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REPORT

Customary management as precautionary and adaptive principles for protecting coral reefs in Oceania

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Abstract Marine conservation programs in Oceania are increasingly turning to precautionary and adaptive management, particularly approaches which emphasize local participation and customary management. Although the application of community-based natural resource management is widespread in the region, the full integration of local knowledge and practices into the design, implementation, and monitoring of community-based conservation programs has been limited. There is also little empirical data to show whether or not community-based conservation projects are meeting their stated objectives. This paper summarizes an integrated method for selecting Marine Protected Area (MPA) sites and presents empirical evidence that illustrates how an MPA that was largely conceived using indigenous ecological knowledge and existing sea tenure governance (i.e., customary management practices), as part of a regional precautionary and adaptive community-based management plan, is showing signs of biological and social success. More generally, the paper shows how hybrid natural and social research approaches in tandem with customary management for designing MPAs can protect coral reefs in Oceania.

Keywords Precautionary and adaptive management · Indigenous ecological knowledge · Sea tenure · Marine Protected Areas · Oceania

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Introduction

Customary management as a precautionary and adaptive management approach in marine conservation programs is receiving increasing attention (e.g., Pinkerton 1989; Clark 1996; Johannes 1998; Castilla and Defeo 2001; Gerrodette et al. 2002; Wiber et al. 2004; Grafton and Kompas 2005) because of the frequent failure of science-driven and state sponsored top-down conservation programs. Loosely defined, *precautionary management* is an approach that, given the social and biological outcome uncertainties of human actions and natural processes, takes a proactive and preventive management stance to avert budding resource degradation and to protect biodiversity. Similarly, *adaptive management* is an approach that, under the pervasiveness of imperfect information (Ludwig et al. 1993; Parma et al. 1998; Holling 2001), requires flexibility and willingness to change the design, implementation, and evaluation phases of any conservation program on a recurring basis, particularly as new information about a given social and ecological system is obtained.

For many researchers and conservation practitioners, an important component of these management approaches is an emphasis on local participation through the incorporation of indigenous common property institutions (e.g., sea tenure), customary management practices (e.g., taboos), and ecological knowledge (e.g., ethno-ichthyology) in community-based conservation programs, instead of relying on science-driven and top-down conservation directives exclusively (e.g., Gadgil et al. 1993; Acheson and Wilson 1996; Berkes et al. 2000). Research in the Pacific has shown that customary practices can provide a hedge against social and biological uncertainty and can be resilient enough to adapt to socioeconomic and ecological change (Aswani 2002; Cinner et al. 2006). Indeed, customary management is not designed for conservation (Aswani 1998) but, nonetheless, it can provide an institutional context, which under certain socioeconomic and political conditions, can result in good resource stewardship (Aswani 2005; Cinner and McClanahan 2006).

In the Pacific Islands, centralized and science-driven fisheries programs have had a precarious history. A number of factors have contributed to fisheries mis-management, including inadequate scientific models, environmental variability, ignorance about natural systems, poor data, non-compliance with management measures, and the complex inter-relationships between biological, economic, and socio-cultural systems. In fact, managing inshore, small-scale, multi-species, and multi-method fisheries that are spread over thousands of kilometers is too complex and too expensive for small Pacific Island nations. Given this scenario, a number of authors have called for a more holistic approach to fisheries management in the region (e.g., Adams et al. 1997; Ruddle 1998; Sadovy 2005). While the application of community-based natural resource management is widespread in the region, the full integration of local knowledge and practices into the design, implementation, and monitoring of community-based conservation programs has been limited. Furthermore, with few exceptions (Cinner et al. 2005; McClanahan et al. 2006), there is little empirical evidence to show whether or not community-based conservation projects, which emphasize customary management, are meeting their stated objectives of biological conservation, social equity, and food security.

This study provides empirical evidence of how customary management practices can be combined with elements of natural and social science to protect coral reefs in Oceania. The paper summarizes an integrated method for selecting Marine Protected Area (MPA) sites and examines the biological and social trends of an MPA conceived using indigenous ecological knowledge and existing sea tenure governance, as part of a regional precautionary and adaptive community-based management plan. For the biological study, algal settlement tiles were used to assess the fish grazing intensity of herbivores both within and outside the Nusa Hope community-based MPA in the Roviana Lagoon, New Georgia Island (Fig. 1). To supplement the algal indicator data, fish and coral reef conditions were quantified using a conventional underwater visual census (UVC). In addition, the density and size-distribution of several species of parrotfish were measured in the same MPA to assess the algal study results independently. The parrotfish family was chosen because these are herbivores and bio-eroders, they are pursued avidly (along with other herbivores such as surgeonfishes) by local divers and fishermen in adjacent non-MPA sites (see Aswani and Hamilton 2004; Hamilton 2004), and their presence can be used as an indication of relative coral reef health and recovery status.

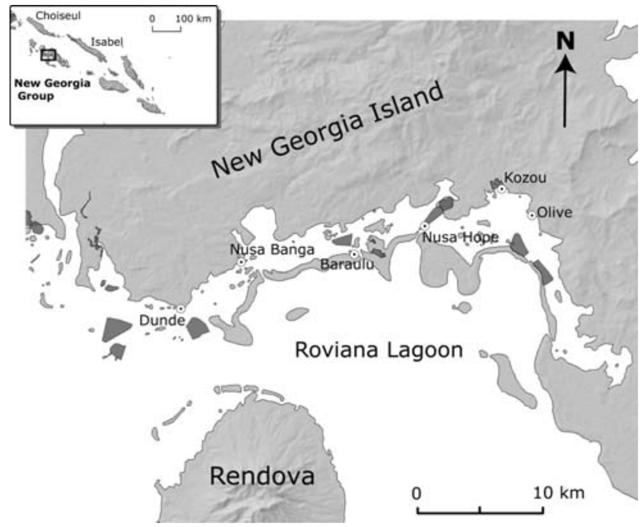

Fig. 1 The Roviana Lagoon, New Georgia, Solomon Islands [marine protected area (*MPA*) sites shown in *dark gray*]

For the socioeconomic study, the impact of the Nusa Hope MPA was assessed by measuring people's perceptions of their livelihoods, and empirically evaluating the possible effects of the MPA on human nutrition. The Nusa Hope results were compared with those of a cross-sectional analysis of people's perceptions and nutrition in other villages with MPAs of varying success and in a village without an MPA. This paper draws from experience in designing, implementing, and monitoring MPAs in the Western Solomon Islands (Aswani 2000; Aswani and Hamilton 2004; Aswani and Lauer 2006a).

