Factors contributing to the effectivenss of marine protected areas in a traditional Fijian fishing ground, Kubulau District, Vanua Levu

Stacy D Jupiter, Daniel P Egli, Akuila Cakacaka,
Thomas Tui, Akanisi Caginitoba,
Ingrid QauqauWayne Moy, Waisea Naisilisili,
Sirilo Dulunaqio, Sunil Prasad

This study was supported by grants from the NOAA Coral Reef Conservation Program (NA07NOS46630035), the David and Lucile Packard Foundation (2007-31847) and the Gordon and Betty Moore Foundation (540.01).

This document to be cited as:
Jupiter SD, Egli DP, Cakacaka A, Tui T, Moy W, Naisilisili W, Dulunaqio S, Qauqau I, Prasad S (2010) Factors contributing to the effectiveness of marine protected areas in a traditional Fijian fishing ground, Kubulau District, Vanua Levu. Wildlife Conservation Society-Fiji Technical Report no. 08/10. Suva, Fiji, 36 pp.

Executive Summary

The main objective of this study was to identify factors contributing the current management effectiveness and future prospects at three marine protected areas (MPAs) within a traditional Fijian fishing ground (qoliqoli) of Kubulau District, Vanua Levu. In 2005, an MPA network was established within Kubulau qoliqoli that includes 17 village-managed, periodic closures (*tabu*) and three district-wide, permanent, no-take MPAs (Nasue, Namuri, Namena), though Namena had been informally protected since the mid-1990s. Management of the district MPAs in governed by the Kubulau Resource Management Committee, made of up representatives from each of the ten villages in the district, though approval of all rules must be authorized by the hierarchy council of chiefs (*Bose Vanua*).

In 2008 and 2009, underwater visual census (UVC) surveys of fish and benthos were carried out at sites both inside and adjacent to the district-wide MPAs. Socioeconomic asssessments were performed in 2008 and refined in 2009 to specifically focus on differences between the three villages (Navatu, Kiobo and Nakorovou) whose traditional fishing areas (*kanakana*) were displaced by the district MPAs. We focused on physical (i.e. proximity to adjacent districts) and socioeconomic (i.e. access to markets) factors that would influence different levels of compliance with MPA rules.

Results for the Nasue MPA were equivocal. Though there was more total fish and primary fish biomass inside the MPA in 2008, there was significantly greater abundance of fish outside the MPA (particularly scarids) in 2009. Prior analyses of benthic habitat composition suggest that benthic characteristics are not driving broad differences in reef fish assemblages between Nasue MPA and the adjacent Drokana reef. Instead, both external and internal poaching is likely to play a major role. Proximity to Wailevu district was one of the major factors which contributed significantly to reef fish biomass structure at the site level. The Nasue MPA shares a boundary with the neighbouring Wailevu qoliqoli and Wailevu fishers have been repeatedly caught fishing in the MPA, a problem compounded by the fact that the MPA is not visible from any of the villages in Kubulau. Internal poaching is also a problem, as indicated by the catch locations inside the Nasue MPA reported by Kubulau fishers.

The Namuri MPA appeared to be effectively protecting marine resources in 2008, with significantly higher total fish and primary food fish biomass inside compared with adjacent fished. The opposite pattern was observed from 2009 surveys, provoking some concern that when Kubulau fishers were made aware of the exceptionally high biomass inside Namuri MPA during a management planning workshop in February 2009, they may have proceeded to covertly fish the area. Indeed, the monitoring sites within Namuri all had exceptionally low consumption-weighted distance-to-village scores (ω), indicating that they are near numerous villages whose residents frequently consume fish. Thus, in an attempt to use the monitoring data to foster discussions related to management implementation, its public presentation may have had detrimental consequences for the fishery.

The Namena MPA demonstrated the strongest results in terms of increasing food fish biomass and abundance. The most likely reasons for its success are: strong commitment to enforcement; natural geomorphic features which promote recovery; longevity of

protection; and distance from villages. The longevity and permanence of the closure has enabled recovery of large-bodied piscivores such as serranids and lutjanids. However, the future success of the Namena MPA is in jeopardy due to present conflicts that have emerged between the management authority and members of one of Navatu's two clans who have lost access to their traditional fishing grounds due to the establishment of the MPA. Observational evidence and socioeconomic surveys have indicated that loss of respect for traditional authority and access to markets may be primary drivers of repeated and public incidents of illegal fishing in the Namena. One important lesson learned from these experiences is the importance of ensuring that distribution of costs and benefits is considered early in the management planning process in order to reduce potential conflict. In addition, mapping tenure boundaries, including overlapping and competing claims, may help to avoid management conflicts.

Table of Contents

Introduction

Recent and historical overfishing, in conjunction with rapid land cover change, has led to a collapse of coastal fisheries, biodiversity and supporting ecosystem services around the globe (Jackson et al. 2001; Pauly et al. 2005; Worm et al. 2006). As many as 55% of island nations may be over-exploiting coral reef fisheries stocks (Newton et al. 2007). Increases in fishing pressure may result in declines of biomass of targeted, largely carnivorous species; declines in species richness; and potential shifts in benthic habitat condition as grazing herbivores and predators of crown-of-thorns starfish (*Acanthaster planci*) are removed (Jennings and Polunin 1996, 1997; Pet Soede et al. 2001; Dulvy et al. 2004; Mumby et al. 2007). There is great concern to manage inshore fisheries populations both to preserve food security and because ecosystem shifts can occur even under modest levels of artisanal fishing (Jennings and Polunin 1996; McClanahan and Arthur 2001; Dulvy et al. 2004; Campbell and Pardede 2006)

In the Fiji Islands, although fisheries data are often uncertain, there has been a high level of pressure on coastal fisheries in the past few decades (Teh et al. 2009). Of the 400 traditionally managed fishing grounds (*qoliqoli*), at least 70 are considered over-exploited while a further 250 are fully developed (Hand et al. 2005). Rising prices for fish and fishery products have contributed to declines in artisanal catches from 1996 to 2002 (Raj and Evans 2004). Meanwhile percentages of catches sold are increasing: catch per unit effort (CPUE) from recent surveys of village catch from locations across Fiji suggest that >70% of catch is being sold (IAS 2009). Over a century of beche-de-mer harvesting has resulted in notable depletion of stocks on reefs in southern Viti Levu and Bua Province of Vanua Levu (Teh et al. 2009), with unknown consequences on reef ecosystems.

In recognition of declines in coastal fisheries and marine biodiversity, there has been a global movement to increase the amount of area in the oceans under some form of management (IUCN 2009). The benefits of marine protected areas (MPAs) are recognized to include increases in abundance and biomass of targeted species (Trexler and Travis 2000; Russ 2002; Halpern 2003; Russ et al. 2004; Lester et al. 2009), which may lead to increased recruitment (Tetreault and Ambrose 2007; Evans et al. 2008) and migration of adults into neighbouring areas ("spillover"; Russ and Alcala 1996a). These benefits, however, rely strongly on selection of appropriate size and spacing of MPAs within a network. Furthermore, most positive and lasting effects have been observed in permanent no-take areas compared with partial protection (Denny et al. 2004) or periodically harvested areas (Alcala et al. 2005).

The composition of fish species assemblages within an MPA may additionally be affected by benthic habitat structure and complexity. On a broad-scale, different habitat zones (e.g. lagoons, backreef, forereef, outer slope) can support naturally different fish communities with different size and trophic structures, which may be due to habitat utilization preferences, degree of disturbance and/or ontogenetic shifts (Friedlander et al. 2003; Adams et al. 2006). Sites with high reef complexity and low disturbance frequency have been shown to support high biomass of reef fish (Friedlander and Parrish 1998). Disturbance (i.e. storms, mortality following coral bleaching) that alters reef complexity may therefore have strong negative effects on reef fish assemblages (Graham et al. 2006; Graham et al.

