil	HI	Arraial do Cabo	MultiSpp	Coastal	Art	PreImplem	
134	SA	Brazil	HI	Caete Estuary	Benthic	Coastal	Art	PreImplem	
135	SA	Brazil	HI	Patos Lagoon	MultiSpp	Coastal	Art	PreImplem	
136	SA	Brazil	HI	Para	Benthic	Inland	Art	Implem	S240-S242
137	SA	Brazil	HI	Patos Lagoon	MultiSpp	Coastal	Seq	PreImplem	
138	SA	Brazil	HI	Mamiraua	MultiSpp	Inland	Art	Implem	S243-S244
139	SA	Brazil	HI	Mamiraua	MultiSpp	Inland	Art	Implem	S243-S244
140	SA	Brazil	HI	Santarem	MultiSpp	Inland	Art	PreImplem	
141	SA	Brazil	HI	Santarem	MultiSpp	Inland	Art	PreImplem	
142	SA	Brazil	HI	San Francisco	MultiSpp	Inland	Art	PostImplem	S245-S246
143	SA	Brazil	HI	Arraial do Cabo	MultiSpp	Coastal	Art	PostImplem	S245-S246
144	SA	Brazil	HI	Corumbao	MultiSpp	Coastal	Art	PostImplem	S246, S248
145	SA	Brazil	HI	Ibiraquera	MultiSpp	Coastal	Art	PostImplem	S249-S250
146	SA	Chile	HI		Benthic	Coastal	Art	PostImplem	S251-S253
147	SA	Chile	HI		Benthic	Coastal	Art	PostImplem	S254-S255
148	SA	Chile	HI		Benthic	Coastal	Art	PostImplem	S255, S256-S263
149	SA	Chile	HI		Benthic	Coastal	Art	PostImplem	S255, S264-S265
150	SA	Chile	HI		Benthic	Coastal	Art	PostImplem	S266-S267
151	SA	Ecuador	HI	Galapagos	Benthic	Coastal	Art	PostImplem	S268-S274
152	SA	Ecuador	HI	Galapagos	Benthic	Coastal	Art	PostImplem	S268, 275-S277
153	SA	Colombia	HI	San Andres	MultiSpp	Coastal	Art	PreImplem	
154	NAC	Mexico	HI	Punta Allen	Benthic	Coastal	Art	PostImplem	S251, S278-S279
155	NAC	Mexico	HI	Baja California	Benthic	Coastal	Art	PostImplem	S280
156	NAC	Mexico	HI	Baja California	Benthic	Coastal	Art	PostImplem	S281
157	NAC	Barbados	HI		Benthic	Coastal	Art	PreImplem	
158	NAC	Belize	ME	Laughing Bird	Benthic	Coastal	Art	PreImplem	
159	NAC	Grenada	HI	Gouyave	Benthic	Coastal	Art	PreImplem	
160	NAC	Grenada	HI	Gouyave	Benthic	Coastal	Art	PreImplem	
161	NAC	St Lucia	HI	Vieux-Fort	Benthic	Coastal	Art	PostImplem	S282-S284
162	SA	Peru	HI	Chino, Tahuayo	Pelagic	Inland	Art	PostImplem	S285
163	SA	Uruguay	HI	Barra del Chuy	Benthic	Coastal	Art	PostImplem	S251, S286-S287
164	SA	Argentina	HI	San Jose Gulf	Benthic	Coastal	Art	Implem	S288-S289

165	NAC	Barbados	HI		MultiSpp	Coastal	Art	Implem	S290-S291
166	NAC	Grenada	HI	Gouyave	Pelagic	Coastal	Art	PreImplem	
167	NAC	Belize	ME		Pelagic	Coastal	Art	Implem	S292
168	EU	Denmark	VH	Denmark	MultiSpp	Coastal	Ind	PreImplem	
169	EU	Denmark	VH	N. Jutland	Pelagic	Offshore	Ind	PostImplem	S293
170	EU	Denmark	VH	Kattegat	MultiSpp	Coastal	Ind	PostImplem	S293-S294
171	EU	Denmark	VH	Denmark	MultiSpp	Coast/Off	Ind		
172	EU	Denmark	VH	Denmark	MultiSpp	Offshore	Ind		
173	EU	Denmark	VH	Greenland	Pelagic	Coastal	Art	Implem	
174	EU	Europe	VH		MultiSpp	Coast/Off	Ind		
175	EU	Europe	VH		MultiSpp	Coast/Off	Ind		
176	EU	Europe	VH		MultiSpp	Coast/Off	Seq		
177	EU	Europe	VH		MultiSpp	Coast/Off	Seq		
178	EU	Europe	VH		MultiSpp	Coast/Off	Ind		
179	EU	Finland	VH	Findland	MultiSpp	Inland	Seq	PostImplem	S295-S296
180	EU	France	VH	Bay of Brest	Benthic	Coastal	Art	PostImplem	S297
181	EU	France	VH	Mediterranean	MultiSpp	Coastal	Art	PreImplem	
182	EU	Iceland	VH	Iceland	MultiSpp	Offshore	Ind		
183	EU	Ireland	VH	Dingle Bay	MultiSpp	Coastal	Ind		
184	EU	Netherlands	VH	Netherlands	MultiSpp	Coast/Off	Ind	PreImplem	
185	EU	Netherlands	VH	Wadden Sea	Benthic	Coastal	Ind	Implem	S298
186	EU	Netherlands	VH	North Sea	MultiSpp	Coastal	Ind	PostImplem	S299
187	EU	Netherlands	VH	Wadden Sea	Benthic	Coastal	Art	PostImplem	S299
188	EU	Netherlands	VH	Lake IJsselmeer	MultiSpp	Inland	Ind		
189	EU	Norway	VH	Norway	MultiSpp	Coastal	Art	PostImplem	S300
190	EU	Norway	VH	Lofoten	Pelagic	Coastal	Ind	PostImplem	S299, S301-S302
191	EU	Norway	VH	Sami	Demersal	Coastal	Art	Implem	
192	EU	Norway	VH	Senja	Demersal	Coastal	Art	PostImplem	S303
193	EU	Russia	HI	Peipsi-Pihkva	MultiSpp	Inland	Art	PostImplem	S304
194	EU	Multiple	HI	Bering Strait	Mammal	Coastal	Art	Implem	
195	EU	Multiple	HI	Bering Strait	Mammal	Coastal	Art	PostImplem	
196	EU	UK	VH	Orkney-Shetland	Benthic	Coastal	Art	PostImplem	S305
197	EU	UK	VH	Shetland	MultiSpp	Offshore	Ind	PostImplem	S306
198	EU	Spain	VH	NW Atlantic	Demersal	Offshore	Ind	PostImplem	S307
199	EU	Spain	VH	Galicia	Benthic	Coastal	Art	PostImplem	S308-S310
200	EU	Spain	VH	Mediterranean	MultiSpp	Coastal	Art	PreImplem	
201	EU	Spain	VH	Galicia	Benthic	Coastal	Art	PostImplem	S311-312
202	EU	Spain	VH	Andalucia	MultiSpp	Coastal	Art	Implem	
203	EU	Spain	VH	Celtic Sea	Demersal	Offshore	Ind	PostImplem	S313
204	EU	Spain	VH	Spain	MultiSpp	Coast/Off	Ind	PreImplem	
205	EU	Spain	VH	Asturias	Benthic	Coastal	Art	Implem	S314
206	EU	Spain	VH	Cadiz	Benthic	Coastal	Art	Implem	S299
207	EU	Sweden	VH	Sweden	Demersal	Coast/Off	Seq	PreImplem	
208	EU	Sweden	VH	Gullmar Fjord	Benthic	Coastal	Art	PostImplem	S315