Materials and methods

Study site

The Western Solomon Islands lie within the Bismarck-Solomon Seas eco-region, which is an area that covers the Solomons, the north coast of Papua New Guinea, and the northern West Papua region. Marine habitats are biodiverse and are moderately undamaged by human activities, making this area one of the world's marine biodiversity hotspots (Hughes et al. 2002; WWF South Pacific Program 2003). The most direct threat to coral reefs and marine resources in the Western Solomon Islands is over-fishing and run-off sedimentation from logging. A majority of coastal communities are dependent upon marine resources for subsistence and cash, and the return migration caused by the recent ethnic tension (1998–2003), in tandem with sustained population growth (around 3% per annum), has increased local dependency upon marine resources. This, in turn, has led to environmental degradation and social tensions across many communities. The Roviana Lagoon (Fig. 1), which is formed by raised offshore coral islands and consist of mangroves, freshwater swamps, river estuaries, seagrass beds, sand channels, shallow coral reefs, and outer reef drop habitats, is also being compromised by anthropogenic disturbances.

To address some of these environmental problems, a marine conservation and development program was established in the Roviana and Vonavona Lagoons in 1999 by one of the authors (Aswani 2000). As of 2006, a system of 23 "no-take" marine reserves and "spatio-temporal" refugia had been instituted in Roviana and Vonavona, a system that is currently expanding across various islands in the Western Solomons (e.g., Marovo, Rendova, and Vella LaVella). The Nusa Hope-Heloro MPA was established in Nusa Hope Village, Roviana Lagoon, in 2002. The reserve covers 83 ha of diverse coral reef, seagrass, and mangrove habitat typical of the Roviana Lagoon region. The general biological objectives of the reserve are to enhance fisheries productivity locally, protect vulnerable species and habitats (biodiversity and ecosystem functioning), and to protect susceptible life history stages (spawning and nursery grounds). More specifically, the MPA was designed to (1) conserve spawning/aggregating areas for triggerfish (*Pseudobalistes flavimarginatus* and *Balistoides viridescens*), groupers (e.g., *Epinephelus polyphekadion*), and other species, (2) protect nocturnal aggregations of the bumphead parrotfish (*Bolbometopon muricatum*), and (3) safeguard bumphead parrotfish nursery areas. The social objectives were to build upon practices with which the community was familiar, including customary sea tenure (CST) and indigenous ecological knowledge.

The Nusa Hope-Heloro MPA site was selected for its ecological and social value through a combination of local considerations and social and natural science research. Locally, traditional authorities and fishermen in general agreed that an MPA neighboring the village was the most feasible management strategy. Catch, size, and gear restrictions are difficult to enforce given certain cultural preferences and the extent of the area, but the spotting of interlopers entering and exiting the MPA is not as difficult. The site was also selected through various research strategies, including (1) an ethnographic study of regional CST to assess, among other factors, the feasibility of implementing fisheries management in the area (Aswani 1999, 2005); (2) the incorporation of the visual assessments of local photo interpreters, who identified benthic habitats, resident taxa, and spatio-temporal events of biological significance, into a geographical information system (GIS) database (Aswani and Lauer 2006a); (3) the coupling of indigenous ecological knowledge with marine science to study aspects of life history characteristics of vulnerable species (Aswani and Hamilton 2004; Hamilton 2004, 2005); and (4) the incorporation of fishing time-series data (1994–2004) into the GIS to examine spatial and temporal patterns of human fishing effort and yields (Aswani and Lauer 2006b).

Between 2005 and 2006 a series of biological and social impact assessments of the MPA system and associated villages were conducted to evaluate the strengths and weaknesses of the MPA design and implementation approach. Nusa Hope was the main target community for monitoring because it has one of the oldest MPAs (hence suitable for monitoring) and is one of the most effective villages in terms of containing poaching by inclusive residents and neighboring villages. Pre-MPA biological baseline data was not collected in 2002 due to various logistical constraints and due to the speed of MPA implementation following the research team's recommendations to local authorities. Note that only biological data for the Nusa Hope MPA was available for this analysis, as a comprehensive regional assessment of the status of the other marine reserves is still underway.

Assessment of marine reserve status

First, algal settlement tiles were used to assess the fish grazing intensity of herbivorous fish. An area of reef ($\sim$50 × 50 m^2) inside the MPA and a second area outside the MPA were used as experiment and control sites, respectively. The protected lagoon reefs at each site are representative of the majority of the MPA area, consisting of coral and algal communities growing on predominantly carbonate bedrock interspersed with sandy areas at a depth of $\sim$1 m. The hydrodynamics and water quality were similar at both sites (in terms of distance to clean oceanic water flushing, distance from terrestrial run-off, and similarity of current velocity). Five replicate settlement tiles (7×7 cm^2 PVC; Smith et al. 2001) were attached to concrete blocks and randomly placed on the reef both inside and outside the MPA and collected after six months. Cover of algal functional groups (Steneck and Dethier 1994) was quantified at 24 random points on a digital image of the tiles using Coral Point Count V3.2 (NCRI). Algal biomass (dry weight) on the top surface of the tiles was quantified following oven drying at 60°C. To verify the algal indicator data, fish abundance (St. John et al. 1990) were quantified along three 50 m transects at 1-m depth within each area. Coral reef condition was analyzed along the same three 50 m transects at each site by taking a 1 m^2 digital photo every 2 m and classifying benthos as live coral, dead coral, macroalgae, sponge, substrate (sand) or rock at 24 random points on each digital image using Coral Point Count V3.2 (NCRI). The small number of transects for verifying the algal study resulted from a combination of logistical problems and the participatory nature of this research, which involved local communities in actual research and monitoring.

For the second survey, a strip-transect UVC technique was employed to measure abundance, size-frequency, and spatial distribution patterns for parrotfishes. The decision to focus on this particular family was based on the critical functional role of parrotfish herbivory on the health of shallow water coral reef ecosystems (Hughes 1994; Hawkins and Roberts 2004), their role in maintaining coral reef health within MPAs (Mumby et al. 2006, 2007), due to the fact that they are a main target of Roviana fishermen (Aswani and Hamilton 2004), and to complement the algal study.