2007). On Fijian reefs, decline in abundance of small corallivores and other damselfish have been associated with decreases in branching coral and coral-associated habitat complexity: these habitat-associated reductions in availability of prey can be a more important driver of piscivore abundance than fishing pressure (Wilson et al. 2008). Thus, information on differences in benthic habitat is paramount when evaluating reef fish responses to management measures (i.e. protection). Inclusion of these highly complex habitats in MPA network design should also improve reef resilience to disturbance (McLeod et al. 2009).

Reef fish recovery within MPAs is additionally reliant on fisher compliance with management rules. Compliance with rules and regulations for MPAs is highly dependent on the source of the rules, the respect for the decision-making authorities, and the likelihood and penalties for offenses. In Fiji, as elsewhere in the tropical Western Pacific, MPAs exist within a dual system of national legislative frameworks and local customary management rules (Care and Zorn 2001; Scaglion 2003; NZLC 2006). While these dual systems are sometimes complementary and promote sustainable fisheries management, they are just as often in conflict. This has fostered a high level of non-compliance and, in some cases, has resulted in exploitation of Fiji's inshore fisheries (IAS 2009), even within protected areas.

The main objective of this study was to identify factors contributing the current management effectiveness and future prospects at three MPAs within Kubulau District, Vanua Levu. Both biophysical and socioeconomic variables were assessed to identify natural and human features of the system that have affected the performance of the Namena, Namuri and Nasue district-wide, no-take MPAs to promote reef fish recovery.

Methods

Study region and management context

The Kubulau traditional fisheries management area (*qoliqoli*) of Vanua Levu, Fiji, represents a globally significant area in terms of marine biodiversity (WWF 2004). The southerly facing Kubulau qoliqoli includes a significant portion of the Vatu-i-Ra passage, barrier reef and lagoon (Figure 1). Kubulau District, located in Bua Province, has a population of approximately 1,000 spread between ten villages, seven of which are located on the coast. The area of Kubulau's qoliqoli is 260 km^2 and its MPA network, established in 2005, comprises 17 community-managed MPAs (*tabu*) sites and 3 district-wide no-take MPAs, totaling approximately 80 km^2 (~30% of the qoliqoli; Figure 2, Table 1). Households in Kubulau are highly dependent on fishing and farming to meet their subsistence needs, and thus have differential dependency on fishing, farming and copra harvesting for cash income (WCS, unpublished data).

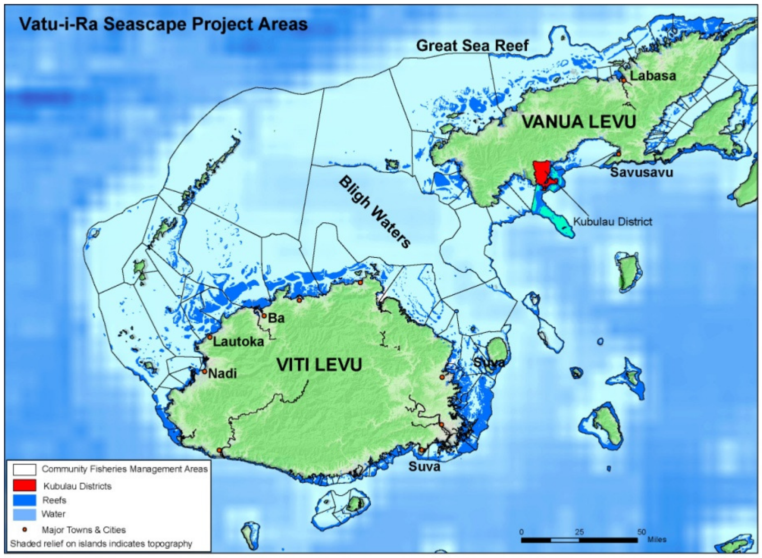


Figure 1. Study locations of Kubulau on the island of Vanua Levu located within the main Fiji islands. Land area of Kubulau District is indicated in red; Kubulau qoliqoli is indicated in aquamarine.

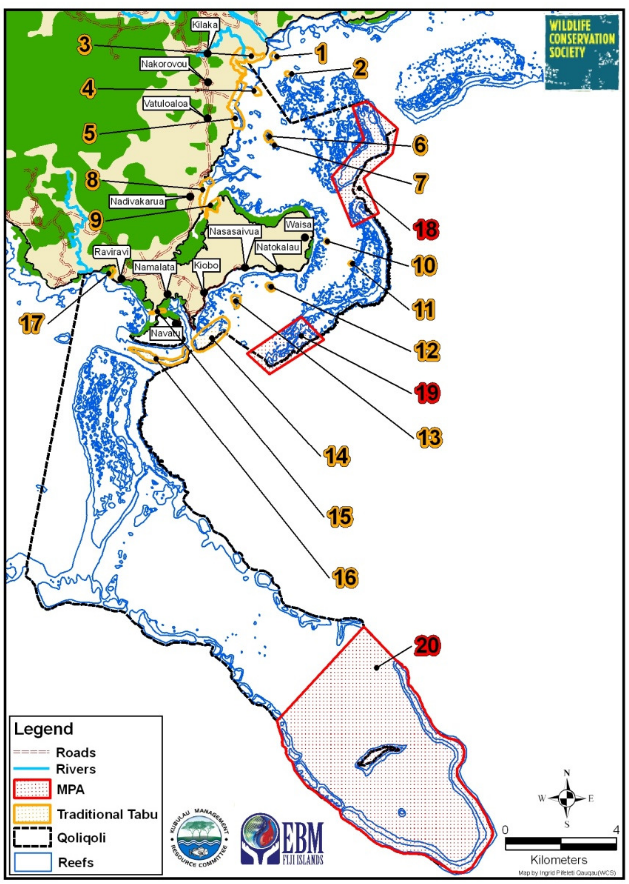


Table 1. List of marine protected areas and sizes (km^2) in Kubulau qoliqoli as of July 2009.

MPA	Size (km^2)
1. Yamotu ni Ogo*	0.09
2. Bovici*	0.04
3. Bagata	0.91
4. Yamotu ni Kake	0.11
5. Rewa Bota	0.86
6.Yamotu Lase	0.13
7. Cakau Vutia	0.03
8. Vatumakaua	0.40
9. Toba Tabu	0.27
10. Nukuvarasa	0.04
11. Yamotu ni Walu	0.04
12. Cakau Vusoni	0.11
13. Cakau Lekaleka	0.20
14. Naitaga	1.54
15. Buiyayamo	0.09
16. Nakali	0.77
17. Nasoga	0.08
18. Nasue	8.14
19. Namuri	4.25
20. Namena	60.61
TOTAL	**78.70**

Figure 2. Location of village-managed traditional tabu areas (orange-highlighted numbers and outlines) and district-managed MPAs (red-highlighted numbers and shading) within Kubulau qoliqoli.

Traditional and hierarchical community-level governance systems have regulated natural resource use and management in the Fiji for centuries (Veitayaki 1997). While the state maintains ownership of qoliqolis throughout Fiji, the *Fisheries Act* explicitly recognizes traditional fishing rights by customary land owners (Clarke and Jupiter in press). The Kubulau Resource Management Committee was established in 2005, made up of representatives from each village whose management decisions require authorization from the high council of chiefs (*Bose Vanua*) in each region. The KRMC makes broad decisions over regulations for the qoliqoli (including the district MPAs), while village chiefs retain the rights to determine gear restrictions, temporary closures and other local regulations in individual village tabu areas (Clarke and Jupiter in press). In 2009, the KRMC and its conservation partners developed an integrated 'ridge-to-reef' management plan for Kubulau that places community management rules alongside national legislation and policy (WCS 2009). The management plan was completed in July 2009 and has been endorsed by the *Bose Vanua*.

UVC surveys of fish and benthos

Surveys of fish and benthos were carried out in Kubulau qoliqoli in 2008 (Program I monitoring) and 2009 (Program II monitoring), with slightly differing methods detailed below. Appendix 1 contains maps of all survey locations.

