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Comanagement of coral reef social-ecological systems

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In an effort to deliver better outcomes for people and the ecosystems they depend on, many governments and civil society groups are engaging natural resource users in collaborative management arrangements (frequently called comanagement). However, there are few empirical studies demonstrating the social and institutional conditions conducive to successful comanagement outcomes, especially in small-scale fisheries. Here, we evaluate 42 comanagement arrangements across five countries and show that: (*i*) comanagement is largely successful at meeting social and ecological goals; (*ii*) comanagement tends to benefit wealthier resource users; (*iii*) resource overexploitation is most strongly influenced by market access and users' dependence on resources; and (*iv*) institutional characteristics strongly influence livelihood and compliance outcomes, yet have little effect on ecological conditions.

common property | governance | human–environment interaction | institutional design principles | common-pool resources

The perceived failure of many open-access and top-down government approaches to managing common-pool resources has inspired a shift in governance toward community-based comanagement arrangements that provide local people with a greater say in the allocation and use of their resources (1). Comanagement is thought to help make resource management initiatives more legitimate in the eyes of stakeholders and more reflective of local conditions, creating better incentives for people to comply with rules on their own accord (2, 3). In the context of small-scale fisheries, which support the livelihoods of some 200 million people, comanagement arrangements can be successful at sustaining resources and improving livelihoods of resource users (Fig. 1) (1, 4, 5). However, comanagement can also create new incentives for overexploitation, exacerbate existing social inequalities, and lead to other undesirable social and ecological outcomes (3, 6–9). Critical questions remain about what communities, donors, and policymakers can do to promote desirable comanagement outcomes.

Contextual conditions such as poverty, dependence on resources, and access to markets influence whether people successfully manage or overexploit common-pool resources (10–12). In addition, specific institutional characteristics, known as design principles, are thought to increase the likelihood of sustained collective action by creating conditions that encourage users to cooperate with common property institutions (10). These principles include graduated sanctions (punishments that increase with the frequency and severity of infringements), clearly defined boundaries, collective choice rules (where users can participate in decision-making processes to change rules), and conflict resolution mechanisms, among others (10, 13, 14). To date, previous empirical studies have not tended to evaluate the potential role of specific institutional designs in achieving successful comanagement outcomes (15).

Here, we examine how social and ecological outcomes are related to key institutional design and socioeconomic covariates in 42 coral reef fishery comanagement arrangements across Kenya, Tanzania, Madagascar, Indonesia, and Papua New Guinea (Fig. 2 and *SI Appendix*, Table S1). We used Ostrom's diagnostic framework for analyzing social-ecological systems (4, 11, 16) to guide our study design (*SI Appendix*, Fig. S1 and Table S1). Using a combination of underwater visual census of reef fishes and semistructured interviews with >1,000 resource users and local leaders (*SI Appendix*), we quantified the relative importance of household and community-scale factors influencing three independent comanagement outcomes. These outcomes were as follows: (*i*) perceived impacts of comanagement on livelihoods of resource users; (*ii*) reported compliance with restrictions; and (*iii*) the exploitation status of fishery resources (*SI Appendix*).

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Results and Discussion

Comanaged fisheries generally perform well on all three measures of success. In particular, 54% of resource users perceived beneficial outcomes for their livelihoods; 88% reported that comanagement arrangements were mostly or fully complied with; and comanaged fisheries generally maintained a greater standing fish biomass than fished areas lacking local management (but, as expected, both were considerably more exploited than most no-take fisheries closures in the same countries; Fig. 3 and *SI Appendix*). Our results are, however, not uniformly positive: There are cases where comanagement has not achieved positive social or ecological outcomes. Determining how these poorly performing comanagement systems can be improved requires a better understanding of how specific social and ecological outcomes are associated with particular institutional and contextual conditions (11) (*SI Appendix*, Fig. S1).

