

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 policy-makers 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*).

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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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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