Fish surveys

Kubulau 2008: Underwater visual census (UVC) was carried out at within the qoliqoli between April and May 2008 to measure fish abundance and size of the following families: Acanthuridae, Balistidae, Carangidae, Carcharhinidae, Chaetodontidae, Ephippidae, Haemulidae, Kyphosidae, Labridae, Lethirinidae, Lutjanidae, Mullidae, Nemipteridae, Pomacanthidae, Scaridae, Scombridae, Serranidae (groupers only), Siganidae, Sphraenidae, and Zanclidae, plus *Chanos chanos* (Chanidae) as it is a targeted food fish. Measurements of fish size (total length) and abundance were recorded along 5 m x 50 m belt transects at deep (12 -15 m) and shallow depths (5 m – 8 m) at forereef sites, and at reef tops (0.5 – 2 m) and shallow depths at backreef sites.

Kubulau 2009: Exploratory data analysis in late 2008 revealed high variability in fish abundance and biomass recorded from backreef sites which made it difficult to detect differences related to management effects from data collected, even when data were pooled across exposure gradients (forereef, backreef). A power analysis indicated that changing the sampling design to increased sample size of *forereef-only* sites would improve the ability to detect differences related to management (Appendix 2). As a consequence only data from forereef sites from datasets prior to 2009 were utilised for all analyses reported herein. In April-May 2009, 33 sites were surveyed from deep and shallow depths on forereefs only in closed and open areas of Kubulau qoliqoli using methods described above.

Data cleaning and biomass calculation

Observer bias was investigated by assessing the mean number of fish species counted per transect, resulting in the exclusion of data from one observer from the Kubulau 2008 surveys (4/391 transects) who routinely counted significantly fewer species than other observers. Biomass was calculated from size class estimates of length (L) and existing published values from Fishbase (Froese and Pauly 2009) used in the standard length-weight (L-W) expression $W = aL^b$, with *a* and *b* parameter values preferentially selected from sites closest to Fiji (e.g. New Caledonia). If no L-W parameters were available for the species, the factors for the species with the most similar morphology in the same genus was used (Jennings and Polunin 1996). If a suitable similar species could not be determined, averages for the genera were used. As many of the L-W conversions required fork length (FL), a length-length (L-L) conversion factor was obtained from Fishbase where necessary to convert from total length (TL) recorded during the surveys to FL before biomass estimation. Because the L-W formula resulted in some grossly overestimated weights for fishes that substantially change morphology as they age, maximum weights were used for certain species when these fish were sighted above threshold sizes (Table 2).

Table 2. Maximum published weights from Fishbase applied to listed species sighted above the indicated threshold size.

Species	Threshold size (cm)	Max published weight (kg)
Trianedon obesus	180	34
Carcharhinus melanopterus	75	13.6
Carcharhinus amblyrhynchos	150	33.7
Chanos chanos	80	14

Benthic substrate composition

Benthic substrate cover was recorded at 0.5 m interval point intercepts along a 50 m transects as described by English et al. (1997). Life form classes were combined into 7 functional strata: unconsolidated substrate (US: rubble, sand, silt); reef matrix (RM: dead coral, reef pavement, crustose coralline algae, coralline algae); macroalgae (MA: all fleshy macroalgae > 2 cm, including cyanobacteria); live hard coral (LC: including *Millepora* and *Tubipora*); other soft substrate (OT: including soft corals, sponges, ascidians, anemones); turf algae (TA: ≤ 2 cm height on reef pavement)p; and upright coralline algae (UC: e.g. *Halimeda* spp). Live hard coral was identified to the genus level. In April-May 2009 only, each 0.25 m^2 surrounding the point was also given a complexity score (1 = minimal relief; 2 = some vertical relief (e.g. boulder corals); 3 = high vertical relief (e.g. branching corals, reef crevices)).

Statistical analyses

For the Kubulau 2008-2009 data, non-parametric Mann-Whitney U tests and parametric t-tests (where appropriate) were used to assess differences in total fish, primary targeted fish, secondary target fish and non-target fish forereef abundance and biomass inside and adjacent to protected areas within the qoliqoli. All tests were performed with Statistica version 7.0 software. To assess potential differences in benthic structure, Analsyis of Similarity (ANOSIM) was performed on a similarity matrix calculated with Euclidean distances between arcsine squareroot transformed mean percent benthic strata cover for each site, plus mean complexity and standard deviation of complexity for each site. One way analysis was performed separately with site and reef as factors in Primer-e version 6 software. ANOSIM generates a value of R which is scaled to lie between -1 and +1 with zero values representing the null hypothesis: R-values > 0.75 are considered well-separated; R >

0.5 are considered overlapping, but clearly different; and $R < 0.25$ are barely separable (Clarke and Warwick 2001).

Additionally, for the Kubulau 2009 data, log10 Modified Gower similarity matrices were calculated from mean fish biomass by species per site and used to ordinate data in multidimensional scaling (MDS) plots in PRIMER-e software. Vectors display trajectories of correlations (>0.35) with benthic habitat variables (7 strata plus mean complexity and standard deviation of complexity) and with potential correlates of fishing pressure and land-based threats (distance from land, distance from runoff, proximity to adjacent districts of Wailevu, proximity to adjacent district of Wainunu, visibility from villages, and distance from villages weighted by fish consumption (ω)). Distance from land was calculated as the perpendicular distance (km) from closest mainland source (including Navatu Island and excluding Namenalala Island). Distance from runoff was calculated as the distance (km) as water would likely flow through the reef network and lagoon to each site from the mouth of the Yanawai River. The proximities to Wailevu and Wainunu were calculated as the distance (km) from each site to the closest point on either qoliqoli boundary through boat passages using a minimum number of turn points. Distances from village were measured as the perpendicular distances (km) from each village to the site: this was weighted based on the frequency of fish consumption in each village as assessed from 2008 household surveys where respondents were asked on how many days of the previous week they consumed caught fin fish, based on the formula:

$$\omega = \frac{\sum_{i}^{N}(d_i * 1/c_i)}{N}$$

where c is the mean number of days per week fish was consumed in the *i*th village, d is the perpendicular distance from the *i*th village to the site, and N is the total number of villages (N = 9 as there was no fish consumption data available for Nasasaivua). All distances were measured in ArcView 3.2a software. Visibility was given a weighted, ranked score as to whether fishers could be spotted from land: 1 = not visible; 6 = can be seen from 1 location or from people walking along coastal fringe; 11 = can be seen from 2 locations; 16 = can be seen from >2 locations.

Socioeconomic surveys

Of the ten villages in Kubulau, we focused our socioeconomic asssessment specifically on differences between the three villages (Navatu, Kiobo and Nakorovou) to gain information in order to evaluate how differences in socioeconomic factors may have influenced differences in biological effectiveness of the three district-wide, no-take MPAs of Kubulau (Figure 2). Each of the district MPAs (Namena, Namuri, Nasue) is located within the traditional fishing areas (*kanakana*) of these villages. All of these MPAs are governed by the KRMC. Meanwhile, each district MPA is subject to different levels of compliance due to various factors, both physical (i.e. proximity to adjacent districts) and socioeconomic (i.e. access to markets). Responses were additionally compared with those from Natokalau village, which does not have traditional fishing areas in any of the three district MPAs, but has been noted to have a high level of community organization (S Jupiter, pers. obs.).

We surveyed residents of Kubulau District in September 2009 in order to determine whether there are specific socioeconomic factors which influence the level of non-compliance with management rules in Kubulau. To ensure minimal language barriers and appropriate cultural context, the data were collected by local project officers. We conducted household surveys and semi-structured interviews in communities. A total of 45 household surveys in 4 villages (6-16 in each community) were collected. The household sampling was conducted by staff from the Wildlife Conservation Society-Fiji and trained community representatives and was conducted in Fijian.