We used a series of Bayesian-hierarchical models to quantify relationships between the probability of successful comanagement outcomes and the 22 household and community-scale covariates (Fig. 4). For our metric of perceived livelihood impacts, we used separate estimates to identify differences between the self-identified losers and winners resulting from comanagement (Fig. 4 *A* and *B*). The most successful comanagement arrangements for the livelihoods of users occur when key institutional designs are in place; when knowledge about the role humans play in ecosystem decline is high; where people have long been involved in comanagement; and when they are wealthier (Fig. 4 *A* and *B* and *SI*

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Fig. 1. (*A*) Coral reefs support small-scale fisheries in many low-income, tropical nations. As with many other types of common-pool resources, reef fisheries are often overexploited when effective institutions are not in place (10). (*B*) The complex and multispecies nature of small-scale reef fisheries, illustrated by this harvest from Indonesia, makes them particularly difficult to effectively manage solely through top-down regulations, especially in the resource-deficient context in which many tropical national fisheries agencies operate (1). (*C*) Comanagement arrangements that allow resource users to develop and enforce locally appropriate rules about resource use, such as this periodically harvested fisheries closure from Papua New Guinea, can provide substantial benefits to resource users, achieve high levels of compliance, and potentially lead toward more sustainable fisheries (24, 41). Photos by J.E.C.

Appendix). This latter result suggests that despite the strong potential for positive social and ecological outcomes, comanagement can contribute to social inequity by creating opportunities for local elites to control resources (6, 7, 17). By providing users with a greater say in the allocation of resources, comanagement is likely to involve a redistribution of access rights (18), and the wealthy may be better poised to take advantage of these changes (17, 19). There is no evidence, however, that comanagement is detrimental to the livelihoods of the poor (Fig. 4*B*), who are often marginalized in other types of governance regimes in regards to resource allocation and entitlements (19, 20). To ensure that comanagement arrangements attain the levels of perceived equity and legitimacy necessary for long-term success (3, 21), managers must find ways to deliver beneficial livelihood outcomes to the poor. Delivering these outcomes will require an equitable distribution of power (6,

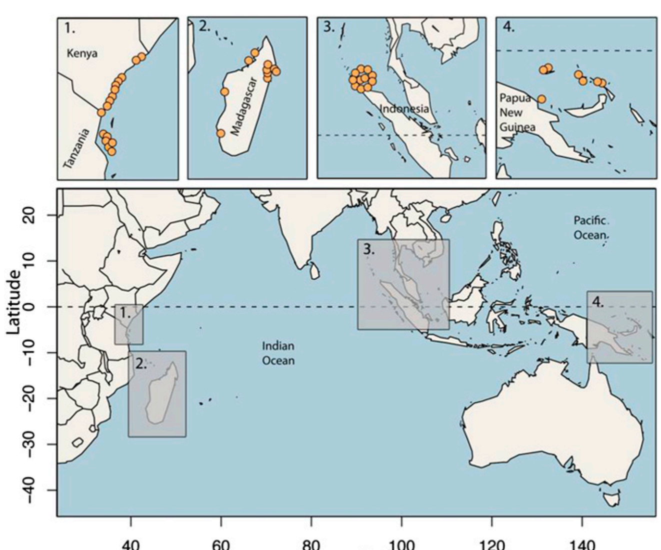

Fig. 2. Map of study comanagement sites across the Indo-Pacific in Kenya and Tanzania (1), Madagascar (2), Indonesia (3), and Papua New Guinea (4). Orange dots indicate approximate locations of fishery comanagement sites.