Underwater Visual Census monitoring within the Nusa Hope MPA was compounded by the fact that the reserve covered a range of shallow biogeographical regions, which made conducting transects difficult, and the visibility was often unsuitable. Initial investigation revealed that the most representative parrotfish habitat, which occurred at both inside and outside the Nusa Hope MPA, were reef slopes adjacent to the passage. Parrotfish abundance was quantified along 18 separate 100×10 m^2 belt transects inside and outside the MPA at 20 m depth (because visibility was best at this depth). Land reference points were used to ensure transects did not overlap. Parrotfishes were recorded down to species level for excavating and scraping individuals, and comparisons made in this paper concern the differences between parrotfish on the reef slope inside and outside of the MPA.

To meet the assumptions of ANOVA, data from algal tiles, benthic cover and coral reef condition transects, and fish surveys were square-root transformed before conducting ANOVA (Tukey 1977; Keppel 1991; Howell 2002). Exploratory data analysis (Tukey 1977) demonstrated that square root expression of these variables was superior to linear or logarithmic transformations in reducing heterogeneity of variance between groups, and in some instances, ameliorating skew. Data, tables, and figures display untransformed values.

Assessment of socioeconomic and nutritional impacts of the marine reserve

The socioeconomic and nutritional impact of the Nusa Hope MPA was assessed in 2005 in tandem with other villages with MPAs of varying success [Kozou, Baraulu, Olive, and Dunde (experiment sites)] and a village without an MPA [Nusa Banga (control site)] (Fig. 1). Villages located in the Saikile and Kalikoqu chiefly districts (Nusa Hope, Kozou, Baraulu, Olive, and Nusa Banga) have similar resource governance systems and forms of customary management, habitats of similar ecological characteristics, and both districts have similar population densities and territorial size. Dunde, on the other hand, has a higher population density and a smaller marine territory, although its reefs are richer ecologically than the inner-lagoon reefs. Nusa Banga was selected as the control site because it does not have an MPA and because it has a similar political, socioeconomic, demographic, and ecological context to other Kalikoqu and Saikile villages. The village rankings for MPA rule adherence were based on the number of poaching incidents reported for each MPA by the local Resource Management Committee (RMC) and by our own general socioeconomic research (see Aswani 2002, 2005), the ranking of "1" being the most effective and ranking of "5" being the least effective in terms of containing poaching by inclusive residents and neighboring villages.

A census conducted in 2005 identified the research population. To understand how members of Nusa Hope and other villages with MPAs of varying success perceived their management programs, between 15 and 100% of households were interviewed, depending upon village size. A total of a 106 interviews were completed, which included open-ended, semi-structured, and structured questions. Interviews focused on issues concerning MPA effectiveness, poaching, conflict resolution and enforcement mechanisms, food security, and perceptions of environmental change. At non-MPA Nusa Banga, interviews (or questions suitable for a non-MPA village) were not conducted for logistical reasons. Hence, for Nusa Banga only nutritional data is presented as a point of comparison with the other villages.

A 24-h dietary recall method was employed in selected hamlets to investigate human nutritional intake. Twenty households were randomly selected in each of the study villages, except that 28 households were sampled in Dunde due to the village's size, and all nine households were selected in Kozou village. For all villages, households were visited once daily. During each visit, household members 15 years and older were asked to recall all food items consumed during the previous day. To minimize interview measurement errors, all data collected by the research assistants were cross-checked independently on the day of the interview. Energy (MJ), protein (g), and fat (g) intake were calculated using each participant's daily food consumption record, concurrently with food value tables for the Pacific region (Dignan 1994; Puwastien et al. 2000). The food items regularly eaten by villagers were measured directly to estimate average food and marine resources protein (reef and pelagic fishes, crustaceans, and mollusks) consumed.

To test for statistically significant differences between Nusa Hope and other villages in perceptions (MPA governance, MPA effectiveness, and food security), a Chi-square was calculated for each question, with a Yates Correction for small expected values (Keppel 1991; Howell 2002). For the cross-sectional comparisons of energy (MJ) and major nutrient (g) intakes of adults in the experiment and control village sites, a one-way ANOVA was calculated, followed by Tukey's honest squared difference (HSD) multiple comparisons test to localize statistically significant differences between villages (Howell 2002). Statistical analysis was made using SPSS (Version 11.02, SPSS Inc., Chicago, IL, USA) and Microsoft Excel (Microsoft Corp, Redmond, WA, USA) software, and comparisons were considered to be statistically significant at $P < 0.05$. Values are expressed as mean ± standard error of the mean (SE) unless otherwise noted.

Results

Biological results

In the algae study, the top surfaces of the settlement tiles from within the MPA were colonized by a diverse algal community that included cyanobacteria (20% ± 3.6; mean ± SE), filamentous algae (2% ± 1.7), foliose algae (23% ± 2.8), and crustose coralline (23% ± 6.0) (Fig. 2). The remaining 32% (±2.1) of the MPA tiles were uncolonized by algae (visible to the naked eye). Fish grazing marks were evident on the tiles within the MPA, suggesting continual removal of both plants and animals that settled on the tiles. In contrast, the settlement tiles in the adjacent reef outside the MPA were colonized predominately by the cyanobacteria *Oscillatoria spp.* (80% ± 4.0) with a smaller area covered by filamentous algae (17% ± 2.9). An average of only 3% (±2) of the tiles collected from outside the MPA was uncolonized (to the naked eye) (Fig. 2). There was also little evidence of grazing marks on the tiles, which suggests that the frequency of substrate removal was less outside the MPA. Specifically, there was a significant difference between the composition of algal groups covering the settlement tiles inside and outside the MPA, as indicated by a significant location x cover interaction ($F(7,64) = 70.2$, $P < 0.0001$). Most apparent, the microalgae (Cyanobacteria) covered 80 ± 4.0% (mean ± SE) of the tiles outside the MPA compared to 20.0 ± 3.6% inside the MPA, $F(1,8) = 85.7$, $P < 0.000001$. In addition, there was also a significantly ($F(1,8) = 21.3$, $P < 0.005$) higher biomass of algae from outside the MPA (10.8 ± 1.8 mg cm^{-2}) compared with inside (2.5 ± 0.4 mg cm^{-2}).