To gauge differences in levels of compliance with management rules, we first asked targeted questions to gauge the levels of awareness of management rules specified in the Kubulau 'ridge-to-reef' plan (Table 3). We then directly asked heads of households to what extent they comply with the management rules. We additionally indirectly assessed compliance by: (1) recording the location of catch landed in villages within Kubulau (as per Cakacaka et al. 2010); and (2) asking about preferred fishing gear types before and after the establishment of Kubulau's MPAs to assess behavioural change in response to customary management. Responses were classified as: "illegal/destructive" (fish poison, fine gill nets, spearguns with SCUBA); "requires management" (larger mesh gillnets, spearguns, Hawaiian sling (trigger-less spears)); and "minimally destructive" (hand nets, hand spear, hook and line). To determine the extent to which disapproval with customary management rules may be influencing non-compliance, we asked: (1) whether rules should be made more or less strict; and (2) whether heads of households agree with decisions by the *Bose Vanua* and the KRMC. We also asked about relative levels of participation since management has been initiated and whether heads of households perceive that their views are being represented. Lastly, to evaluate differences in market access and relative dependency on fishing for income, the proportions of catch consumed, given away and sold were compared across villages for approximately weekly catch landing records collected between May 2008 and June 2009 using methods described in Cakacaka et al. (2010).

Table 3. Questions asked to heads of households in Navatu (n = 15), Kiobo (n = 6), Natokalau (n = 9), and Nakorovou (n = 14) villages to gauge awareness of management rules in Kubulau EBM plan. Scoring system to rank responses is shown at right.

Question	Scoring
How close to a stream bank can you clear vegetation to plant crops?	0 = wrong or don't know; 1 = correct
What needs to happen before commercial logging can begin on any native lands?	0 = wrong or don't know; 0.5 = consultation with stakeholder; 1 = consultation with stakeholder plus Environmental Impact Assessment
What types of nets are permitted to be used in an estuary?	0 = wrong / no response; 0.5 = hand net; 1 = hand net and wading net
When is there a ban on fishing for grouper	0 = wrong or don't know; 1 = August
What species are forbidden to harvest (either under Fijian law or as written in the Kubulau Draft Management Plan)?	0 = 0 correct; 0.333 = 1 species correct; 0.667 = 2-3 species correct; 1 = > 3 species
What types of fishing methods are prohibited within the qoliqoli?	0.2 points for each correct gear (1 = 5 gears)

Results

Biological surveys

2008 UVC surveys

Total reef fish biomass (kg/ha) and abundance (#/ha) was significantly greater on forereefs only inside the Namuri MPA with the highest mean fish abundance (8100 ± 910) recorded from any survey location from the survey (Figure 3a,b, Table 4a,b). Acanthurids and scarids contributed proportionally the most (31% and 37%, respectively) to the elevated abundance inside the MPA. There were no significant differences in biomass or abundance between the Namena MPA and adjacent control area, although the mean biomass within Namena was conderably higher than the means for all other survey locations. The Nasue MPA had significantly greater fish biomass inside.

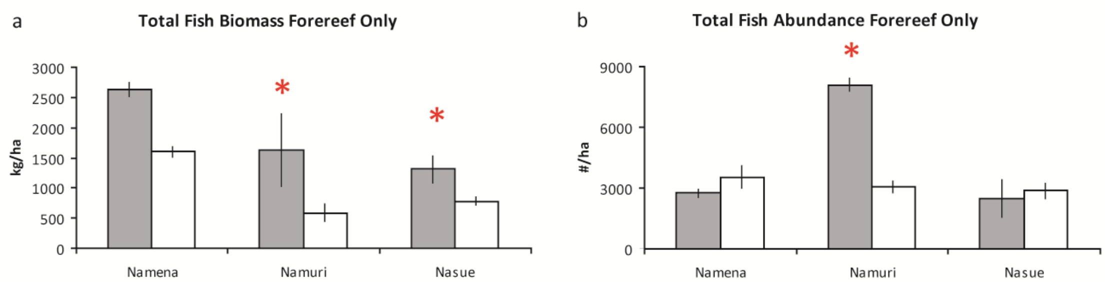


Figure 3. Mean (± standard error) (a) total fish biomass (kg/ha); and (b) total fish abundance (#/ha) from 2008 Kubulau fish survey data on forereefs inside MPAs (grey) and adjacent open fishing grounds (white). Red asterisks indicate significant differences at $p < 0.05$.

Table 4. Mean abundance and biomass (mean ± standard error) for closed and open forereef sites of MPAs and community tabu areas from Kubulau 2008 in: (a) total fish biomass (kg/ha); (b) total fish abundance (#/ha); (c) primary target fish biomass (kg/ha); (d) primary target fish abundance (#/ha); (e) secondary target fish biomass (kg/ha); (f) secondary target fish abundance (#/ha); (g) non-target fish biomass (kg/ha); and (h) non-target fish abundance (#/ha). Z-adjusted values and p-values are reported from Mann-Whitney U tests. Significant p-values are indicated (green = greater in closed; red = greater in open).

Reef	Closed	SE	Open	SE	Z-adj	p-level
(a) Total reef fish biomass (kg/ha) on forereefs						
Namena	2633.82	601.25	1602.71	141.33	1.040	0.299
Namuri	1625.72	226.91	585.39	67.44	4.317	**<0.001**
Nasue	1309.59	211.43	780.67	129.35	2.357	**0.018**
(b) Total reef fish abundance (#/ha) on forereefs						
Namena	2746	303	3535	290	-1.841	0.066
Namuri	8100	910	3069	390	4.258	**<0.001**
Nasue	2480	240	2857	291	-0.733	0.464
(c) Primary target reef fish biomass (kg/ha) on forereefs						
Namena	1897.53	617.53	988.64	123.53	1.911	0.056
Namuri	459.29	172.95	148.75	33.47	2.557	**0.011**
Nasue	759.40	666.50	280.97	74.88	3.387	**<0.001**
(d) Primary target reef fish abundance (#/ha) on forereefs						
Namena	1108	171	842	86	0.816	0.414
Namuri	1010	147	347	80	3.750	**<0.001**
Nasue	654	102	396	56	1.934	0.053

(e) Secondary target reef fish biomass (kg/ha) on forereefs						
Namena	680.13	115.65	796.62	78.67	-1.461	0.144
Namuri	1060.57	114.91	402.70	50.29	4.317	<0.001
Nasue	473.48	105.21	460.59	99.54	-0.158	0.874
(f) Secondary target reef fish abundance (#/ha) on forereefs						
Namena	1374	227	2265	236	-2.938	0.003
Namuri	5954	737	2316	304	4.070	<0.001
Nasue	1422	166	1949	280	-1.159	0.246
(g) Non-target reef fish biomass (kg/ha) on forereefs						
Namena	51.01	26.70	71.93	22.53	-1.298	0.194
Namuri	92.46	14.15	26.96	21.08	2.860	<0.001
Nasue	65.74	21.08	37.63	7.90	1.416	0.157
(h) Non-target reef fish abundance (#/ha) on forereefs						
Namena	254	56	317	66	-0.749	0.454
Namuri	1012	151	375	73	3.534	<0.001
Nasue	380	49	505	90	-0.050	0.960