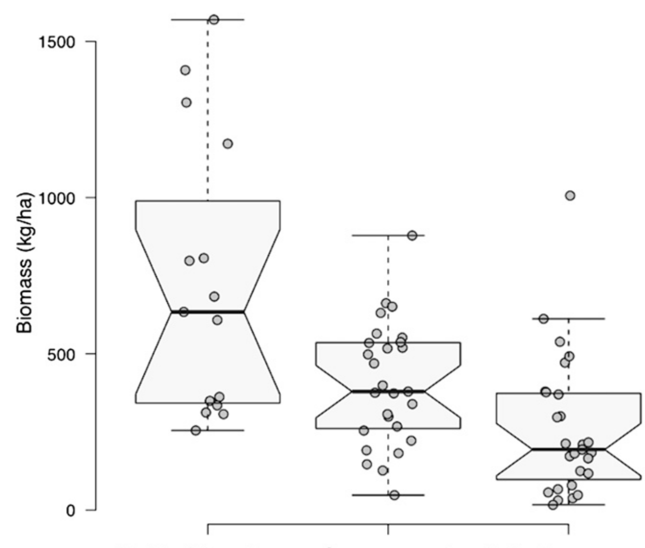

Fig. 3. Comparison of standing biomass in no-take fisheries closures, comanaged fisheries, and sites with no local management. Levels of fish biomass are demonstrably higher in comanaged areas {350 [265, 450] kg/ha; highest posterior density (HPD) [95% uncertainty intervals (UI)], $n = 27$} than in comparable open-access reef fisheries (177 [116, 261] kg/ha, $n = 26$), but no-take fishery closures have the highest expected biomass (619 [417, 818] kg/ha, $n = 16$). HPD and 95% UI are based on a (normal) Bayesian linear random-effects model for log(biomass) given management status. Biomass data for no-take fishery closures and sites with no-local management are from parallel studies on the ecological outcomes of different coral reef management strategies in our study countries (refs. 24 and 40 and *SI Appendix*).

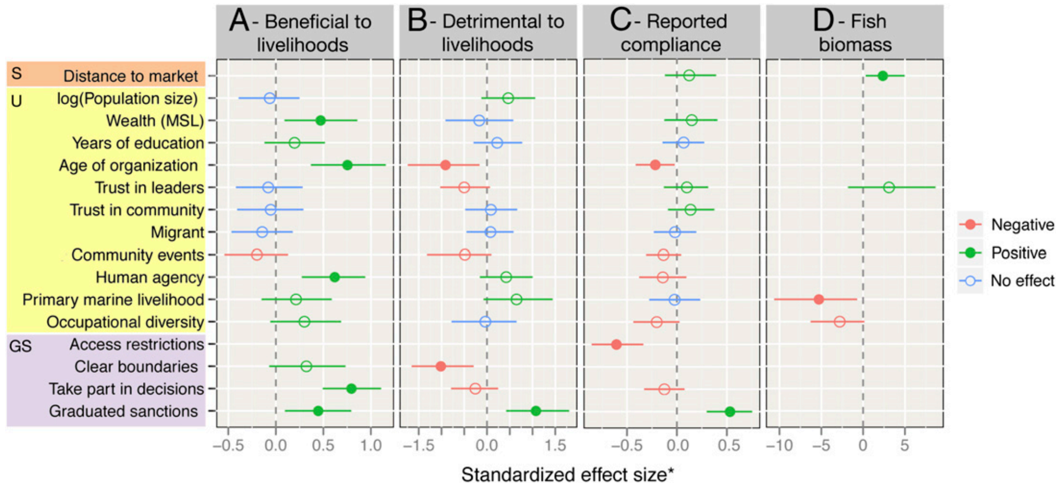

Fig. 4. Influence of social-ecological system attributes of reef-fishery comanagement outcomes across the 42 study sites in the Indo-Pacific. Parameter estimates are Bayesian posterior median values and 95% UI for the 16 model-selected covariates (*y* axis) relating to the local social-economic and political setting (S; orange); characteristics of resource users (U; yellow); and the governance system (GS; purple). The multinomial model provided separate estimates for respondents that perceived positive and detrimental livelihood outcomes from comanagement. Responses include the following: perceived beneficial livelihoods outcomes (*A*); perceived detrimental livelihood outcomes (*B*); reported compliance (*C*); and magnitude of observed fish biomass (kilograms per hectare) (*D*). Positive response estimates are indicated in green; negative are indicated in red; and evidence of no effect is indicated in blue. Filled circles indicate strong evidence of covariate effects; open circles denote estimates with an increased level of uncertainty as to their direction; green and red open circles have >80% of their posterior density in either a positive or negative direction, respectively. These results are discussed in more detail in *SI Appendix*. Response estimates are standardized to be directly comparable within each column and include both household and community-level covariates, modeled at the appropriate scale. Missing variables occurred in models with no DIC-based support (*SI Appendix*). Asterisk indicates that, effect sizes are standardized within each response relative to their mean divided by two times their SD.