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209	EU	Sweden	VH	Baltic coast	Demersal	Coastal	Art	PreImplem	
210	EU	Turkey	HI	Aegean	MultiSpp	Coastal	Art	Implem	S316-S317
211	EU	UK	VH	IV-VII ICES	MultiSpp	Coast/Off	Ind	PostImplem	S318
212	EU	UK	VH	UK	MultiSpp	Coastal	Art	PreImplem	
213	EU	UK	VH	UK	Mammal	Coastal	Art	PostImplem	S319
214	EU	UK	VH	South Devon	Benthic	Coastal	Art	PostImplem	S320
215	EU	UK	VH	UK	Pelagic	Offshore	Ind	PostImplem	S299
216	EU	UK	VH	Shetland	Benthic	Coastal	Art	Implem	S299
217	EU	Multiple	VH	Spain-France	Pelagic	Offshore	Ind	Implem	S321
218	EU	Italy	VH	Torre Guaceto	MultiSpp	Coastal	Art	PreImplem	

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Supplementary Table S2. Coding scheme describing all grouping variables, co-management attributes and outcomes, and their potential direct and indirect effects. Group: CO= co-management; RS= resource system; RU= resource unit; GS= government system; U= users system; O= co-management outcomes.

Group	Code	Name	Description	Potential Direct/Indirect Effects
CO	**TypeCo**	**Type of Co-management**	Consultative (consultation mechanisms and dialogue); Cooperative (cooperation in decision making); Delegated (delegated responsibility to users)	
CO	**Phase**	**Phase of Co-management**	Pre-Implementation, Implementation, and Post-Implementation	
CO	**Tframe**	**Time frame**	Period of time the co-management regime has been in place	
RS	**HDI**	**Human Development Index[12]**	Compounded index of "human development" (life expectancy, literacy rate, GDP)	
RS	**Gov**	**Governance Index[13]**	Average of four governance indicators: governmental effectiveness; regulatory quality; rule of law; control of corruption.	
RS	**PCI**	**Corruption Perceptions Index[14]**	Measure of the perceived level of public-sector corruption	
RS	**ResType**	**Resource Type**	Single-species (Benthic, Demersal, Pelagic, Mammals), Multi-species	
RS	**System**	**System**	Inland (lakes, rivers, beels), Coastal (open water, bays, estuaries, costal lagoons), Offshore	
RS	**Sector**	**Fishing Sector**	Artisanal, Industrial, Sequential (both)	
RS	**Def**	**Defined boundaries**	Clearly defined geographic boundaries (e.g., lakes, coastal lagoons, fjords).	Facilitates protection against outsiders, restricts fishermen dynamics, improves users communication, decreases monitoring effort and costs, increases ecological knowledge. Well-defined boundaries favor the implementation of self-policing strategies and a voluntary cooperative action to avoid infringement of rules.
RU	**Sed**	**Sedentary / Low mobility resource**	Comprises sessile, sedentary and reduced mobility adult stages species with limited behavioral responses to stimuli.	Facilitates targeting rights and responsibilities and local and spatially-explicit management, easier access in well-defined areas and easier monitoring and enforcement.
GS	**Law**	**Co-management in law (National)**	Co-management is supported by laws and decrees in the National Constitution.	Gives users and their institutions the legal right to participate in the co-management process through management plans, enforcement of rules, etc.