The data from the complementary visual census of the herbivorous fish were equivocal. Inside the MPA there were 134 ± 25 fish per 200 m^2 (mean ± SE) compared to 61 ± 18 outside the MPA. However this apparent difference was not statistically significant ($F(1,4) = 5.8$, $P = 0.08$) probably because of the small sample size (three transects per group). Total fish abundance inside the MPA was 247 ± 31 per 200 m^2 compared to outside where it was 175 ± 31 per 200 m^2, but this difference was also not statistically significant, $F(1,4) = 2.8$, $P = 0.17$. There was significantly ($F(1,4) = 12.5$, $P = 0.02$) higher macroalgal cover on the reef area located outside the MPA (6.76% ± 2.7) compared with the area inside the MPA (0.06% ± 0.6) (Table 1). The macroalgae consisted primarily of corticated groups such as *Caulerpa spp.* growing on dead coral and rocks. There were no significant differences for other benthic communities between the two areas.

The parrotfish survey revealed that there were more small (<30 cm) parrotfish inside the MPA (38.7 ± 3.7) compared to outside the MPA (18.4 ± 1.9), $F(1,34) = 25.7$, $P < 0.0001$, and importantly, there were >10× more large

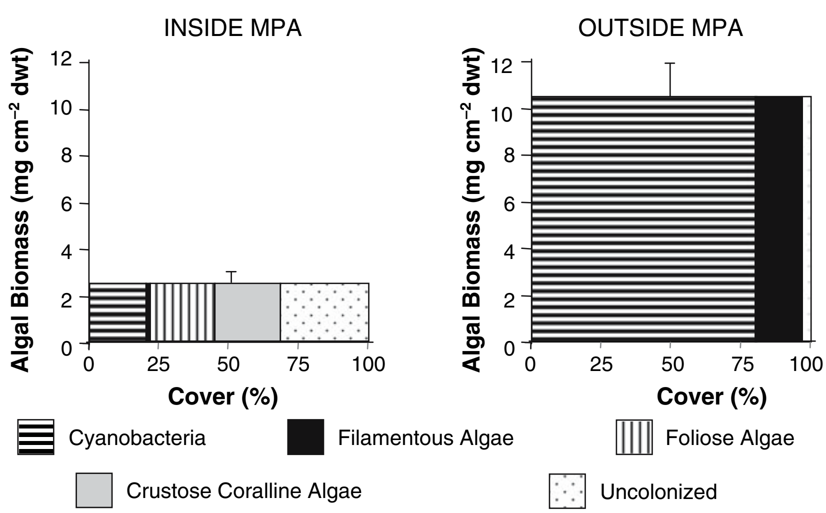

Fig. 2 Biomass and percentage cover of algal communities on the top surface of settlement tiles

Table 1 Percentage cover of Nusa Hope reef communities within the marine protected area (*MPA*) and OPEN sites outside the MPA

	Mean ± SE		*P*-value
	Inside Nusa Hope MPA	Outside Nusa Hope MPA	
Live coral	5.07 ± 1.26	4.69 ± 0.29	0.85
Dead coral	1.33 ± 0.33	2.09 ± 1.08	0.69
Macroalgae	0.06 ± 0.06	6.76 ± 2.70	0.02*
Sponge	1.05 ± 0.35	2.38 ± 1.11	0.29
Substrate	54.8 ± 8.32	58.2 ± 3.64	0.69
Rock	37.7 ± 7.31	25.9 ± 2.77	0.21

There was a significant interaction between MPA and benthic cover (ANOVA $F(5,24) = 4.2$, $P < 0.01$). Significant *P* value is indicated by a star

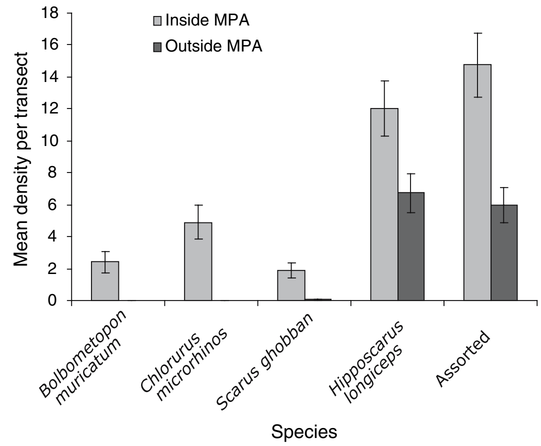

Fig. 4 Mean density per transect for scarids inside/outside of Nusa Hope marine protected area (*error bars* represent ±1 SE)

parrotfish (>30 cm) inside the MPA (9.8 ± 1.1) compared to outside the MPA (0.7 ± 0.2), $F(1,34) = 101.0$, $P < 0.0001$ (Fig. 3). More specifically, inside the reserve there was a higher number of Pacific steephead parrotfish (*Chlorurus microrhinos*) (4.8 ± 1.1 inside, 0.0 outside; $F(1,34) = 20.3$, $P < 0.0001$) and bumphead parrotfish (*Bolbometopon muricatum*) (2.4 ± 0.7 inside, 0.0 outside; $F(1,34) = 14.1$, $P < 0.001$), both of which are excavating species (Fig. 4). Smaller generalist scraping species were also significantly more abundant inside the reserve, including *Scarus ghobban* (1.9 ± 0.5 inside, 0.1 ± 0.1 outside; $F(1,34) = 24.5$, $P < 0.00002$), *Hipposcarus longiceps* (12.0 ± 1.7 inside, 6.7 ± 1.2 outside; $F(1,34) = 8.0$, $P < 0.01$), and other assorted species (*Scarus bleekeri, Scarus oviceps, Scarus globiceps, Scarus quoyi*, and *Scarus schlegeli*) (14.8 ± 2.0 inside, 5.9 ± 1.1 outside; $F(1,34) = 16.1$, $P < 0.0005$) (Fig. 4).