22) and, in some cases, may involve poverty reduction strategies, such as the provision of microcredit loans (23).

Compliance is a continual challenge for many fisheries management and marine conservation initiatives (21, 24). Institutional design principles are thought to create conditions conducive to cooperation in common property scenarios (10), and we found that high levels of reported compliance are positively related to graduated sanctions (Fig. 4*C* and *SI Appendix*). There is also moderate evidence that reported compliance is higher when comanagement arrangements are further from markets, where respondents are wealthier, and where they trust their leaders and other community members (Fig. 4*C*). There are frequent calls to establish territorial use rights that provide local resource users with exclusive rights to their fishing grounds (4), but we found that in a developing country comanagement context, compliance was lowest under this type of restricted access arrangement (Fig. 4*C*). Interviews with resource users revealed plausible explanations for this seemingly counterintuitive result: (*i*) Several key informants and respondents noted that membership (i.e., who had access rights) became difficult to clearly define because of marriage arrangements between members and nonmembers. In the context of many of our study sites, access rights were determined by affiliation with specific social groupings (e.g., community or clan), as opposed to a formal licensing arrangement. Interestingly, we did not find that "clearly defined membership" (one of the institutional design principles) had a consistent effect on compliance throughout the 42 sites, but respondents suggest that confusion about membership may play an important role in some local contexts; and (*ii*) Communities often lacked patrol boats or systems of offshore surveillance to effectively enforce these types of access rights. A number of users noted that by the time they paddled or sailed out to enforce the access rights, infringers with motorized boats had left. In addition to adequate enforcement capacity, comanagement compliance is also about creating conditions that are conducive to people cooperating (10, 21). Managers and donors can help build the legitimacy, social capital, and trust that foster cooperation by making targeted investments that lead toward transparent and deliberative comanagement systems (1, 3, 21, 22, 25).

The state of reef fishery resources is often assumed to be primarily driven by Malthusian overfishing related to the size of nearby human settlements (e.g., refs. 26 and 27). However, a key finding from this study is that the exploitation status of comanaged fisheries is most strongly affected by access to markets and levels of dependence on marine resources (Fig. 4*D*), providing potential levers for policy action. Strategies that address the complex linkages between ecosystems, local livelihoods, and market access will be critical for sustainable fisheries comanagement (14, 28, 29). These strategies may include, for example, livelihoods-focused approaches to poverty reduction (28) and improved market governance through sustainable harvesting certifications (29, 30).

This study models the influence of a range of institutional design principles on common property outcomes using primary data across large geographic and social scales. A surprising finding is that these institutional characteristics thought to influence the sustainability of commons governance are strongly related to social, but not ecological, outcomes in the comanagement of small-scale fisheries (Fig. 4). Critically, these design principles may help people organize effectively and perceive benefits from collective action (10), but they do not ensure that a given organization will sustainably manage resources. Indeed, people may collectively organize to exploit resources rather than to sustain them (9). Consequently, organizing collective action for sustainability rather than short-term exploitation may require an adaptive comanagement approach (31–33) that: (*i*) fosters learning about the social-ecological system (34), (*ii*) incorporates local and scientific knowledge systems (35), (*iii*) creates incentives for ecosystem stewardship (36), and (*iv*) invests in multiscale governance arrangements that network comanagement organizations and foster key linkages with higher levels of social and political organization (10, 37).