Group	Code	Name	Description	Potential Direct/Indirect Effects
GS	LocSup	**Central government support (Local)**	Local government encourages, supports, and participates in the co-management process.	Facilitates the process of implementation of co-management at the local level.
GS	LongTerm	**Long term management policy**	Refers to sustainability in time and stability of management plans and/or management institutions.	Implementation of a long-term policy in a co-management context generates a great incentive to fishers to adhere to and get involved with enforcing regulations, thus reducing the probability of occurrence of free-riders, illegal fishing, and short-term, profit-maximizing behaviors.
GS	SciAdv	**Scientific advice**	Implies scientific advice and participation of Universities, NGOs or governmental institutions in the implementation of the co-management system.	Scientific knowledge and advice on the ecology and resilience of targeted stocks play important roles in guiding co-management policies and governance development processes. Quality and quantity of information is improved through cooperation and information flow.
GS	MCS	**Monitoring, Control & Surveillance**	Fishery control, monitoring and surveillance by co-management authorities/institutions.	Favors reliable information flow from fishers to policy makers, lowering monitoring, enforcement and transaction costs, and providing continuous fine-grained signals about resource status (adaptive co-management).
GS	GQ	**Global catch quotas**	Resources are managed through assignment of global catch quotas (e.g. TACs).	Reinforces co-management if allocated together with other management tools in a context of management redundancy. Requires legislation and enforcement of legal frameworks, and cooperation of fisher-communities, which need to be adapted to countries and idiosyncrasies.
GS	IQ	**Individual or community quotas**	Resources are managed through individual, transferable or not, or community fishing quotas designed and implemented within the co-management regime.	Creates incentives to self-management, self-enforcement and community empowerment.
GS	TURF	**TURF**	Formal Territorial Users Rights of Fishing.	Generates a sense of exclusive use and ownership among fishers, who perceive they are receiving the equivalent of a "land grant" which has the form of a highly productive aquatic area.
GS	Spat	**Spatially-explicit management**	Separate areas of management and/or spatially-explicit tools (e.g., rotational harvest strategies).	Enhances the probability of co-management success, particularly in spatially-structured stocks with low mobility, where the spatial distribution patterns of abundance are heterogeneous, and the spatial dynamics of the fishing process follows closely spatial variations in abundance at the scale of small sub-areas.
GS	MinSize	**Minimum sizes**	Minimum size regulations, through mesh sizes, traps, hooks, etc.	Reduces fishing mortality of undesired individual sizes and increases survival of spawning stocks. Particularly useful under co-management regimes when implemented with the active participation of fishers, promoting compliance with regulations.

Group	Code	Name	Description	Potential Direct/Indirect Effects
GS	PA	**Protected Areas**	Formal no-take areas, marine reserves and/or protected areas with a considerable degree of fishermen/communities involvement (community-based reserves)	Enhances fisheries management and conservation of biodiversity, particularly in multi-species or on sedentary stocks, or for which broader ecological impacts of fishing are an issue. Successful use of protected areas in a co-management context required in this study a case-by-case understanding of the spatial structure of impacted fisheries, ecosystems and human communities.
GS	Restock	**Seeding or restocking**	Includes low-cost stock enhancement activities such as extensive culture, natural restocking or transplanting	Enhances stock productivity and population replenishment
U	Cohes	**Social cohesion**	Social cohesion including unity, trust, harmony, communication and cooperation given by common interests among users (e.g., effective participation of most community members in meetings). Generally related with community homogeneity	Enhances user's cooperation, conflict resolution, collaboration with external partners, ability to exclude outsiders, and willingness to report rules breaking. Increases awareness and promotes co-management sustainability
U	Lead	**Leadership**	Key influential users with entrepreneurial skills, highly motivated, respected as local leaders, and directly involved in management decisions.	Promotes local self-organization, influences enforcement and rules compliance, alleviates attitudes towards destructive practices and helps conflict resolution. Improves communication, teamwork and systems thinking skills
U	SelfEnf	**Self-enforcement**	User's ability and effectiveness in enforcing management regulations (e.g., clear and effective system of penalties imposed by strong operational rules specified, enforced and controlled by local fishers).	Encourages compliance on regulations resulting from management measures imposed in each co-managed site by the communities themselves, in agreement with the fishery management authorities, in order to sustain catch levels over time.
U	Trad	**Tradition in self-organization**	History and tradition in self-organization and self-governance. Traditional social hierarchies and local institutions (e.g. native, religious, etc.)	May facilitate implementation of co-management when fisher communities have taken the responsibility for managing resources, often building upon old or traditional roots that include strong community rules
U	LocMarket	**Influence in local market**	Users have influence in fish trading, rules and price control mechanisms.	Co-management alters the power relations of different players, promoting shorter marketing chains and mitigating deleterious middlemen effects on economic returns perceived by fishers.
O	Status	**Fishery Status**	Denotes under-exploited, fully-exploited and over-exploited fisheries.	The health of the fishery is improved after the implementation of the co-management regime (before-after analysis) or when compared with control (open access) sites (control-impact analysis).
O	IncAbun	**Increase in Abundance**	Increase in stock abundance as a result of co-management practices.	Abundance increases as a result of the implementation of co-management (before-after analysis) or when compared with open access areas (control-impact analysis).
O	IncCPUE	**Increase in CPUE**	Increase in Catch Per Unit Effort as a result of co-management practices.	CPUE increases as a result of the implementation of co-management (before-after analysis) or when compared with open access areas (control-impact analysis).

Group	Code	Name	Description	Potential Direct/Indirect Effects
O	IncPrices	**Increase in Unit Prices**	Increase in unit prices as a result of co-management practices, including improvement in final product quality, marketing strategies and excluding market externalities.	Higher unit prices are used here as indicator of success only in cases when reflect shorter marketing chains that pass along a larger fraction of value to fishers, as a result of increasing product quality (e.g., individual size and condition), etc. Higher prices could also reflect increased scarcity due to resource overfishing or higher exposure to world markets. Thus, a clear distinction was made in this study to include higher prices as attribute of success by carefully reading each individual case.
O	Sust	**Sustainable catches**	Sustainable catches regarding stock productivity in the long-term.	Evidence of sustainable catches in the long-term as a result of the implementation of co-management.
O	Empow	**Community Empowerment**	Increase in spiritual, political, social, and/or economic strength of communities.	Co-management enhances community unity, improves community cohesion, fishermen communication, information sharing, and influenced economic trade.
O	IncWelf	**Increase in Social Welfare**	Increase in community welfare, including incomes and social equity.	Co-management has positive effects in the economic welfare of fishers when compared with previous unregulated schemes (before-after analysis) or with areas without co-management (control-impact) that threaten livelihoods, reduce economic welfare and the nutritional status of fishers.
O	Conserv	**Add-on Conservation Benefits**	Direct and indirect species and habitat conservation benefits through co-management practices.	Co-managed systems afford benefits for biodiversity conservation. Perceptions and environmental awareness of fishers engaged with the co-managed policy is changed, with evidence of fishers themselves becoming environmental stewards.