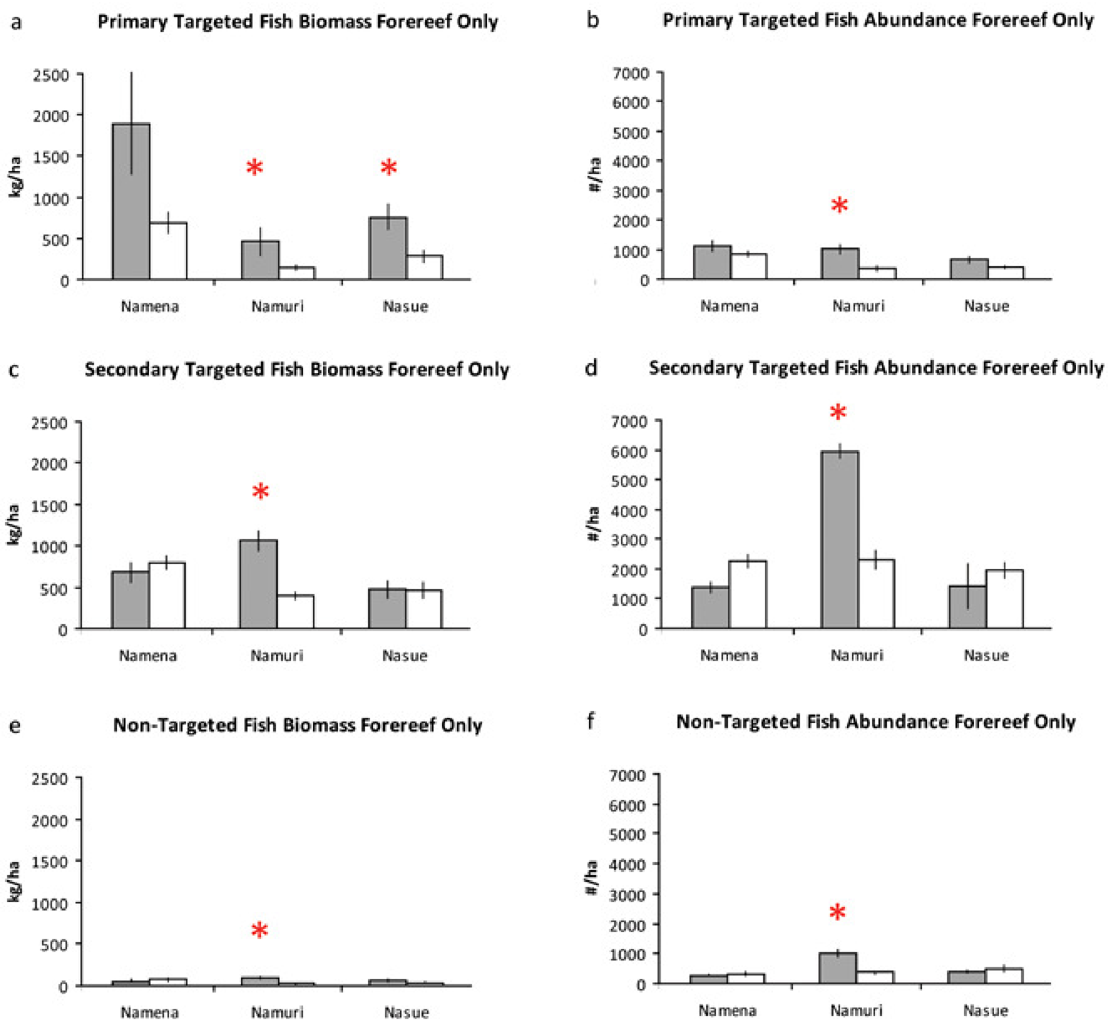


Figure 4. Mean (± standard error) fish biomass (kg/ha) and abundance (#/ha) of (a,b) primary targeted fish species; (c,d) secondary targeted fish species; and (e,f) non-targeted fish species inside and adjacent to MPAs from Kubulau 2008 surveys. Red asterisks denote significant differences at p < 0.05.

The Namuri and Nasue MPAs had significantly greater biomass of primary targeted reef fish species than at adjacent open sites, while the Namena MPA had greater biomass which was not statistically significant (Figure 4, Table 4c,d). The Namuri MPA also had significantly greater biomass and abundance of secondary targeted food fish (Figure 4c,d, Table 4e,f). Secondary food fish made up the bulk of the fish sighted during the entire 2008 survey. There were significantly more and bigger non-targeted fish inside the Namuri MPA. The contribution of non-target fish to the overall biomass of sites surveyed in the qoliqoli was very low.

2009 UVC surveys

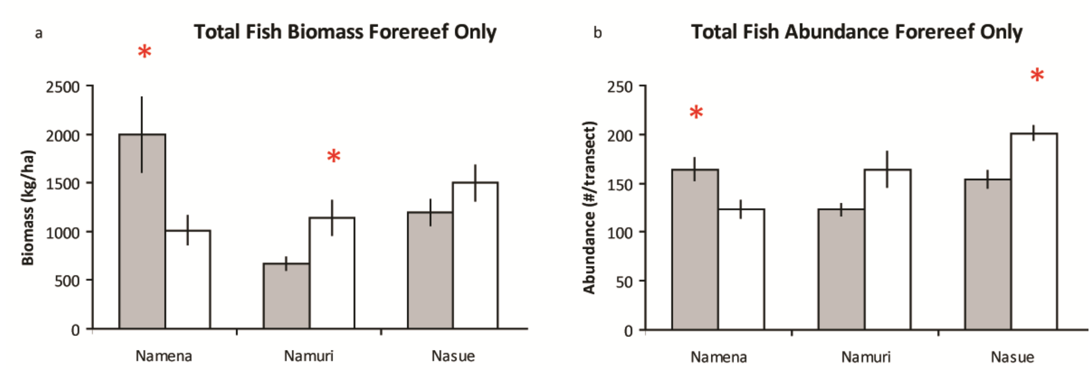


Figure 5. Mean (± standard error) (a) total fish biomass (kg/ha); and (b) total fish abundance (#/ha) from 2009 Kubulau fish survey data on forereefs inside MPAs (grey) and adjacent open fishing grounds (white). Red asterisks indicate significant differences at p < 0.05.

Total fish biomass and abundance was significantly higher inside the Namena MPA (Figure 5a,b, Table 5a,b). Opposite patterns were true for the Namuri and Nasue MPAs: total fish biomass was significantly greater outside the Namuri MPA, while total fish abundance was greater outside the Nasue MPA (Figure 5a,b, Table 5a,b).

Table 5. Mean abundance and biomass (± standard error) between forereef closed and open areas for MPAs and tabus from Kubulau 2009 survey data in: (a) total fish biomass (kg/ha); (b) total fish abundance (#/transect); (c) primary target fish biomass (kg/ha); (d) primary target fish abundance (#/transect); (e) secondary target fish biomass (kg/ha); (f) secondary target fish abundance (#/transect); (g) non-target fish biomass (kg/ha); and (h) non-target fish abundance (#/transect). P-values are reported from nonparametric Mann-Whitney U tests (*) and t-tests (†) where data were normal. Significant p-values are indicated (green = greater in closed; red = greater in open).

Reef	Closed	SE	Open	SE	p-level
(a) Total reef fish biomass (kg/ha) on forereefs					
Namena	1994.50	387.98	1009.31	147.87	**0.007***
Namuri	673.47	66.47	1143.99	174.66	**0.042***
Nasue	1194.76	8.87	1498.94	7.39	0.353*
(b) Total reef fish abundance (#/transect) on forereefs					
Namena	164	11	124	9	**0.006**†
Namuri	123	6	164	18	0.199*
Nasue	154	9	201	7	**<0.001**†

(c) Primary target reef fish biomass (kg/ha) on forereefs					
Namena	986.87	284.29	350.23	72.60	**0.002***
Namuri	256.30	58.71	438.66	106.12	0.166*
Nasue	481.42	80.51	627.35	163.38	0.504*
(d) Primary target reef fish abundance (#/transect) on forereefs					
Namena	33	5	19	3	**0.004***
Namuri	18	3	21	5	0.912*
Nasue	26	4	28	4	0.942*
(e) Secondary target reef fish biomass (kg/ha) on forereefs					
Namena	886.36	156.76	599.17	110.52	0.091*
Namuri	356.38	32.66	617.75	85.48	**0.025***
Nasue	635.88	75.99	770.89	86.88	0.130*
(f) Secondary target reef fish abundance (#/transect) on forereefs					
Namena	90	9	69	7	0.129*
Namuri	64	6	98	12	0.078*
Nasue	84	6	111	6	**0.002†**
(g) Non-target reef fish biomass (kg/ha) on forereefs					
Namena	80.50	8.17	57.51	7.92	**0.003***
Namuri	56.87	3.67	67.17	10.55	0.379*
Nasue	64.89	5.38	80.26	7.26	0.095*
(h) Non-target reef fish abundance (#/transect) on forereefs					
Namena	40	2	34	3	0.060*
Namuri	40	2	43	2	0.365*
Nasue	43	3	60	4	**<0.001†**

Part of the reason for the greater biomass outside Nasue and Namuri is due to the unusually high abundance and biomass of parrotfish (Scaridae) which observers visually observed spawning on Drokana reef (Figure 6). For other targeted fish families, there was significantly higher biomass of serranids, acanthurids, and lutjanids insides Namena MPA compared with adjacent open fishing areas (Figure 7). There was additionally more lutjanid biomass inside the Nasue MPA, though the Nasue MPA had less biomass of acanthurids than in adjacent controls (Figure 7b,d).