Our study provides empirical evidence that comanagement can help to sustain fisheries and the people that depend on them, even in the social-ecological contexts most susceptible to failure: artisanal, multispecies, coastal fisheries in low-income countries (1). However, the likelihood of this happening is higher when certain social, economic, and institutional conditions are in place. Managers and donors can facilitate desirable comanagement outcomes by working with resource users on context-dependent strategies to improve livelihoods and governance, such as dampening the negative influence of global markets, providing equitable livelihood benefits, and strengthening local institutions (10, 29, 38). These policy actions will be a substantial departure from the norms of many fisheries managers, and implementing them effectively will require forging partnerships with social scientists, donors, financial institutions, and civil society (39).

Methods

Details are provided in *SI Appendix*.

We studied 42 independent comanagement arrangements spanning five Indo-Pacific countries: Kenya, Tanzania, Papua New Guinea, Indonesia, and Madagascar. We used purposive sampling to ensure variation in independent variables. To gather information and triangulate results in each study site, we used a combination of household surveys, semistructured interviews with key informants (community leaders, resource users, and other stakeholders), underwater visual census, and analyses of secondary sources such as population censuses (*SI Appendix*, Table S1). In total, we conducted 960 resource user interviews, 53 key informant interviews, 54 community leader interviews, and 51 organizational leader interviews. Our data collection provided information on three dependent variables (perceived impact of comanagement on the livelihoods of users; perceived levels of compliance, and reef fish biomass); and 22 covariate attributes relating to the local governance system, the social, economic, and political setting, and the socioeconomic characteristics of resource users in each community (*SI Appendix*, Fig. S1 and Table S1). Additionally, fish biomass data from comanaged sites were compared with 26 sites without local-level management and 16 no-take fishery closures in our study countries (*SI Appendix*). We used Ostrom's diagnostic framework (11, 40) to build a series of Bayesian hierarchical models that quantify the relationship between our 22 measured covariates and three dimensions of comanagement success (*SI Appendix*, Table S3).

