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Report

A Comparison of Marine Protected Areas and Alternative Approaches to Coral-Reef Management

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Summary

Marine protected areas (MPAs) have been widely adopted as the leading tool for coral-reef conservation, but resource users seldom accept them [1, 2], and many have failed to produce tangible conservation benefits [3]. Few studies have objectively and simultaneously examined the types of MPAs that are most effective in conserving reef resources and the socioeconomic factors responsible for effective conservation [4–6]. We simultaneously explored measures of reef and socioeconomic conservation success at four national parks, four comanaged reserves, and three traditionally managed areas in Indonesia and Papua New Guinea. Underwater visual censuses of key ecological indicators [7, 8] revealed that the average size and biomass of fishes were higher in all areas under traditional management and at one comanaged reserve when compared to nearby unmanaged areas. Socioeconomic assessments [6, 9, 10] revealed that this "effective conservation" was positively related to compliance, visibility of the reserve, and length of time the management had been in place but negatively related to market integration, wealth, and village population size. We suggest that in cases where the resources for enforcement are lacking, management regimes that are designed to meet community goals can achieve greater compliance and subsequent conservation success than regimes designed primarily for biodiversity conservation.

Results and Discussion

From an ecological perspective, effective coral-reef conservation can be viewed as increasing or maintaining key ecosystem parameters such as fish biomass or coral cover, maintaining ecosystem processes and function, or increasingly, promoting resilience to disturbances and fluctuations [11]. Due to the synchronic nature of our comparative study, we adopted an easily measurable and commonly used definition of effective conservation—namely, that effective management would cause utilized resources or key ecological indicators to be higher inside compared to outside managed areas [12, 13]. This measure can be potentially weaker than those derived from comparisons of resources before and after closure [14], but it has been used because it requires significantly less time and fewer research expenses. This measure was also found to produce comparable results in the intensively studied management systems of the Philippines [15]. We studied the effectiveness of three broad types of management: national parks, comanaged areas, and traditionally managed areas. National parks were large areas (6,600–111,625 ha), managed and enforced by the national government with the explicit goals of sustainable use and improving the condition of reef resources. Comanaged reserves were small areas (11.8–60 ha), managed and enforced by the community in partnership with nongovernmental organizations (NGOs), tourism operators, and universities for a variety of social and ecological goals, such as improving resources and providing income through tourism revenue. The traditionally managed areas we examined were small (33.2–58 ha), periodic reef closures or gear-restricted areas that were instigated and maintained by the community for the explicit goals of providing food for celebratory feasts, reinforcing of intercommunity relations, or mitigating conflicts, and in one case, "taming" the fish to make them easier to spear [16].

The effectiveness of management in conserving reef resources was examined with underwater visual censuses of key resources and ecological parameters at replicate study sites located inside and outside managed areas. Unmanaged control sites were carefully selected to be as similar to managed sites as possible in environmental and physical characteristics such as reef geomorphology, level of exposure to wave action, and current regimes, so that the only expected major difference between management and control sites was the presence or absence of a management system.

Only two ecosystem variables, average size and biomass of targeted fish species, were commonly found to be different inside versus outside managed areas (Table 1). The most provocative finding was that three of the four sites that had a greater average size and biomass of fishes within the managed areas were the self-governing, traditional management regimes (Figure 1). Contrary to the widely accepted idea that permanent closures are the most effective ways to improve reef ecosystem health [17], none of the traditional management regimes involved permanent reef closures. Each involved periodic closures, whereby protected reefs were periodically opened to fishing, either briefly or for extended periods of time, and one of these systems actually allowed line fishing inside the protected area throughout the entire year. Interestingly, the traditional management systems were implemented to meet utilitarian community goals, such as providing food for

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Table 1. Selection of Ecological Variables Measured and Significance Obtained from MANOVA in Comparisons between Managed and Unmanaged Sites