Socioeconomic and nutritional results

Nusa Hope, which has a high MPA effectiveness ranking, was significantly different than villages with lower ratings in MPA effectiveness in terms of MPA governance and food security (Table 2). For MPA governance awareness and conformity, the two higher-ranking villages in MPA effectiveness (less poaching and good enforcement) (Nusa Hope and neighboring Kozou) viewed their MPAs and surrounding areas as effectively guarded and reported that poaching by members and neighbors was restricted, i.e., the higher the enforcement, the higher the perception of MPA effectiveness. In particular, Nusa Hope differed significantly from villages with lower MPA effectiveness ranking, whose members viewed their MPAs and neighboring reefs as either poorly or not sufficiently guarded (Table 2). In terms of food security, a majority of people in all villages recognized that they had enough food to eat and that seafood was their main source of protein. However, Nusa Hope respondents (and other villages with effective or semi-effective MPAs) viewed their MPAs as having increased the amount of fish for consumption and market, whereas in the village with the most ineffective MPA (Dunde) only half of the informants did (Table 2). The data suggests a strong link between perceived quality MPA governance and quality dietary outcomes.

For the nutritional status of Nusa Hope and other MPA and non-MPA villages, the general sufficiency of energy and protein intakes, energy requirements at the moderate activity level (physical activity level = 1.78; FAO/WHO/UNU 2001), and safe levels of protein intake (0.75 g kg^{-1} body weight; FAO/WHO/UNU 1985) was calculated by referring to average body weights. The average body weights of adults aged 30–60 years were 66.5 kg for males and 59.9 kg for females, and these results showed no significant inter-village differences. As the required amounts of energy intake per day for males and females are 12.0 and 9.8 MJ, respectively (FAO/WHO/UNU 2001), a sufficient amount of energy was consumed by both sexes at Nusa Hope (12.8 MJ for males and 12.1 MJ for females, see Table 3), for males in Kozou (12.4 MJ), and for females in

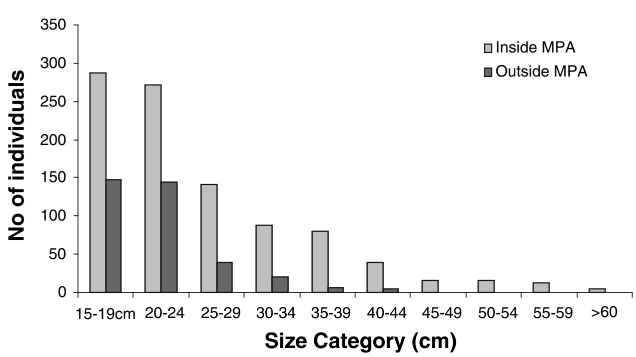

Fig. 3 Size-frequency distribution for excavating and scraping parrotfishes inside/outside of the Nusa Hope marine protected area

Table 2 Peoples perceptions of MPA governance, MPA effectiveness, and food security in Roviana hamlets (*T* True, *F* False, *U* Unsure; Percent of total listed with and without *Unsure*)

Question	Nusa Hope ($n = 33$)			Kozou ($n = 9$)			Baraulu ($n = 19$)			Olive ($n = 22$)			Dunde ($n = 23$)			Significantly different than Nusa Hope[a]
	T	F	U	T	F	U	T	F	U	T	F	U	T	F	U	
MPA effectiveness rank[b]	2			1			3			4			5			
MPA governance																
Is there effective control of resources within the MPA?	32	0	1	9	0	0	14	4	1	13	5	4	8	6	9	B, O < NH
	(97%)	(0%)	(3%)	(100%)	(0%)	(0%)	(74%)	(21%)	(5%)	(59%)	(23%)	(18%)	(35%)	(26%)	(39%)	
	(100%)	(0%)		(100%)	(0%)		(78%)	(22%)		(72%)	(28%)		(57%)	(43%)		
Is there effective control of resources outside the MPA?	24	4	5	9	0	0	9	10	0	14	4	4	5	11	7	B, D < NH
	(73%)	(12%)	(15%)	(100%)	(0%)	(0%)	(47%)	(53%)	(0%)	(67%)	(18%)	(18%)	(22%)	(48%)	(30%)	
	(86%)	(14%)		(100%)	(0%)		(47%)	(53%)		(78%)	(22%)		(31%)	(69%)		
Is there poaching in the MPA by people in your village?	10	20	3	1	8	0	13	5	1	8	5	9	11	3	9	NH < B, D
	(30%)	(61%)	(9%)	(11%)	(89%)	(0%)	(68%)	(27%)	(5%)	(36%)	(23%)	(41%)	(48%)	(13%)	(39%)	
	(33%)	(67%)		(11%)	(89%)		(72%)	(28%)		(62%)	(38%)		(79%)	(21%)		
Do people from other villages fish in your MPA?	9	20	4	1	8	0	4	11	3	7	10	5	12	4	7	NH < D
	(27%)	(61%)	(12%)	(11%)	(89%)	(0%)	(21%)	(58%)	(16%)	(32%)	(45%)	(23%)	(52%)	(17%)	(30%)	
	(31%)	(69%)		(11%)	(89%)		(27%)	(73%)		(42%)	(58%)		(75%)	(25%)		
MPA effectiveness and environmental change																
Are there more fish within the MPA now than before?	32	0	1	8	0	1	17	0	2	16	0	6	11	2	10	No significant differences
	(97%)	(0%)	(3%)	(89%)	(0%)	(11%)	(89%)	(0%)	(11%)	(73%)	(0%)	(27%)	(48%)	(9%)	(43%)	
	(100%)	(0%)		(100%)	(0%)		(100%)	(0%)		(100%)	(0%)		(85%)	(15%)		
Are there more fish outside the MPA now than before?	28	3	2	8	0	1	15	3	1	14	2	6	12	5	6	No significant differences
	(85%)	(0%)	(6%)	(89%)	(0%)	(11%)	(79%)	(16%)	(5%)	(64%)	(9%)	(27%)	(52%)	(22%)	(26%)	
	(88%)	(12%)		(100%)	(0%)		(83%)	(27%)		(88%)	(12%)		(71%)	(29%)		
Food security and resource availability																
Does your household has enough food to eat every day?	32	1	0	8	1	0	18	1	0	17	3	2	22	1	0	No significant differences
	(97%)	(3%)	(0%)	(89%)	(11%)	(0%)	(95%)	(5%)	(0%)	(77%)	(14%)	(9%)	(96%)	(4%)	(0%)	
	(97%)	(3%)		(89%)	(11%)		(100%)	(0%)		(85%)	(15%)		(96%)	(4%)		
Does your household rely mostly on fish as a source of protein?	30	3	0	6	3	0	19	0	0	14	8	0	21	2	(0%)	O < NH
	(91%)	(9%)	(0%)	(67%)	(33%)	(0%)	(100%)	(0%)	(0%)	(64%)	(36%)	(0%)	(91%)	0		
	(91%)	(9%)		(67%)	(33%)		(100%)	(0%)		(64%)	(36%)		(91%)	(9%)	(9%)	
Has the MPA increased the amount of fish you consume and sell?	31	1	1	8	0	1	18	0	1	16	5	1	12	6	5	D < NH
	(94%)	(3%)	(3%)	(89%)	(0%)	(11%)	(95%)	(0%)	(5%)	(73%)	(23%)	(4%)	(52%)	(26%)	(22%)	
	(100%)	(0%)		(100%)	(0%)		(97%)	(3%)		(76%)	(24%)		(67%)	(33%)		