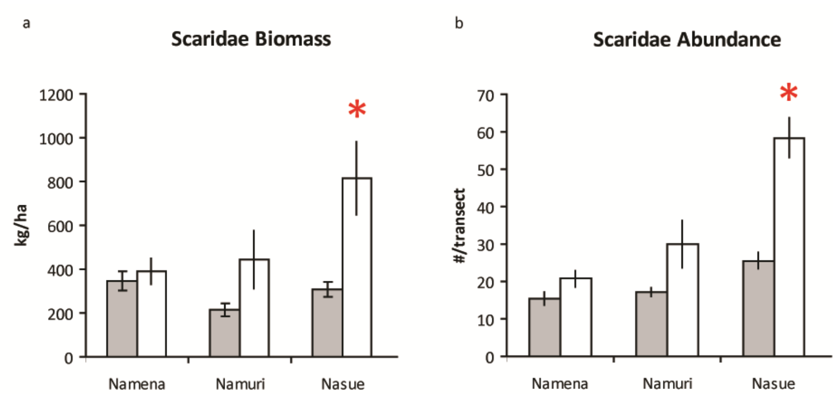


Figure 6. Mean (± standard error) (a) biomass (kg/ha) and (b) abundance (#/transect) of Scaridae on forereefs inside MPAs (grey) and adjacent open fishing grounds in Kubulau qoliqoli in 2009. Red asterisks denote significant differences at $p < 0.05$.

As with the 2008 monitoring data, primary and secondary targeted food fish comprise the bulk of the biomass, while secondary targets are the most abundant of reef fish surveyed (Figure 8). The Namena MPA had significantly greater amounts of primary targeted fish than adjacent control areas (Figure 8a,b; Table 5c,d). By contrast, the Namuri and Nasue MPAs had significant lower secondary targeted fish biomass and abundance, respectively (Figure

8c,d, Table 5e,f), and the Nasue MPA additionally had lower abundance of non-targeted fish (Figure 5f, Table 5h).

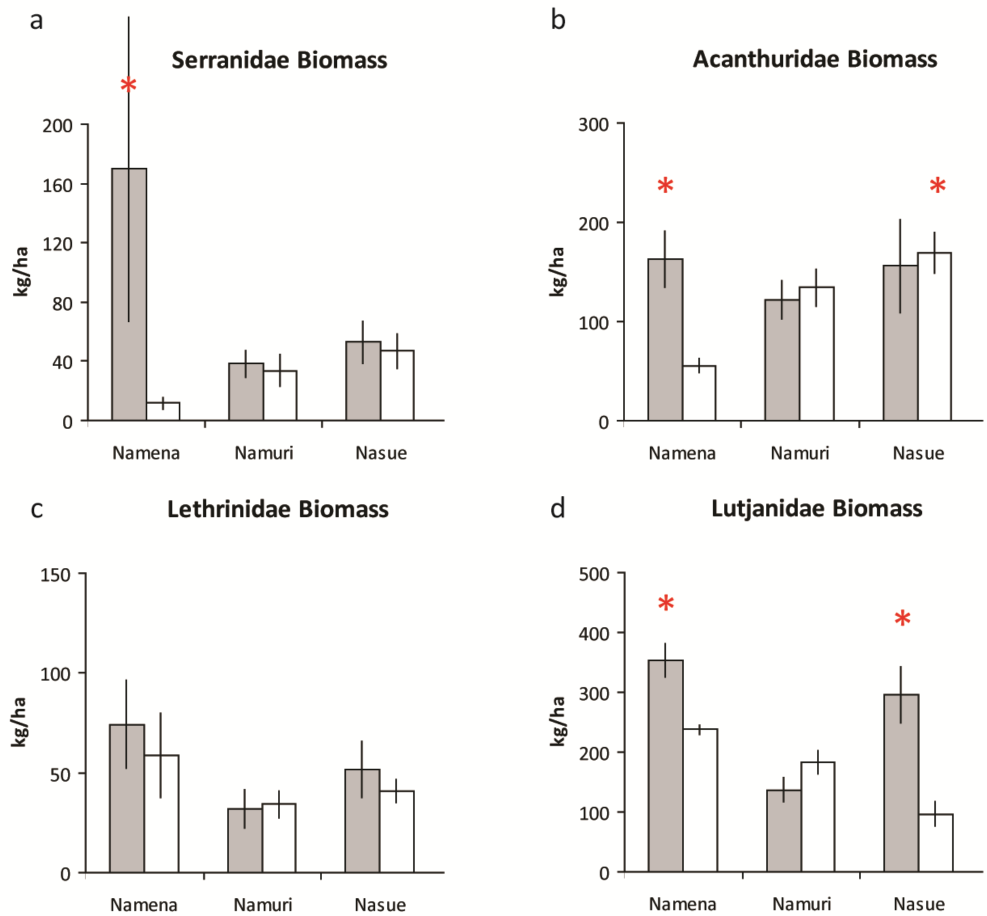


Figure 7. Mean (± standard error) biomass (kg/ha) of (a) Serranidae; (b) Acanthuridae; (c) Lethrinidae; and (d) Lutjanidae on forereefs inside MPAs (grey) and adjacent open fishing grounds in Kubulau qoliqoli in 2009. Red asterisks denote significant differences at $p < 0.05$.

ANOSIM results comparing 2009 benthic composition at the site level showed no overall difference between open and closed sites in the Kubulau qoliqoli (R = 0.014; Figure 9). When benthic composition was compared between reefs, there were only strong differences between Nakali and Namuri reefs and between Namena and Cakaunivuaka reefs (which were not directly compared for fish composition) (Table 6). Namuri and Cakaunivuaka reefs were also significantly different, however control sites for Namuri MPA only contained 2 sites from Cakaunivuaka reef and 2 from Drokana reef, which was highly similar to Namuri.