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Supplementary Table S3. Correlation matrices for (a) co-management attributes and (b) outcomes or performance indicators across the 130 case studies. Bold values indicate correlation coefficients r > 0.50. Colors denote magnitude of the correlation coefficients according to traffic-light shades from red (negative) to green (positive). Values of variance inflation factor (VIF) > 5 are considered evidence of collinearity. Variable codes are explained in Table S1.

a

	Def	Sed	Law	LocSup	LongTerm	SciAdv	MCS	GQ	IQ	TURF	Spat	MinS	PA	Restock	Cohes	Lead	SelfEnf	Trad	LocMarket
Sed	0.0																		
Law	-0.1	0.2																	
LocSup	0.1	0.1	0.1																
LongTerm	0.1	0.1	0.2	0.2															
SciAdv	-0.1	0.1	0.1	-0.1	0.1														
MCS	0.0	0.3	0.1	0.1	0.2	0.3													
GQ	-0.2	0.2	0.0	0.2	0.1	0.2	0.3												
IQ	-0.1	0.2	0.1	0.2	0.2	0.2	0.4	0.5											
TURF	0.2	0.3	0.3	0.1	0.2	0.1	0.2	0.0	0.3										
Spat	0.2	0.3	0.2	0.1	0.2	0.1	0.2	0.0	0.3	0.4									
MinS	0.0	0.2	0.2	0.3	0.1	0.1	0.2	0.2	0.1	-0.1	0.0								
PA	0.1	0.2	0.1	0.1	0.1	0.2	0.3	0.0	0.1	0.2	0.3	0.0							
Restock	0.2	0.2	0.2	0.1	0.1	0.1	0.0	-0.1	0.1	0.2	0.2	0.1	0.1						
Cohes	0.0	0.0	0.0	0.0	0.5	0.2	0.2	-0.1	0.2	0.1	0.2	0.1	0.2	0.1					
Lead	0.1	0.2	0.1	0.3	0.5	0.1	0.4	0.1	0.4	0.2	0.1	0.2	0.3	0.1	**0.6**				
SelfEnf	0.1	0.0	0.1	0.4	0.5	0.0	0.3	0.1	0.4	0.2	0.2	0.2	0.1	0.2	**0.6**	0.5			
Trad	0.0	0.0	0.0	0.1	0.0	-0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.0	-0.2	0.1	0.1	0.1		
LocMarket	-0.1	0.3	0.2	0.2	0.2	0.1	0.3	0.2	0.4	0.2	0.2	0.2	0.1	0.1	0.2	0.4	0.3	0.1	
VIF	1.5	1.8	1.5	1.1	2.6	1.6	1.5	1.8	2.0	1.9	2.2	1.2	1.5	1.3	2.8	2.6	2.1	1.4	1.5

b

	Status	Inc Abund	Inc CPUE	Inc Price	Sust	Empow	Inc Welf
IncAbund	0.4						
IncCPUE	0.5	0.5					
IncPrices	0.2	0.0	0.2				
Sust	**0.7**	0.4	0.5	0.2			
Empow	0.3	0.2	0.3	0.1	0.4		
IncWelf	**0.6**	0.2	0.4	0.2	0.5	0.4	
Conserv	0.1	0.3	0.2	0.1	0.2	0.3	0.3

Supplementary Table S4. Summary of ANCOVA results and multiple comparisons (Fisher LSD test: P< 0.05) performed to test whether the co-management success score differed among socio-economic conditions and ecological settings. * P< 0.05, ** P <0.01.

Main factor	F_{ratio}		*Multiple comparisons*
Covariate: number of management attributes (see Figure 2a)			
HDI	4.82	*	Low = Med < High = Very High
Fishing sector	7.16	**	Artisanal < Industrial
Ecosystem	5.39	**	Coastal < Inland < Offshore
Resource type	2.26	*	Multispecies < Pelagic < Demersal = Benthic
Covariate: relative management attributes (Treatments: GS & U: see Figure 2c)			
Attribute system	8.87	**	Governance attributes > Users attributes

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Supplementary Table S5. Results of regression tree for co-management success (see Fig. 3a). Nodes in green correspond to the optimal (pruned) tree and their horizontal positions determine node levels.

Node/leaf	Splitting variable	Splitting criteria	Study cases (*n*)	Deviance	Mean Square Error	Mean Success
1	**Root**		**130**	**734**	**5.65**	**4.40**
2	Leadership	No	40	77	1.93	1.92
4	Social cohesion	No	31	44	1.41	1.52
8	Spatial management	No	19	17	0.89	1.00
9	Spatial management	Yes	12	14	1.19	2.36
5	Social cohesion	Yes	9	12	1.28	3.22
3	Leadership	Yes	90	280	3.16	5.54
6	Sedentary resource	No	52	170	3.23	4.86
10	Individual quotas	No	33	130	3.91	4.31
14	Protected areas	No	21	77	1.71	3.56
15	Protected areas	Yes	12	21	1.11	5.59
11	Individual quotas	Yes	19	11	0.55	5.94
7	Sedentary resource	Yes	38	63	1.66	6.42
12	TURF	No	21	36	3.67	6.00
13	TURF	Yes	17	19	1.74	6.94
Residual deviance						
Total tree		**206**				
Optimal tree		**227**				
% Deviance explained						
Total tree		**72**				
Optimal tree		**69**				