	National Park				Comanagement				Traditional Management		
Ecological variables	Bunaken (Indo)	Pulau Seribu (Indo)	Karimun-jawa (Indo)	Bali Barat (Indo)	Pemuteran (Indo)	Kilu (PNG)	Sinub (PNG)	Blongko (Indo)	Muluk (PNG)	Kakarotan (Indo)	Ahus (PNG)
Target fish biomass	ns (0.23)	ns (0.11)	ns (0.15)	ns (0.13)	ns (0.15)	ns (0.20)	ns (0.19)	+ve** (0.20)	+ve* (0.09)	+ve* (0.09)	+ve** (0.11)
Average size of target fish species	ns (0.03)	ns (0.06)	ns (0.06)	ns (0.06)	ns (0.08)	ns (0.07)	ns (0.07)	+ve** (0.10)	+ve** (0.04)	+ve* (0.04)	+ve** (0.05)
Density of target fish species	ns (0.19)	ns (0.10)	ns[a] (0.15)	ns (0.18)	ns (0.20)	ns (0.08)	ns (0.13)	ns (0.26)	ns (0.21)	ns (0.19)	ns (0.26)
Fish species richness	ns (0.05)	ns (0.02)	ns (0.03)	ns (0.04)	ns (0.09)	ns (0.06)	ns (0.06)	ns (0.05)	ns (0.13)	ns (0.08)	ns (0.05)
Percent live hard coral cover	ns (0.06)	ns (0.10)	ns (0.15)	+ve*,[a] (0.20)	ns (0.49)	ns (0.20)	ns (0.16)	ns (0.13)	ns (0.16)	ns (0.43)	ns (0.17)
Coral diversity	ns (0.06)	ns (0.07)	ns (0.05)	ns (0.04)	ns (0.05)	ns (0.15)	ns (0.03)	ns (0.05)	ns (0.04)	ns (0.27)	ns (0.02)
Number of study sites (managed, control)	6,5	8,6	9,6	5,5	5,5	6,6	6,6	5,5	5,5	3,3	3,3

Variables presented include those that were significantly different inside versus outside managed areas as well as variables commonly measured in monitoring programs. ns = nonsignificant; +ve = significantly higher within managed area; * = $p < 0.05$; ** = $p < 0.01$.
[a] Data that did not conform to MANOVA assumptions were analyzed with Mann-Whitney U tests. Precision of results is given in parentheses.

celebratory feasts, rather than to fulfil western ecological concepts of conservation [18]. Despite the periodic nature of these protected areas, the absence of external funding, and the explicit goals of resource utilization, traditional management systems still appeared to provide significant conservation benefits for reef fish stocks. The fourth site to display strong differences in fish biomass and size structure was a comanaged, protected area with a permanent reef closure (Table 1). This MPA was designed largely from a social perspective after intensive social surveys and community consultation. Key informants noted that the reserve location was chosen specifically because it was visible to the community. The community received significant external assistance to establish and maintain the management regime in the form of funding, awareness and education programs, and community support programs. One national park site displayed significantly greater hard coral cover within the protected area compared to surrounding reefs; however, this difference was marginal (Table 1), and the site did not show a response to management in other ecosystem variables.

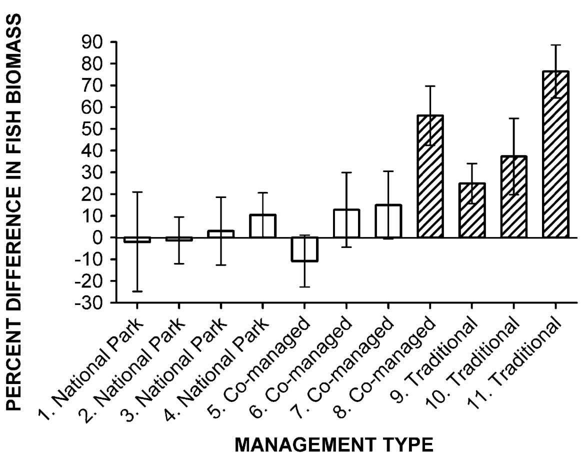

Figure 1. The "Effectiveness" of Coral-Reef Conservation as Measured by the Percent Difference ±95% C.I. in the Total Biomass of Commonly Targeted Reef Fishes between Managed or Conserved Reefs and Matched Control Reefs Where No Conservation or Management Was Imposed

Large positive percentages suggest a highly effective conservation result. Confidence intervals were calculated from means of replicate study sites located within each set of managed and control reefs. Site means were calculated from four to six transects within each site. The number of replicate sites sampled within management and matched control reefs are listed in the order presented in Table 1.