[a] $P < 0.05$, Chi-square with Yates Correction for Continuity. Note that the true–false–unsure survey data were analyzed with unsure responses excluded, so only true and false answers were included

[b] These rankings are based on number of poaching incidents reported for each MPA by the local Resource Management Committee (see Aswani and Furusawa 2007 for further discussion)

Olive (10.5 MJ) and Dunde (10.0 MJ). Safe levels of daily protein intakes were 49.9 and 44.9 g for males and females, respectively (FAO/WHO/UNU 1985), and thus both sexes in all villages consumed a sufficient amount of protein (Table 3). However, there were significant differences in the amounts of energy and marine-derived protein consumed between Nusa Hope and villages with functioning MPAs, on the one hand, and those without or with poorly functioning ones, on the other.

For men and women, the energy and protein intakes were highest in Nusa Hope, which were significantly higher than in Nusa Banga, Olive, and Baraulu. These data suggest that energy and protein intakes were generally higher in villages with high MPA effectiveness scores and that they were lower in villages with no MPAs (Nusa Banga) or villages with lower MPA effectiveness rankings (e.g., Olive). One exception was Dunde, which, for different reasons (e.g., modernization), had a high intake of fat and protein. Note, however, that Dunde had a low protein/fat ratio (Table 3), indicating a comparatively poor diet, as inferred from fat consumption. Olive and Baraulu also had low protein/fat ratios. Finally, Nusa Hope had the highest intake of protein derived from marine resources for males and females (Fig. 5), followed by Kozou or Baraulu, and it was the lowest in Dunde, Nusa Banga, and Olive for both sexes. These findings suggest a strong link between quality MPA governance and quality dietary outcomes for both sexes, as well as relatively more fish consumed in Nusa Hope.

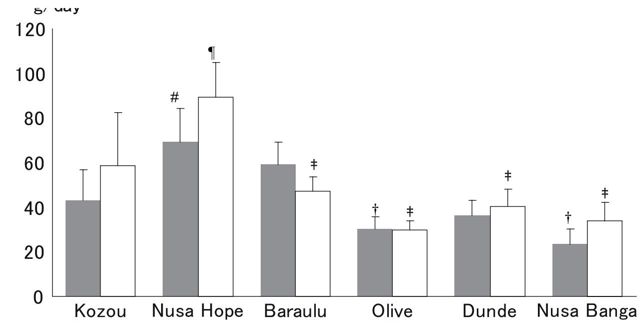

Fig. 5 Mean male (*gray*) and female (*white*) intakes of marine protein across five marine protected areas (*MPA*) and 1 non-MPA villages in Roviana. Villages were sorted in the order of MPA effectiveness ranking (*error bars* represent +1 SE). Note: Nusa Hope males (#) is significantly higher than Olive and Nusa Banga males (†) and that Nusa Hope females (¶) is significantly higher than all other villages (‡) except Kozou, at $P < 0.05$ (Tukey's multiple comparison test)

Discussion

Biological trends of the Nusa Hope MPA

The combined results from the algal tiles and the two fish surveys suggest a positive trend toward greater abundance of grazing fish, particularly parrotfish, within the Nusa Hope-Heloro MPA compared to the adjacent area which is open to local fishing pressures which target these species. The link between algae communities and herbivore

Table 3 Cross-sectional comparisons of energy (MJ) and major nutrient (g) intakes of adults (15 years and older) among MPA villages and a non-MPA village

MPA effectiveness rank	Nusa Hope	Kozou	Baraulu	Olive[a]	Dunde	Nusa Banga	$P < 0.05$[b]
	2	1	3	4	5	NA	
Male							
Energy	12.8 ± 0.9	12.4 ± 1.4	9.7 ± 0.6	11.4 ± 0.4	10.1 ± 0.6	8.7 ± 0.8	NH > O, B, NB
Protein	110.3 ± 16.4	77.7 ± 13.0	86.2 ± 9.9	63.1 ± 5.4	91.6 ± 7.9	62.5 ± 8.3	NH > O, NB
Fat	25.0 ± 2.7	26.4 ± 4.6	33.7 ± 4.3	25.5 ± 3.0	41.6 ± 3.8	19.7 ± 4.0	D > O, NH, NB
P/*F* ratio	4.4	2.9	2.6	2.5	2.2	3.2	
N	40	9	32	93	57	22	
Female							
Energy	12.13 ± 0.9	8.3 ± 1.1	8.9 ± 0.4	10.5 ± 0.4	10.0 ± 0.6	8.9 ± 1.0	NH > B, NB
Protein	128.0 ± 16.7	83.7 ± 23.3	76.0 ± 6.7	58.1 ± 4.2	96.5 ± 9.3	68.8 ± 10.6	NH > O, B, NB
Fat	35.7 ± 5.0	16.4 ± 3.6	31.2 ± 2.8	25.0 ± 2.8	42.8 ± 6.8	25.6 ± 14.5	NS
P/*F* ratio	3.6	5.1	2.4	2.3	2.25	2.7	
N	40	10	44	127	67	33	

Data reflect mean ± standard error of the mean

NS not statistically significant, *P/F ratio* protein divided by fat

[a] *N* shows person-days: each participant was interviewed 1–4 days

[b] Tukey's honest squared difference (*HSD*) for localizing differences in this multiple comparisons test

abundance has been well documented in other parts of the world (e.g., Mantyka and Bellwood 2007). Coral reef algal communities are primarily controlled by top-down (grazing disturbance) and bottom-up (nutrient stimulation) processes (McCook 1999; Smith et al. 2001). The balance between nutrients and grazing is essential in maintaining a healthy reef ecosystem. Numerous studies report that reductions in herbivore populations (e.g., due to fishing) cause an increase in algal biomass, which subsequently leads to (or which has been suggested to lead to) a decline in the health and condition of coral reefs (Stimson et al. 2001; Thacker et al. 2001). At Nusa Hope Village, parrotfish as well as other herbivorous fish species are targeted by fishermen outside the MPA with mass-harvesting techniques such as night diving, fish poisoning, netting, and fish-drives (Aswani and Hamilton 2004), increasing the susceptibility of these reefs to algal overgrowth.