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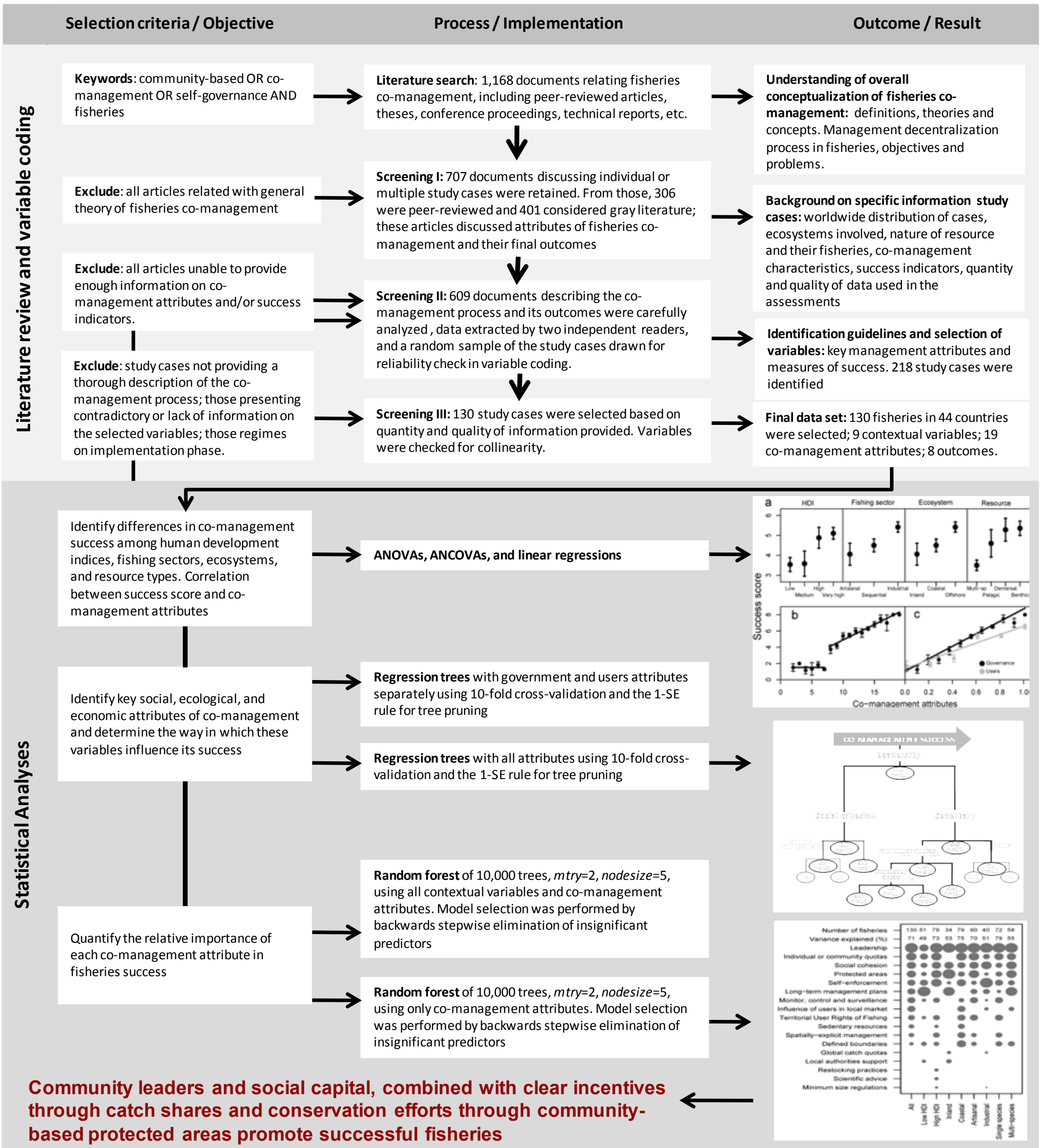
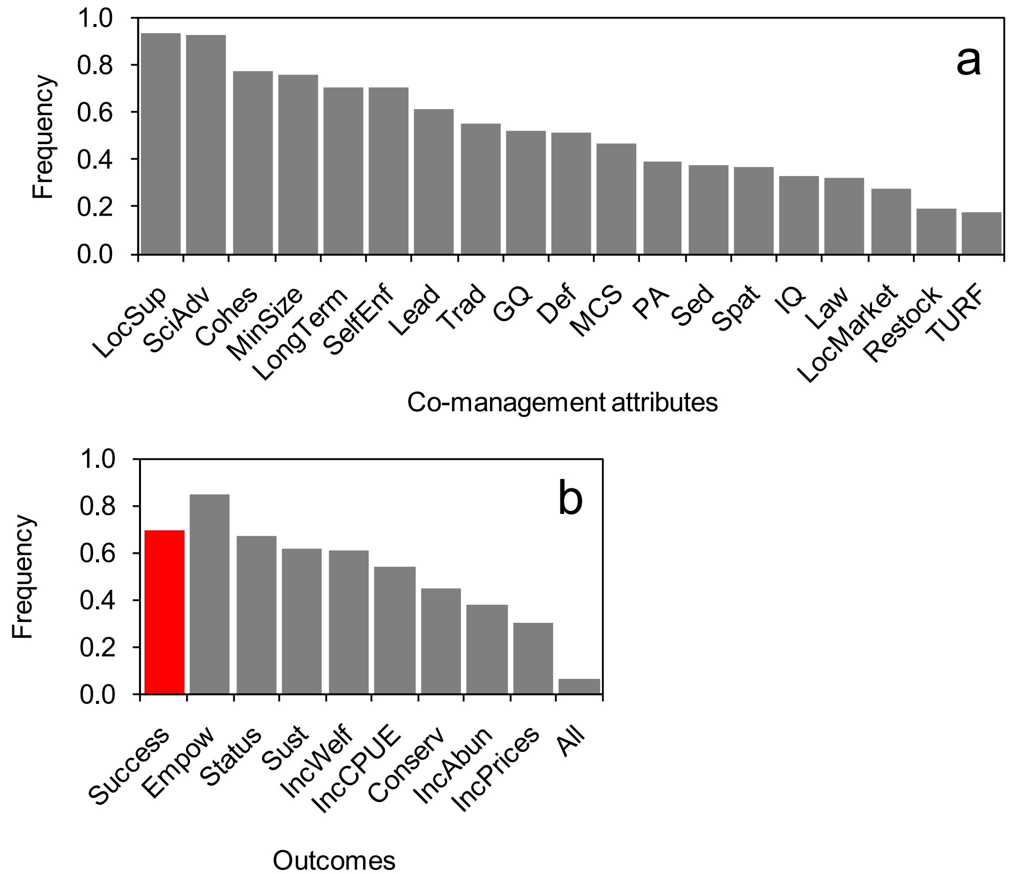
Supplementary Table S6. Comparisons of Kendall's concordance indices (*W*) for those categories used in the sub-groups random forest models (in green) and for additional categories not included in the analysis due to smaller differences in their indices (in red; $W \geq 0.9$); *W* ranges from 0 (no agreement) to 1 (complete agreement).