The majority of the other ecosystem variables, such as coral and fish diversity, coral cover, and the overall abundance of targeted fishes, showed little difference in magnitude inside versus outside protected areas at any of the management sites. The explanation for the lack of significant difference in other ecological variables was likely to be (1) that management was largely ineffective in conserving coral reefs in all of the cases examined, (2) sampling was not powerful enough to detect differences in most ecological variables, (3) local fishing pressure was too light for management to have significant effects on reef resources, or (4) most parameters did not respond as strongly to management as expected. Although sampling precision was low in a few instances, variables were sampled intensively at each site, and relatively good precision was achieved for most variables (Table 1). Parameters that would be expected to respond the most strongly to effective management were those that were most directly affected by resource users, and hence, alleviated when protected by management. At almost all sites, reef fishes were the most commonly targeted resource. The parameters that were expected to most directly and precisely describe the changing condition of fished stocks, population-size structure [19] and, in relation, the biomass of fish stocks showed the greatest difference between managed and unmanaged areas under some of the management regimes. This would suggest that the

Table 2. List of Socioeconomic Variables Examined and Range of Values Obtained

	National Park				Comanagement				Traditional Management		
Variable	Bunaken (Indo)	Pulau Seribu (Indo)	Karimun-jawa (Indo)	Bali Barat (Indo)	Pemuteran (Indo)	Kilu (PNG)	Sinub (PNG)	Blongko (Indo)	Muluk (PNG)	Kakarotan (Indo)	Ahus (PNG)
"Effective" management	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
Time closed (years)	3	8	15	10	3	4	4	4	60+	60+	60+
Percent of fishers aware of closure	98	34	25	75	50	83	76	97	79	98	73
Compliance index (−100 = low, 100 = high)	0	−57	13	−14	13	−100	67	74	75	100	100
Reserve in sight of village	No	No	No	No	Yes	No	No	Yes	Yes	Yes	Yes
Active enforcement	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	No	No
Population	3122	12322	9473	8606	7955	584	1136	1332	333	730	544
Number of households fishing	426	1525	1647	222	301	53	120	124	43	129	101
Household fortnightly expenditures (US $)	39	178	70	63	51	48	45	44	43	21	44
Percent of fish sold to market	72	85	83	91	81	32	56	44	44	24	68
Mean number of occupations per household	2.2	1.7	2.3	1.8	1.8	4.3	3	2.6	3.3	3.9	2.7
Percent engaged in fishing	55	71	71	10	16	58	97	40	88	90	96
Percent engaged in farming	48	0	37	82	77	100	100	89	100	35	22
Percent engaged in salaried employment	16	28	13	20	18	35	35	10	5	10	14
Percent engaged in tourism	18	14	2	8	12	28	0	0	0	0	54
Percent engaged in informal economy	44	37	49	30	41	70	33	33	2	83	69
Percent active in decision-making	12	20	25	18	27	35	76	17	29	23	62
Mean number of community organizations per household	1.5	0.7	1	1	1.1	1.5	0.8	0.6	1	1.6	1.6
Percent Immigration	21	30	47	48	23	25	11	52	8	2	4
Mean years of formal education	6.7	6.7	5.3	6.4	6.4	7.2	7.4	5.7	5	7.3	7.7

PNG = Papua New Guinea; Indo = Indonesia.

fourth explanation is likely, and only those parameters that documented changes in the most heavily targeted resources were effective indicators of management success. The densities of targeted reef fishes were also expected to provide a reliable indication of the effect of management. However, target fish densities were highly variable among sites, and good precision was difficult to achieve. Other studies suggest that the density of reef fishes may respond to fishing pressure in an unpredictable manner as a result of phenomena such as prey release and reduced competition among smaller individuals when large individuals are removed by fishing [20]. By comparison, the size structure of targeted fish populations, and in relation, the biomass of fishery stocks, were less variable among sites than fish density alone and appeared to provide the most precise indication of management effects.

Because few of the ecological indicators showed differences inside versus outside managed areas, we used the most responsive of our ecological indicators to define whether a study site had "effective conservation" for the purposes of our socioeconomic analysis. We categorized sites as having effective conservation if they had a significantly greater biomass or average size of targeted fish inside versus outside managed areas. Coral cover responded to management at only one of the sites examined; this response was fairly weak, and the management site did not show differences in any other ecological variables. Therefore, coral cover was not deemed an appropriate indicator of effective management in this study's analyses.