The study of algal communities is a first step toward developing a spatially and temporally integrated measure of herbivorous fish at experiment and control sites in this region. Low biomass communities of grazing-resistant algae were present on tiles within the MPA. The foliose and crustose coralline algae that dominated tiles in the MPA site are typical of a healthy reef system with high grazing rates (Steneck and Dethier 1994). In contrast, outside the MPA the algal biomass on tiles was 400% higher than inside the MPA and consisted primarily of cyanobacteria and brown filamentous algae, which are typical of a stressed reef suffering from an imbalance between nutrient availability and grazing pressure (Steneck and Dethier 1994). The higher biomass of algae on tiles outside the MPA is congruent with results from the benthic survey showing a significantly higher cover of algae on the reef outside of the MPA. Changes in algae type and quantity outside the MPA appear to be primarily due to the reduced grazing pressure at the site, as other factors such as water quality and reef structure are similar between both areas. These results complement other studies, which have identified a link between herbivore abundance and algal community structure and biomass (e.g., McCook 1999; Smith et al. 2001; Mumby et al. 2006, 2007).

The fish surveys indicate that herbivorous parrotfish were more abundant and were also larger in size inside the MPA. Given that scraping parrotfishes may be more closely tied to their food source this may be an indication of suitable or preferable algal growth inside of the reserve, as indicated by the algal tile study. The justification for higher numbers of excavating scarids within the reserve is less conclusive given that larger parrotfishes have been known to travel longer distances (Hamilton 2004) and may not necessarily be ecologically tied to a specific region. However, during the monitoring survey apparent spawning aggregation of *C. microrhinos* localized within the reserve boundary were observed for a period of ~3 weeks, suggesting the maintenance of key ecosystem processes within the MPA. In sum, parrotfish are of crucial functional importance because they are grazers and bio-eroders in the reef ecosystem and their abundance can be used as an indication of coral reef health status (Hughes et al. 2006). As parrotfish abundance increases as a result of the MPA treatment, so does grazing activity, which reduces macroalgae and enhances coral reef growth (Mumby et al. 2006, 2007).

In spite of these encouraging results, it is impossible to statistically conclude that the observed differences between the experiment and neighboring control sites are due to the management treatment because of a lack of pre-MPA baseline data (Botsford et al. 2003; Edgar et al. 2004) and replication of this study in multiple-MPA and non-MPA sites across the lagoons. Neither can it be claimed that there is a spillover effect occurring, as the monitoring focused on measuring the effects of reserves on fish within MPA boundaries. Also note that only life history and larval and adult dispersal flows data for one species in the region were collected (bumphead parrotfish) prior to MPA implementation (Aswani and Hamilton 2004). Indeed, additional research of other species would have allowed making fully scientifically informed decisions when designing the Nusa Hope MPA. Instead this project has utilized adaptive management by assisting communities to make management decisions based on the best available marine science and traditional ecological knowledge. As the replication and body of scientific knowledge expands management regimes will adapt accordingly.

Socioeconomic and nutritional trends of the Nusa Hope MPA

Results of the socioeconomic and nutritional study indicate that respondents in the two highest-ranking villages, in terms of MPA effectiveness (i.e., less poaching and good enforcement–Nusa Hope and neighboring Kozou), had the most positive views with respect to ocean governance and food availability. Results also showed that Nusa Hope members (as well as those villages with effective MPAs) had higher energy and protein intakes (particularly marine-derived protein) than those that did not have MPAs (Nusa Banga) or had less effective ones. In the case of Dunde, higher intake of protein and fat can be attributed to modernization processes and to the availability of cash to purchase fresh fish, rather than to effective marine governance and management (see Aswani 2005 and Aswani and Furusawa 2007). Yet, note that Dunde had the lowest protein/fat ratio (2.2), or about half the average for Nusa Hope and Kozou combined (4.0). This indicates far greater dietary fish in the two villages with the strongest MPA governance (Nusa Hope and Kozou). Concurrently, the poorest dietary protein/fat ratio was found in the village with the worst MPA governance (Dunde). The results suggest that good MPA governance combined with good customary management, as in the Nusa Hope case, can affect the diet of villagers positively. On the other hand, results hint at the dangers of poor MPA governance and poor customary management, as in the case of Dunde. In short, Dunde cannot translate customary governance into effective MPA management because of the erosion of indigenous social and political institutions caused by tenurial conflicts with neighbors and modernization (see Aswani 2005).

We cannot claim categorically that there is a linear relationship between the Nusa Hope MPA and improved food security and health, as there are other independent socioeconomic and ecological variables that could be affecting changes in people's livelihoods. That is, all the potential independent variables related to the dependent variable, particularly the state of marine resources prior to the implementation of the MPA, could not be controlled for. Nonetheless, given the trends shown by the biological assessment concurrently with the socioeconomic and nutritional data, it is not unreasonable to suggest that the Nusa Hope MPA, which exists under good governance and customary management, is having a positive effect on people's overall intake of marine-derived protein and the quality of life.

Customary management practices as precautionary and adaptive management

The Nusa Hope-Heloro MPA was designed using local knowledge and sea tenure (customary management practices) as elements of a precautionary and adaptive management approach. Local practices can be similar to precautionary management because they offer empirical knowledge and governance institutions, which can complement (or be used in lieu of) scientific data and statutory law and can be used to design and enforce conservation programs. Further, local practices are similar to adaptive management because inclusive actors can be resilient in the face of ecological uncertainty and because they have enough feedback learning mechanisms to allow for institutional and behavioral change (Berkes et al. 2000).