Groups	Fishing Sector	HDIa	Ecosystem	Fishing target	All	Resource type	HDIb	Continent	All
Categories	Artisanal Industrial	Low High	Coastal Inland	Single Multiple		Benthic Demersal Pelagic Multiple	Low Medium High Very High	Asia Africa Europe Oceania North America South America	
Variables			19				19		
Groups	2	2	2	3	8	4	4	5	13
Kendall *W*	**0.82**	**0.75**	**0.79**	**0.85**	**0.75**	**0.90**	**0.91**	**0.95**	**0.89**
χ^2_{18}	29.6	28.1	28.5	30.6	107.0	64.2	65.1	86.1	210.0
P	0.041	0.051	0.049	0.031	<0.001	<0.001	<0.001	<0.001	<0.001



Supplementary Figure S1. Flowchart depicting the literature review process, and the statistical analysis, their objectives, process/implementation, and outcomes.



Supplementary Figure S2. Frequency of: (a) co-management attributes; and (b) performance indicators present in the study cases analyzed (*n* = 130). A frequency of 1.0 indicates that 100% of the final set of co-management studies reported information on a respective metric. Red bar indicates proportion of fisheries achieving all social, economic and ecological co-management objectives (i.e., success score = 8) according to study authors' judgment. Variable codes are explained in Table S2.