The effectiveness of management regimes in conserving reef resources depends not only on whether the dynamics of the conservation strategy can complement the local ecology, but also on whether resource users adhere to the associated rules and regulations of the regimes. Despite lowering benefits for the entire user group, an individual's rational self-interest can be to overutilize collectively owned resources, because the short-term benefit of such action is almost entirely acquired by the individual, whereas the burden is shared with the entire group of users [21]. However, this opportunistic behavior is not inevitable in common-property resource scenarios, and decisions to act in collective rather than individual interest can be influenced by social and economic factors [22, 23].

We used a combination of household surveys, key-informant interviews, and participant observation to examine the socioeconomic conditions in communities within and adjacent to the managed areas [6, 9, 10]. The socioeconomic conditions in our study sites varied widely, from the peri-urban Pulau Seribu, with high populations and market connectivity (indicated by a high proportion of fish sold and engagement in salaried employment), to remote sites such as Kakarotan, with low populations and primarily subsistence fisheries (Table 2). We examined whether socioeconomic factors were related to the outcomes of reef-management

Table 3. List of Socioeconomic Variables Examined at Each Site and Their Relationship to the Ecological Outcomes of Protected Areas

Variable	Z	p	Effect Size (*d*)	Effect
Visibility of reserve (in sight of village)*	*	0.01	na	+ve
Compliance indicator	−2.65	0.01	1.5	+ve
Percent households involved in salaried employment	−2.47	0.02	−1.4	−ve
Percent fish sold to markets	−1.90	0.06	−1.24	−ve
Population	−2.08	0.04	−1.2	−ve
Fortnightly expenditure	−2.08	0.04	−0.78	−ve
Time management has been in place (time closed)	−1.90	0.06	1.40	+ve
Number of households involved in fishing	−1.71	0.10	−0.88	ns
Mean number of occupations per household	−1.51	0.16	0.81	ns
Percent immigration	−1.32	0.23	−0.71	ns
Percent fishers aware of closure	−1.23	0.22	0.94	ns
Percent involved in fishing	−1.13	0.26	0.80	ns
Involvement in community organizations	−0.57	0.65	0.28	ns
Percent dependent on informal economy	−0.0	1.00	0.16	ns
Percent involved in tourism	−1.06	0.29	0.11	ns
Percent involved in farming	−0.19	0.93	−0.04	ns
Percent of community active in decision-making	−0.19	0.93	0.11	ns
Mean years of education	0.00	1.00	−0.11	ns
Presence of active enforcement patrols*	*	0.76	na	ns

The socioeconomic characteristics of communities with "effective" management were compared to communities with "ineffective" management with the Mann-Whitney U test for ordinal indicators and the Fisher's Exact test for dichotomous indicators. ns = nonsignificant ($p > 0.1$); +ve = significantly higher in communities with effective conservation ($p < 0.1$); −ve = significantly higher in communities with ineffective conservation ($p < 0.1$); * = Fisher's Exact test used; effect size = $(M_a - M_b)/\sigma$; na = not applicable.

strategies by testing whether communities with effective fishery conservation had differed from communities without effective conservation in 21 socioeconomic characteristics. We used the Mann-Whitney U test to determine whether significant differences existed, and we also used effect size (*d*) to examine the strength of relationships. This provided us with a gradient of relationships; communities with statistically significant differences and high effect sizes, communities with considerable effect sizes but no significant differences (indicating that relationships may exist but our power may have been too low to detect differences), and communities with low effect sizes and nonsignificant differences (Table 3).

We found that sites that were effective at conserving resources had significantly higher observed compliance (measured as the amount of discarded fishing gear recorded inside the closure compared to the control sites), were visible to the community, and had been closed longer than ineffective areas (Table 3). These communities also had significantly less market influences (i.e., proportion of fish sold or bartered and involvement in formal economic activities such as teaching, government employment, and other salaried positions), lower population sizes, and less wealth (i.e., fortnightly expenditures). We were willing to accept significance values of $p < 0.1$ as statistically significant for two indicators (percentage of fish sold to markets and time of closure of managed areas) because of the exploratory nature of the study and the high effect sizes of these indicators. High-cost activities that are typically the focus of conservation programs, such as fostering awareness of the management rules and maintaining active enforcement patrols, were not found to be significantly related to effective management, although awareness had a considerable effect size.