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1. Gutiérrez NL, Hilborn R, Defeo O (2011) Leadership, social capital and incentives promote successful fisheries. *Nature* 470:386–389.
2. Jentoft S, McCay BJ, Wilson DC (1998) Social theory and fisheries co-management. *Mar Policy* 22:423–436.
3. Jentoft S (2000) Legitimacy and disappointment in fisheries management. *Mar Policy* 24:141–148.
4. Gelcich S, et al. (2010) Navigating transformations in governance of Chilean marine coastal resources. *Proc Natl Acad Sci USA* 107:16794–16799.
5. Evans L, Cherrett N, Pemsl D (2011) Assessing the impact of fisheries co-management interventions in developing countries: A meta-analysis. *J Environ Manage* 92: 1938–1949.
6. Béné C, et al. (2009) Power struggle, dispute and alliance over local resources: Analyzing 'democratic' decentralization of natural resources through the lenses of africa inland fisheries. *World Dev* 37:1935–1950.
7. Blaikie P (2006) Is small really beautiful? Community-based natural resource management in Malawi and Botswana. *World Dev* 34:1942–1957.
8. Gelcich S, Edwards-Jones G, Kaiser MJ, Castilla JC (2006) Co-management policy can reduce resilience in traditionally managed marine ecosystems. *Ecosystems (N Y)* 9: 951–966.
9. Hutric M (2005) Lobster and conch fisheries of Belize: A history of sequential exploitation. *Ecol. Soc.* 10:21.
10. Ostrom E (1990) *Governing the Commons: The Evolution of Institutions for Collective Action* (Cambridge Univ Press, Cambridge, UK).
11. Ostrom E (2009) A general framework for analyzing sustainability of social-ecological systems. *Science* 325:419–422.
12. Adams WM, Brockington D, Dyson J, Vira B (2003) Managing tragedies: Understanding conflict over common pool resources. *Science* 302:1915–1916.
13. Agrawal A (2001) Common property institutions and sustainable governance of resources. *World Dev* 29:1649–1672.
14. Dietz T, Ostrom E, Stern PC (2003) The struggle to govern the commons. *Science* 302: 1907–1912.
15. Cox M, Arnold G, Tomas SV (2010) A review of design principles for community-based natural resource management. *Ecol. Soc.* 15:38.
16. Ostrom E, Cox M (2010) Moving beyond Panaceas: A multi-tiered diagnostic approach for social-ecological analysis. *Environ Conserv* 37:1–13.
17. Christie P (2004) Marine protected areas as biological successes and social failures in southeast Asia. *Am Fish Soc Symp* 42:155–164.
18. Schlager E, Ostrom E (1992) Property-rights regimes and natural-resources - a conceptual analysis. *Land Econ* 68:249–262.
19. Adger WN, Kelly PM (1999) Social vulnerability to climate change and the architecture of entitlements. *Mitig Adapt Strategies Glob Change* 4:253–266.
20. Sen A (1982) *Poverty and Famines: An Essay on Entitlement and Deprivation* (Oxford Univ Press, Oxford), p 257.
21. Sutinen JG, Kuperan K (1999) A socio-economic theory of regulatory compliance. *Int J Soc Econ* 26:174–193.
22. Berkes F (2009) Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. *J Environ Manage* 90:1692–1702.
23. Karlan D, Zinman J (2011) Microcredit in theory and practice: Using randomized credit scoring for impact evaluation. *Science* 332:1278–1284.
24. McClanahan TR, Marnane MJ, Cinner JE, Kiene WE (2006) A comparison of marine protected areas and alternative approaches to coral-reef management. *Curr Biol* 16: 1408–1413.
25. Pollnac R, et al. (2010) Marine reserves as linked social-ecological systems. *Proc Natl Acad Sci USA* 107:18262–18265.
26. Sandin SA, et al. (2008) Baselines and degradation of coral reefs in the Northern Line Islands. *PLoS ONE* 3:e1548.
27. Pauly D (1990) On Malthusian overfishing. *Naga*. *The ICLARM Quarterly* 13:3–4.
28. Allison EH, Ellis F (2001) The livelihoods approach and management of small-scale fisheries. *Mar Policy* 25:377–388.
29. Berkes F, et al. (2006) Ecology. Globalization, roving bandits, and marine resources. *Science* 311:1557–1558.
30. Lewis D, et al. (2011) Community Markets for Conservation (COMACO) links biodiversity conservation with sustainable improvements in livelihoods and food production. *Proc Natl Acad Sci USA* 108:13957–13962.
31. Armitage DR, et al. (2009) Adaptive co-management for social-ecological complexity. *Front Ecol Environ* 7:95–102.
32. Folke C, Hahn T, Olsson P, Norberg J (2005) Adaptive governance of social-ecological systems. *Annu Rev Environ Resour* 30:441–473.
33. Schultz L, Duit A, Folke C (2011) Participation, adaptive co-management, and management performance in the world network of biosphere reserves. *World Dev* 39: 662–671.
34. Armitage D, Marschke M, Plummer R (2008) Adaptive co-management and the paradox of learning. *Glob Environ Change* 18:86–98.
35. Aswani S, Hamilton R (2004) Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (Bolbometopon muricatum) in the Roviana Lagoon, Solomon Islands. *Environ Conserv* 31:69–83.
36. Steneck RS, et al. (2011) Creation of a gilded trap by the high economic value of the Maine lobster fishery. *Conserv Biol* 25:904–912.
37. Berkes F (2007) Community-based conservation in a globalized world. *Proc Natl Acad Sci USA* 104:15188–15193.
38. Scales H, Balmford A, Liu M, Sadovy Y, Manica A (2006) Keeping bandits at bay? *Science* 313:612–614, author reply 612–614.
39. Hughes TP, Bellwood DR, Folke C, Steneck RS, Wilson J (2005) New paradigms for supporting the resilience of marine ecosystems. *Trends Ecol Evol* 20:380–386.
40. Ostrom E (2007) A diagnostic approach for going beyond panaceas. *Proc Natl Acad Sci USA* 104:15181–15187.
41. McClanahan TR, et al. (2011) Critical thresholds and tangible targets for ecosystem-based management of coral reef fisheries. *Proc Natl Acad Sci USA* 108:17230–17233.