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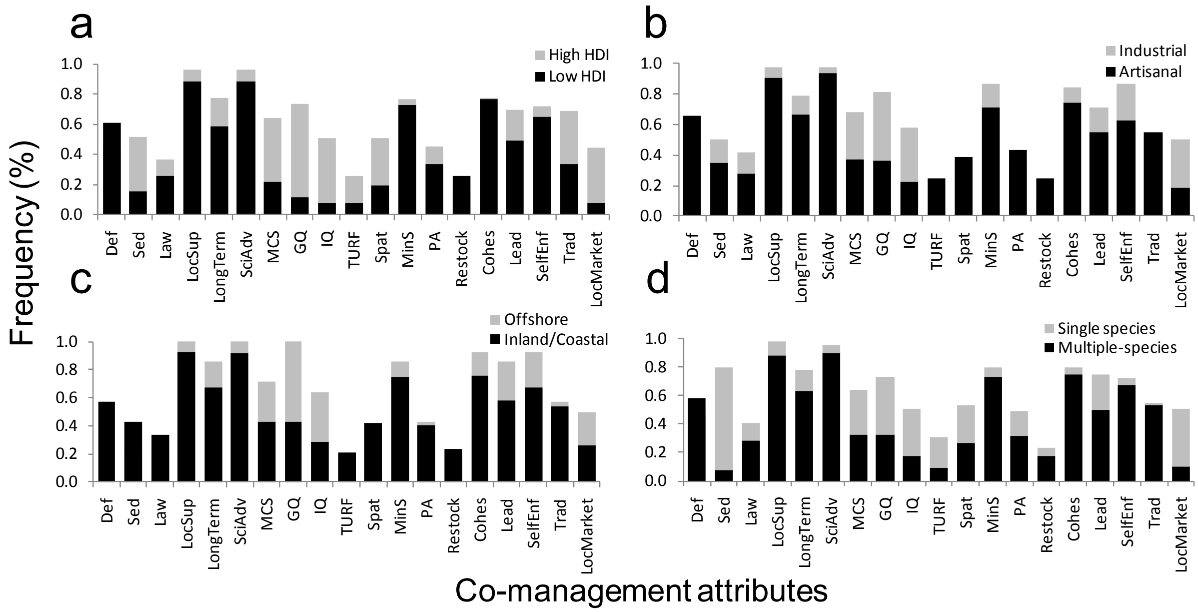
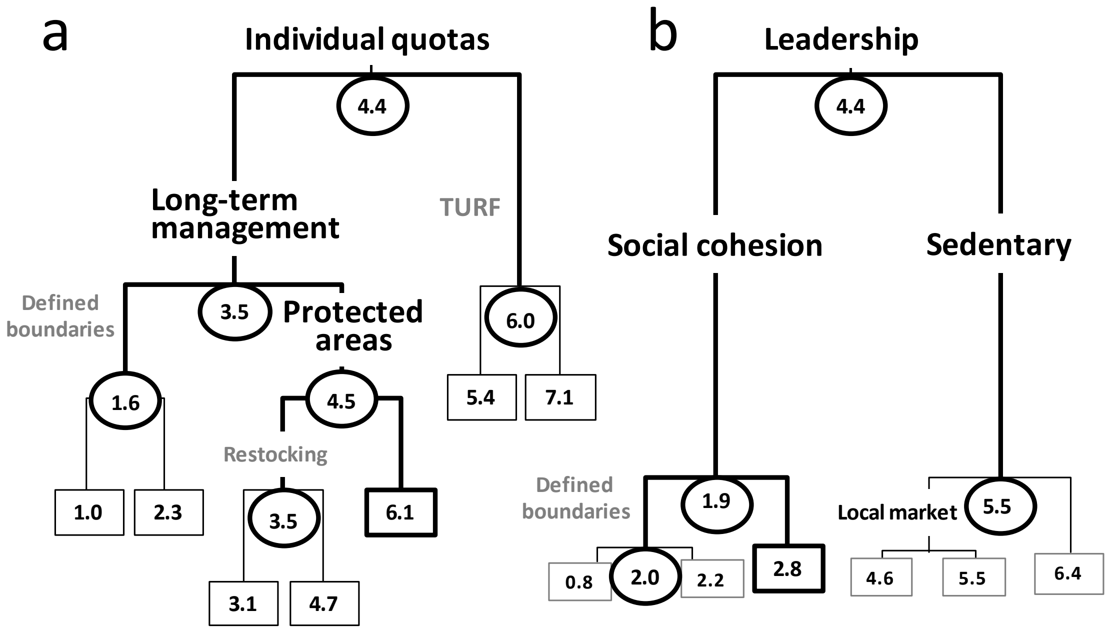
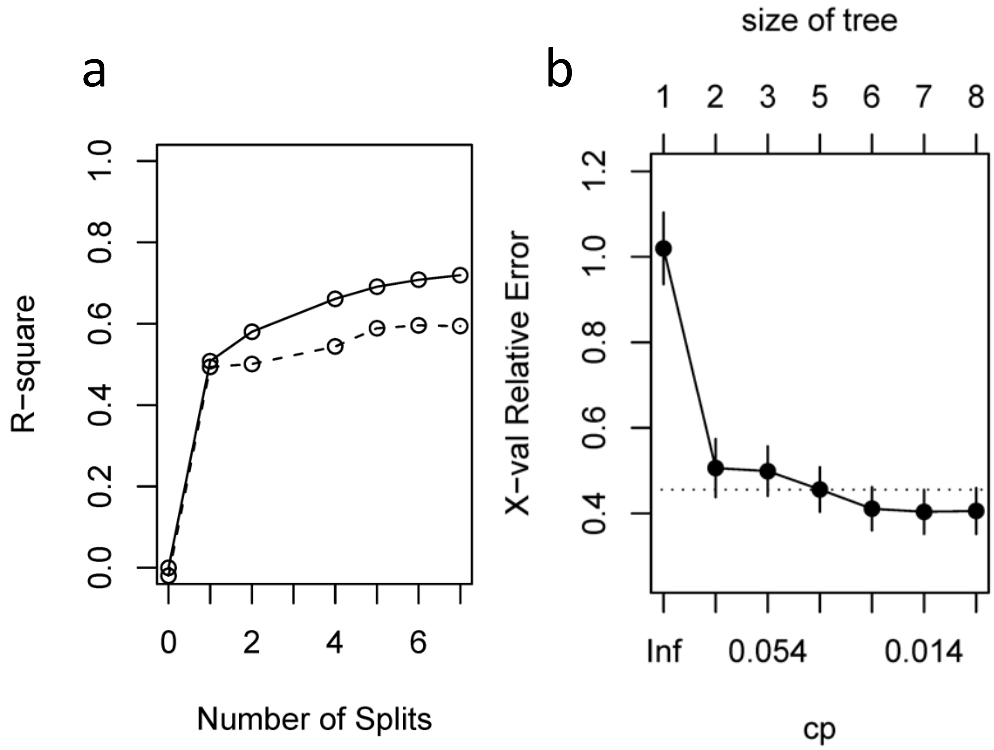


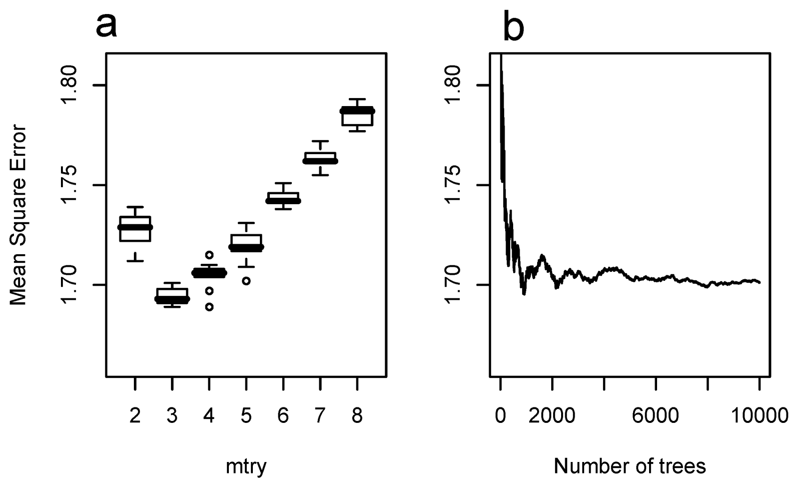
Supplementary Figure S3. Frequencies of co-management attributes occurrence for different categories of fisheries based on statistical differences in co-management success (AN OVAs; see Table S4). Frequencies are overlapped to highlight increases in frequency from less successful to more successful categories. (a) High Human Development Index > low Human Development Index; (b) industrial > artisanal; (c) offshore > inland/coastal; (d) benthic/demersal>pelagic > multi-species. Variable codes are explained in Table S2.



