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Leadership, social capital and incentives promote successful fisheries

Nicolás L. Gutiérrez[1], Ray Hilborn[1] & Omar Defeo[2]

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.

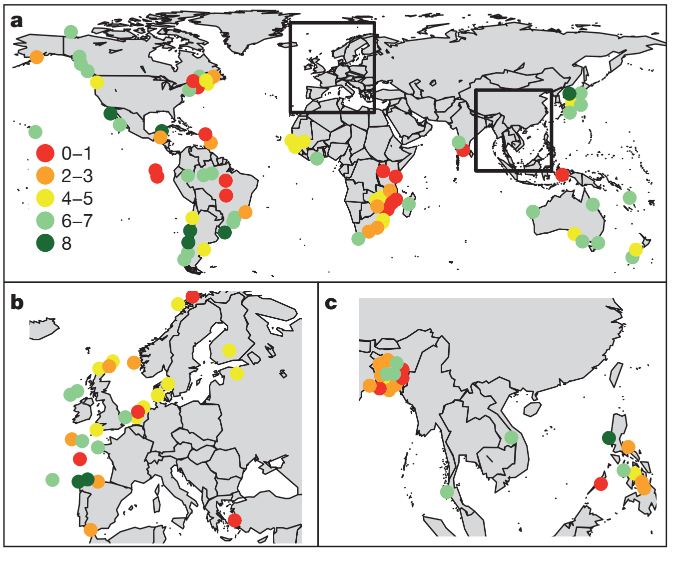

Figure 1 | Location and success score for all study cases of fisheries co-management. a–c, Success was grouped in five categories according to number of social, ecological and economic outcomes achieved. **a**, Global map. Insets are Europe (**b**) and Southeast Asia (**c**). $n = 130$.

[1]School of Aquatic and Fishery Sciences, Box 355020, University of Washington, Seattle, Washington 98195-5020, USA. [2]UNDECIMAR, Facultad de Ciencias, Iguá 4225, PO Box 10773, Montevideo 11400, Uruguay.

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.

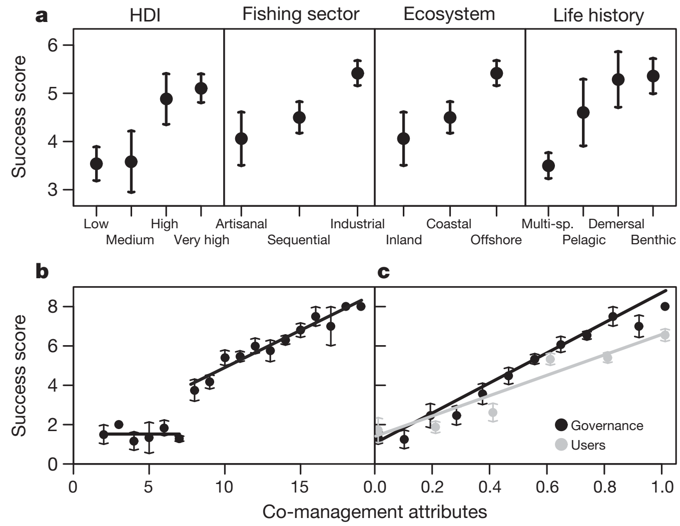

Figure 2 | Fisheries co-management performance. **a**, Success score discriminated by the HDI, fishing sector, ecosystem and life history. Multi-sp., multi-species. **b**, Success score correlated with the number of all co-management attributes present in the fishery. **c**, Success score correlated 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

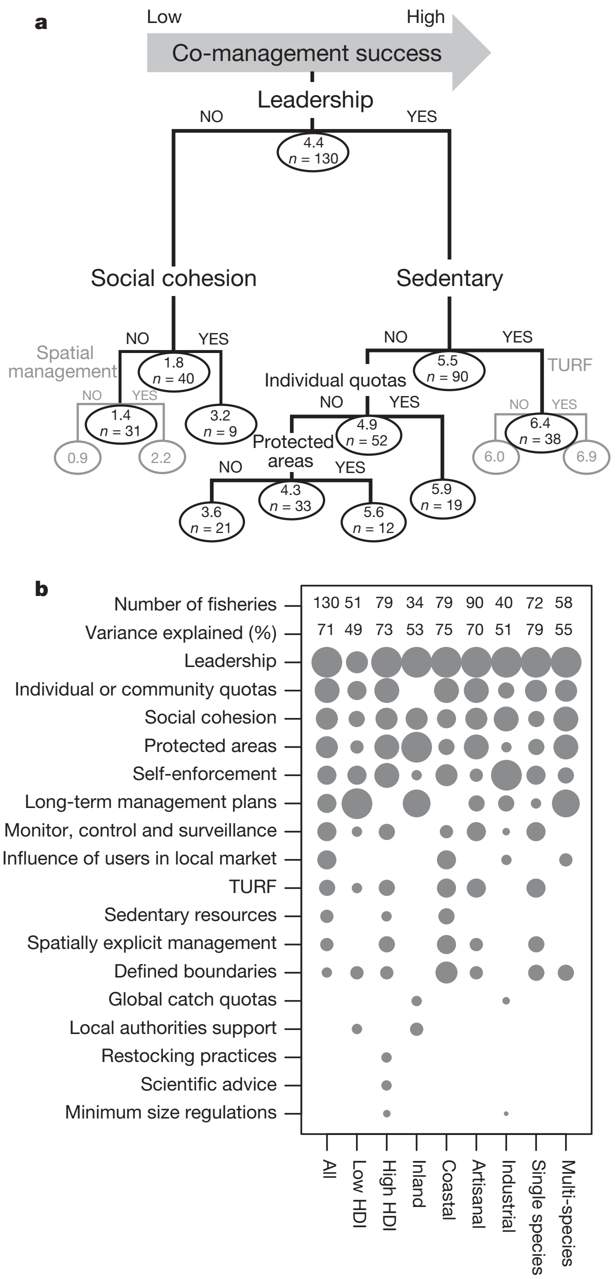

Figure 3 | Key co-management attributes for fisheries success. **a**, Regression tree showing the most important factors determining success. Higher branches offer greater explanatory power. Average success score and number of fisheries are listed at each node. The optimal tree explained 69% of the total 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 multidisciplinary 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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