Several other factors that demonstrated substantial effect sizes ($d > 0.8$ or < -0.8 [24]) but were not statistically significant ($p \geq 0.1$) included total number and percentage of households engaged in fishing, occupational multiplicity, and the proportion of immigrants in communities. These high effect sizes indicate that substantial relationships may exist between these factors and the outcomes of marine conservation initiatives, but with our relatively limited sample size, we could not detect statistically significant differences. Factors such as active involvement in decision making, involvement in community groups, the mean years of formal education, and the proportion of the community involved in alternative occupations such as tourism and farming did not demonstrate substantial effect sizes or statistically significant differences, suggesting that their relationship to the outcomes of reef management was weak.

All effective sites were able to exclude "outsiders" at a relatively low cost because of placement of the managed areas were near the village. In addition, the effective traditional sites had strong customary marine tenure institutions, which prohibited nonowners from accessing reef resources [6, 9, 16]. Interestingly, observed compliance was highest in the three self-governing traditionally managed areas, which did not have regular enforcement patrols, suggesting that the effectiveness of these sites in conserving reef resources was because of intrinsic motivations to act collectively and comply with regulations [25, 26]. Our in-depth case studies of these traditionally managed sites [9, 16] found that social influences promoting collective action and the perceived justness and legitimacy of regulations [27] may have been particularly high in traditional management institutions because they reflected local understandings of human-environment interactions, were an integral part of local cultures and traditions, and provided the communities with tangible benefits. For example, communities periodically fished these areas and perceived direct benefits of the management system; thus, these systems met more individual and community goals than systems of permanent closure. In addition, most members of the community were regularly reminded of the closures through participation in the traditions and feasts [28]. High compliance in the effective comanagement site in Indonesia may have stemmed from the significant input of external resources to this community; similar factors were found to be responsible for effective management at sites in the Philippines [4].

In all traditionally managed sites, village leaders had some control over when and how much harvesting occurred within the protected area. Leaders also had the autonomy not only to develop rules that were congruent to local ecological and social conditions but also to adapt management to observed changes in ecosystem dynamics, socioeconomic influences, and evasion of governance rules [29–31]. For example, in Muluk, clan leaders instituted a temporary closure when they observed a decrease in fish abundance [31]. The size of the closure, length of time, and sanctions for violations could vary to meet the changing needs of the village and ecosystem.

The ability of periodic closures to improve fish stocks is likely to depend upon the intensity of the harvesting when the areas are opened to fishing as well as the life histories of the targeted species. In the case of one of these sites, Ahus, periodic harvesting was found to be relatively benign in its effects on the overall standing stocks of reef fishes, with harvests being carried out on only one day every 6–12 months and removing only around 5% of the available biomass on each occasion [16]. However, if similar management methods were to be employed elsewhere, especially in areas of intense fishing pressure, the extent and type of harvesting to occur in managed areas would have to be carefully monitored and regulated, because differences in fishing effort, gears used, and frequency of harvests could influence the outcomes and management benefits. Although meta-analysis studies of MPAs suggest that recovery of some target species can occur within the first few years of area closure [12], some species may require recovery periods of longer than two decades, particularly when fishing is intense around boundaries [14, 15, 32]. Consequently, although the use of small, limited-harvest areas under certain conditions may bring direct benefits to reef ecosystems and fishing communities by allowing a buildup in fish biomass, there is still likely to be a need for larger, permanently closed areas for species that require long periods without disturbance [33] or large areas within which the fish can safely move and not be regularly caught.

In conclusion, this study suggests that the consideration of local socioeconomic factors and development of locally appropriate adaptive regulations are essential if we are to improve the ability of coral-reef management regimes to conserve resources. Coral-reef conservation based on large MPAs with weak enforcement may be ill-suited to the social, economic, and cultural context of many communities within the center of coral diversity, and insistence on these conservation methods may lead to polarization between national-government regulators and local communities [1, 2]. In situations where the resources for proper enforcement are lacking, alternative management regimes that are better able to meet a range of community goals may achieve greater acceptance, compliance, and subsequent conservation success than systems designed primarily for national interests of tourism and biodiversity conservation. Although large, permanent MPAs may provide the best protection for species that are highly susceptible to overfishing, a combination of MPAs and alternative systems of management, such as traditional systems, may provide the best overall solution for meeting conservation and community goals and reversing the degradation of reef ecosystems within the center of coral diversity.

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