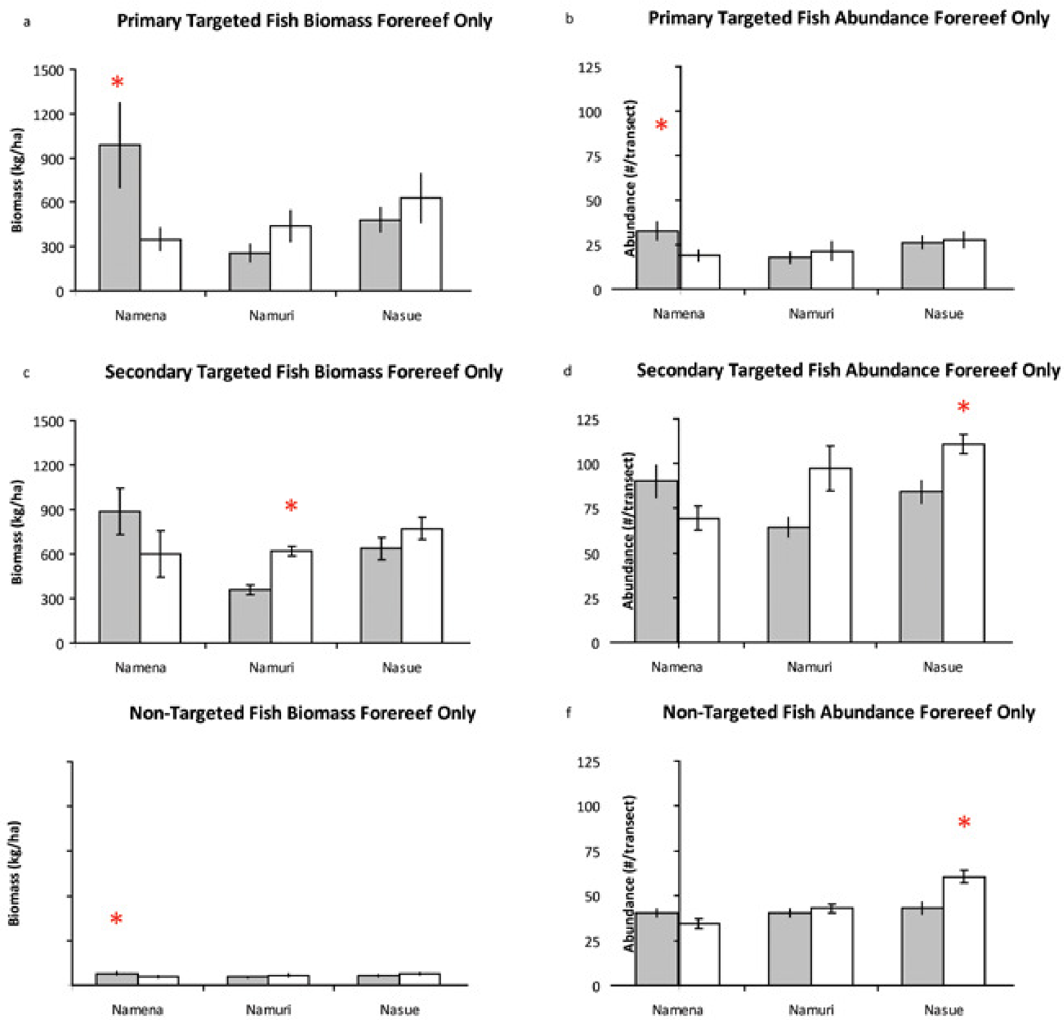


Figure 8. Mean (± standard error) fish biomass (kg/ha) and abundance (#/transect) of (a,b) primary targeted fish species; (c,d) secondary targeted fish species; and (e,f) non-targeted fish species inside and adjacent to MPAs from Kubulau 2009 surveys. Red asterisks denote significance at $p < 0.05$.

Table 6. R values from ANOSIM comparison of benthic composition between reefs. Significant differences at $p < 0.05$ are highlighted in red.

	Nakadamu	Cakaunivuaka	Nakali	Namena	Namuri	Drokana
Nakadamu						
Cakaunivuaka	0.267					
Nakali	0.079	-0.063				
Namena	0.091	0.420	0.200			
Namuri	0.290	0.700	0.531	-0.200		
Drokana	-0.003	0.300	0.163	-0.124	-0.038	
Nasue	0.060	0.363	0.271	-0.131	0.052	-0.144

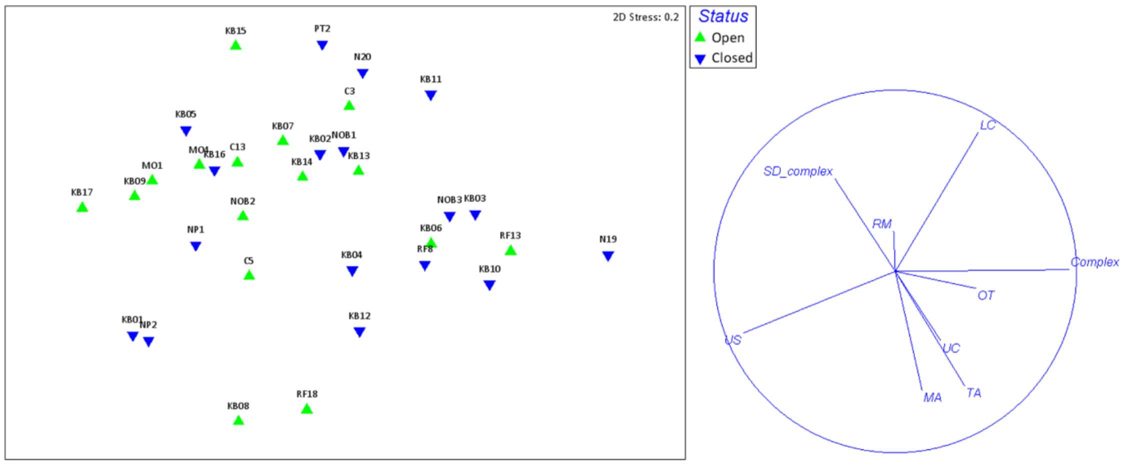


Figure 9. MDS plot of Kubulau 2009 mean benthic community composition by site at closed (blue) and open (areas). Axes to right show trajectories of vectors for each benthic habitat variable.

Ordination of 2009 fish biomass data using centroid distance at the site level across all sites surveyed revealed no distinct clustering between closed and open sites (Figure 10). However, the closed (green) sites with high negative values along MDS axis 1 are all highly productive sites within the Namena (and Nakali MPAs). The sites that also have strong negative scores along MDS axis 2 (N20, KB03, C3) are all categorized by large distances from runoff, land, villages (weighted by fish consumption), and the Wailevu qoliqoli boundary. These biophysical factors all had significant ($p < 0.05$) negative Pearson correlations with sites values along MDS1, while macroalgae was significantly positively correlated with MDS2 (Table 7).

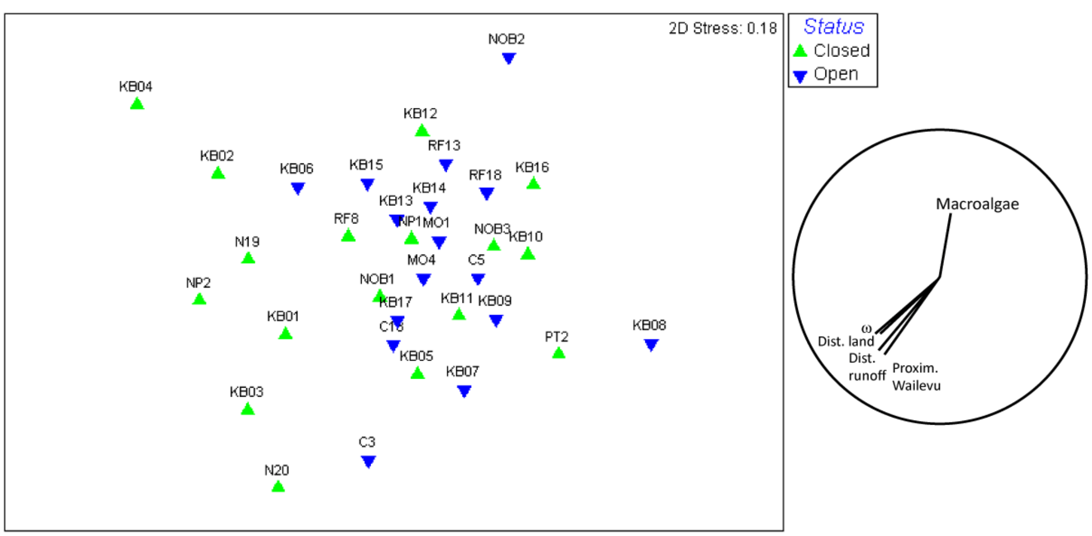


Figure 10. MDS plot of Modified Gower resemblance matrix of fish biomass by species for each site, shown with vector trajectories of biophysical factors with Pearson correlations of at least ±0.35 with data positions along MDS axis 1 or 2.