Supplementary Figure S4. Regression tree analyses of co-management success for (a) binary government system (GS) attributes, with 4 leaves and 68% of the variance explained; and (b) binary user system attributes (U) with 3 leaves and 64% of the variance explained. Optimal trees were selected using the modal tree size from 50 cross-validations and the 1-SE rule. Branches from the smaller, optimal tree are shown in bold. Averaged (predicted) co-management success is indicated at each node. Squares denote terminal nodes/leaves. Vertical depth of each split is proportional to the variation explained by each attribute or explanatory variable (note leadership explained >60% of the total deviance). Splitting criteria was absence or presence of attributes and fisheries with higher success score are at the right of each branch point.



Supplementary Figure S5. Pruning regression tree of co-management success for the 19 fisheries co-management attributes. (a) Plot of the (1-apparent error; solid line) and (1-relative error; dotted line) showing that the first split offers the most information (biggest improvement in R^2); (b) Plot of average relative errors for 50 10-fold cross validations versus regression tree size. A tree of 6 leaves (5 nodes) with a complexity parameter (cp) of 0.018 is selected under the 1-SE rule (dotted line).



Supplementary Figure S6. Parameter tuning for random forest using the whole co-management data set (*n* = 130) and all the 19 co-management attributes. Boxplot of 50 10-fold cross-validation mean square errors (MSE) at (a) various numbers of a subset of randomly selected explanatory variables (*mtry*). The plot suggests that *mtry* is optimal near 3 and that performance is similar for values ranging from 2 to 4; and (b) plot of the effect of number of trees (*ntree*) on the reduction of MSE; and (c) various minimum node sizes. Horizontal lines inside the boxes are the median MSE.

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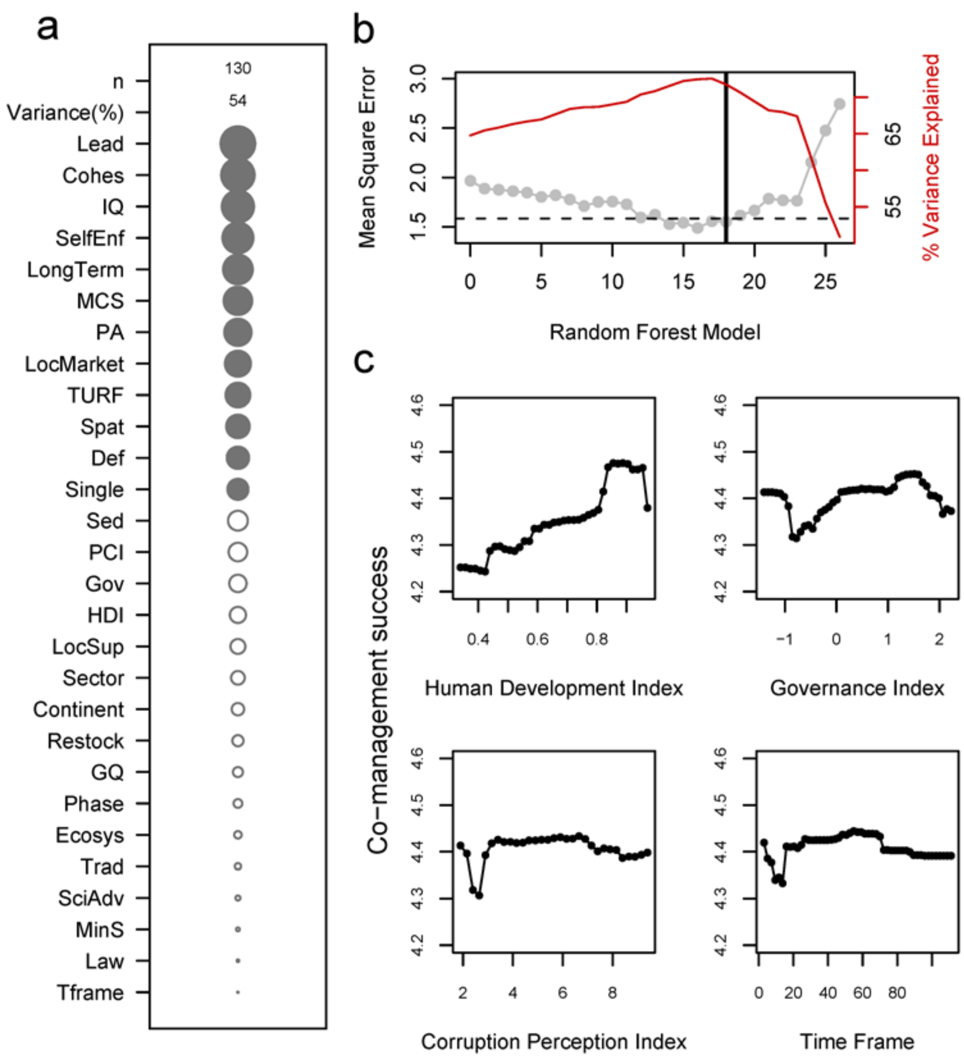

Figure S7. Random forest for the whole dataset including all grouping variables (*n*=9) and co-management attributes (*n*=19). (a) Relative variable importance was measured in terms of decrease in predictive accuracy and is proportional to the size of the bubble. Filled bubbles represent those variables selected with the backwards elimination procedure. Number of study cases and variance explained by the random forest model is also indicated. Variables' descriptions are given in Table S2. (b) Nested random models used in variable selection for the whole data set. Model 0 refers to the full model (26 variables). The horizontal dotted line denotes 1 standard deviation of the minimum mean square error (MSE) model used to select the best model. Vertical line shows the chosen model; (c) Partial dependence plots (i.e., marginal functional relationship between predictor and response variable, after averaging out the effects of all other predictors' effects on the response variable) for all continuous grouping variables.