Indeed, indigenous ecological knowledge is not intended for resource management or conservation purposes, and local fishers often do not understand the biological consequences of overfishing (Sadovy 2005). In addition, sea tenure is not always effective at controlling interloping and resource over-exploitation by exclusive stakeholders, as illustrated by the Dunde case. Nonetheless, indigenous informants can recognize local ecological processes, including habitat structure (habitat delineation), species composition and distribution, and spatio-temporal biological events (spawning aggregations). This information, in turn, can be used to identify sites that incorporate the ecological processes that support biodiversity, including the presence of exploitable species, vulnerable life stages, and inter-connectivity among habitats (Roberts et al. 2003). Secure sea tenure governance—i.e., circumscribed territorial boundaries, centralized traditional political authority, and regionally recognized and uncontested sea entitlements—can offer, on the other hand, an institutional context that is pre-adapted to resource management schemes such as MPAs.

In the Nusa Hope case, the strong emphasis on customary management practices when designing the MPA has had a number of early benefits, although the long-term outcomes of this strategy are still uncertain. First, at present this effort has produced a conservation area that represents an indigenously cognized and delineated natural and social seascape (Aswani and Lauer 2006b). Community members have been better able to understand the biological value and the use restrictions of the MPA because this builds upon local cultural practices with which the community members are familiar—a situation that facilitates MPA rule enforcement and monitoring.

Second, using local knowledge and practices has reinvigorated traditional authority over peoples' marine resources and has generated innovative governance institutions, which are being articulated with customary and statutory law. For instance, Nusa Hope villagers have established an RMC that is constituted by different village constituencies including chiefs, church authorities, and women representatives. The Nusa Hope RMC not only supervises the conservation program but has also encouraged neighboring villages to establish their own management regimes. When a local group closes a reef, the benefits of their MPA are potentially reaped by neighboring groups because larvae produced in the closed site are expected to recruit in neighboring or distant reefs that often belong to other groups (who may not be bounded by the same management restrictions) (Foale and Manele 2004). However, by encouraging neighboring communities to design and establish management regimes modeled after their ecological knowledge and governance institutions (e.g., Kozou and Olive villages), Nusa Hope and the neighboring villages are sharing the costs (e.g., spatial relocation of effort) and benefits (e.g., possible spillover effects) of the MPAs more equitably.

Third, the inclusion of local knowledge and institutions has been a low-cost adaptable and flexible method for designing the Nusa Hope MPA. For instance, following the establishment of the MPA in 2002, the RMC realized that a spawning aggregation (as locally recognized) of various species of grouper (e.g., *Epinephelus polyphekadion*) had not been included in the original boundaries of the MPA. Following several meetings, the community rapidly extended the MPA to cover this aggregation. To compensate for the loss of additional fishing grounds, it created a buffer zone between Nusa Hope Island and the MPA to allow children to forage and fishermen to collect bait. Furthermore, the RMC extended the no-take MPA to cover an adjacent mangrove, which was declared an MPA with a spatio-temporal regime. The RMC determined that the opening and closing of this area should follow the ritual cycles of the village (e.g., opening the shell beds for a mortuary feast) rather than relying on biological data (e.g., spawning periodicity of various mollusk species) for determining the management strategy. This kind of adaptiveness and flexibility is seldom found in MPAs designed by science-driven programs implemented by national agencies, which tend to be more inflexible managerially and statutorily, and more expensive.

Finally, one of the biggest conservation values of the Nusa Hope MPA has been in building social capital. The participatory nature of the summarized MPA designation approach closely involved local stakeholders at all levels of the MPA designation process, thus familiarizing them with resource management and conservation principles, and thus building community good-will toward marine conservation. In addition, the MPA has served as a tool for environmental education. By witnessing positive environmental change (e.g., rapid change in the densities of benthic organisms such as bêche-de-mer), the Nusa Hope people have been encouraged to participate in keeping their MPA and adopt sustainable harvesting practices more generally. In sum, building upon customary management practices seems not only advantageous but also the most realistic way socio-culturally to implement precautionary and adaptive management regimes in this region.

The biological and social trends summarized in this paper are encouraging and suggest that the Nusa Hope-Heloro MPA has the potential to protect biodiversity and enhance fisheries in a socially acceptable manner. Additionally, it should be noted that anecdotal evidence and preliminary data of other MPAs in the Western Solomons (currently underway), suggest that communities with strong MPA and customary management are reaping beneficial biological and social outcomes. Indeed, results from a single area cannot be extrapolated to categorically say that customary management practices are a panacea for current environmental woes in the Pacific Islands. Nonetheless, empirical evidence from other regions (Cinner et al 2005; McClanahan et al. 2006) is increasingly pointing toward the necessity to create hybrid institutions, which combine customary management with western models of resource management. Management of coral reefs is a complex interaction of active management, ecological knowledge and institutions, and regular monitoring. The relative importance of each of these factors must be adapted to the social and ecological context in which they are applied. The Nusa Hope case study illustrates how employing straightforward ecological and social research techniques can supplement indigenous ecological knowledge regarding the benefits that are occurring as a result of the local decision to establish an MPA. For instance, the visual nature of the algal indicator has proved to be an effective means of transferring this ecological information to the community. This experience has shown that it is essential to incorporate local concerns, interests, and knowledge into a project's research design more genuinely, especially because scientific studies are increasingly being intended for biodiversity conservation. This paper does not suggest that customary management practices should be an absolute substitute for conventional scientific methods for designing MPAs. Rather, the idea is to combine Western and indigenous forms of knowledge and governance and to make sure those management regulations that include indigenous practices are sanctioned by the local people and ultimately designed to benefit local communities. In the process, the socioeconomic and cultural factors that lead to success or failure of customary management should also be evaluated carefully (Aswani 2005; Cinner and McClanahan 2006). Simply, when designing conservation programs, biological success will be difficult to achieve unless the socioeconomic and cultural precepts that are important to people are considered carefully.

In conclusion, finding alternative ways for designing MPAs is particularly pressing given the dearth of reliable quantitative scientific data on life history patterns of fish in tropical multi-species fisheries—knowledge that is essential for designing MPAs using the rigorous scientific biological principles advocated by many marine biologists. Given the current rate of marine resource degradation and biodiversity loss, however, it is incumbent upon researchers and conservation practitioners to apply customary management practices as precautionary and adaptive management in community-based conservation programs more systematically. This paper shows hybrid research approaches in tandem with participatory engagements with local peoples that can produce beneficial biological and social outcomes, and it suggests ideas by which future MPAs can be designed and monitored for the protection of coral reefs in Oceania.

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