Table 7. Pearson correlations (r) with positions of resemblance matrix of mean fish biomass per species ordinated along MDS axes 1 and 2. Values highlighted in red are significant at $p < 0.05$ with univariate regressions.

Biophysical Factor	MDS1	MDS2
Distance from land	-0.376	-0.359
Distance from runoff source	-0.413	-0.490
Visibility	0.040	0.101
Proximity to Wailevu	-0.371	-0.517
Proximity to Wainunu	-0.150	0.143
Weighted distance from villages	-0.398	-0.367
Reef complexity	-0.232	0.160
STDEV reef complexity	-0.048	-0.165
Live coral	-0.196	-0.199
Macroalgae	0.082	0.457
Other substrate	0.042	-0.142
Reef matrix	0.260	0.232
Turf algae	-0.134	0.106
Unconsolidated substrate	0.042	0.006
Upright coralline algae	0.036	0.294

Socioeconomic surveys

While the level of awareness of management rules was generally fairly similar across all villages (Figure 11), certain patterns emerge. For example, a large majority of households in Nakorovou (79%) identified that landowners must be consulted prior to commercial logging operations commencing. However, they had comparatively lower awareness of specific marine regulations (i.e. types of species forbidden to harvest). Natokalau residents had the broadest awareness of management rules (highest average rank of scores for all questions asked), while Navatu village had the lowest mean rank of scores. By contrast, actual catch locations suggest that Nakorovou fishers have the least awareness of MPA boundaries as they indicated that they fished in all of their *tabu* areas, plus within the boundaries of the Nasue and Namuri MPAs (Figure 12). Only one fisher from Navatu recorded catching fish from inside a district MPA.

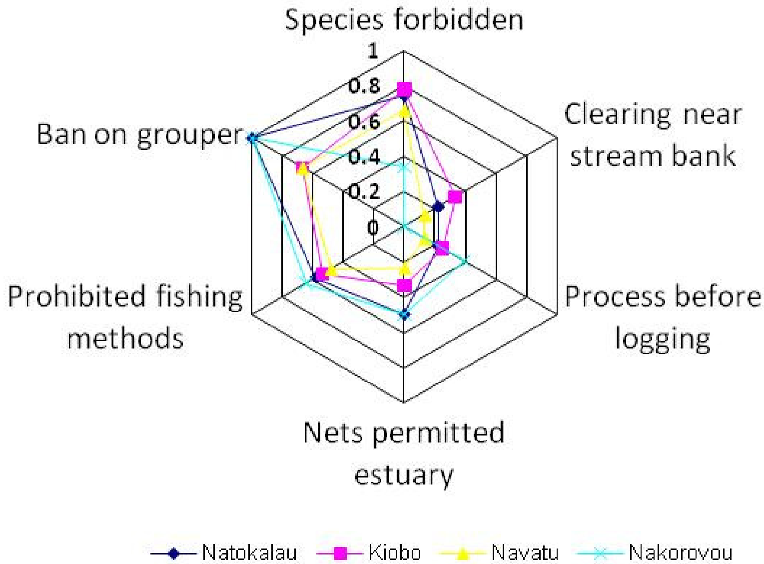


Figure 11. Radar plot of scored responses to questions relating to awareness of management rules in the Kubulau EBM plan (see Table 3 for questions and scores). Location of symbols for each village are mean response of all households surveyed.

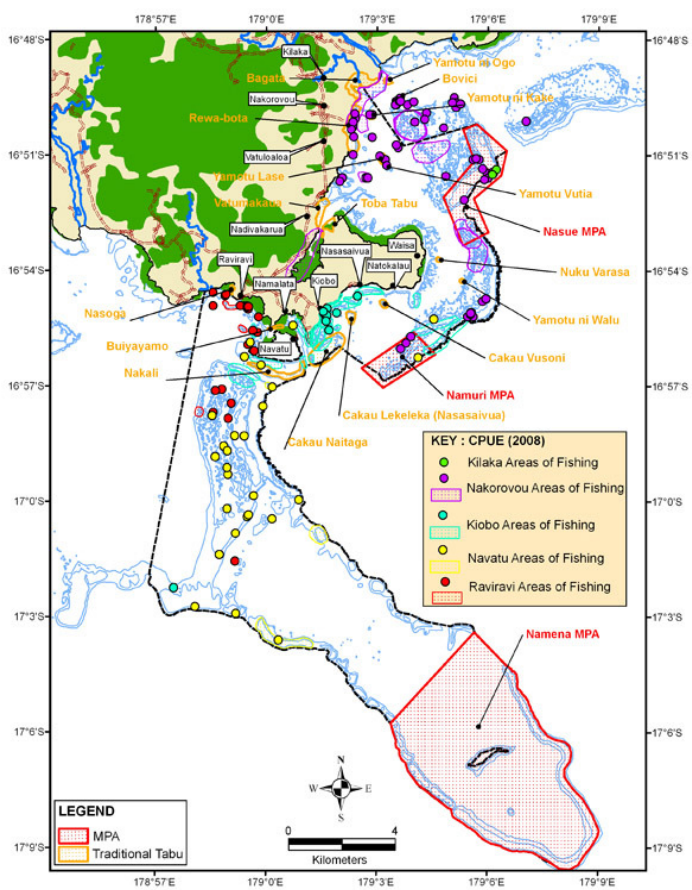


Figure 12. Catch locations recorded by village from CPUE surveys collected ~weekly between May 2008 and June 2009 by trained community volunteers. As with the resource mapping exercise, fishers were given blank maps on which to record locations. Colors indicate village: green – Kilaka; purple – Nakorovou; turquoise – Kiobo; Yellow – Navatu; red – Raviravi.

Heads of households in Navatu were the most likely to state that mangement rules should be made less strict, whereas the large majority of respondents from other villages believe the current rules are not strict enough (Figure 13). Members of Navatu are open and honest about their non-compliance: 8 of 15 heads of households surveyed reported that they personally never or only sometimes comply with protected area rules (Figure 14), including respecting boundaries. Furthermore, Navatu residents are the only ones to admit to continued use of illegal gear following the establishment of the protected area network (Table 8).

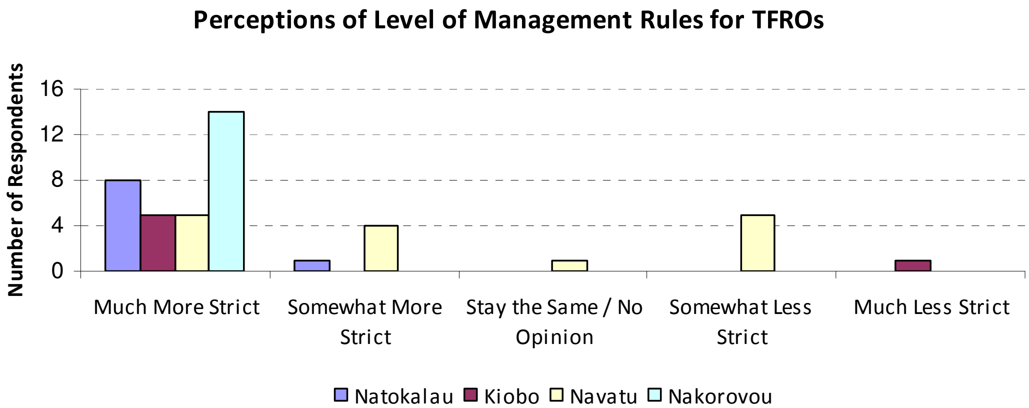


Figure 13. Responses of traditional fishing rights owners (TFROs) in Natokalau (n = 9), Kiobo (n = 6), Navatu (n = 15) and Nakorovou (n = 14) to the question: 'How do you feel about the current level of rules and regulations for resource owners and their family members?'

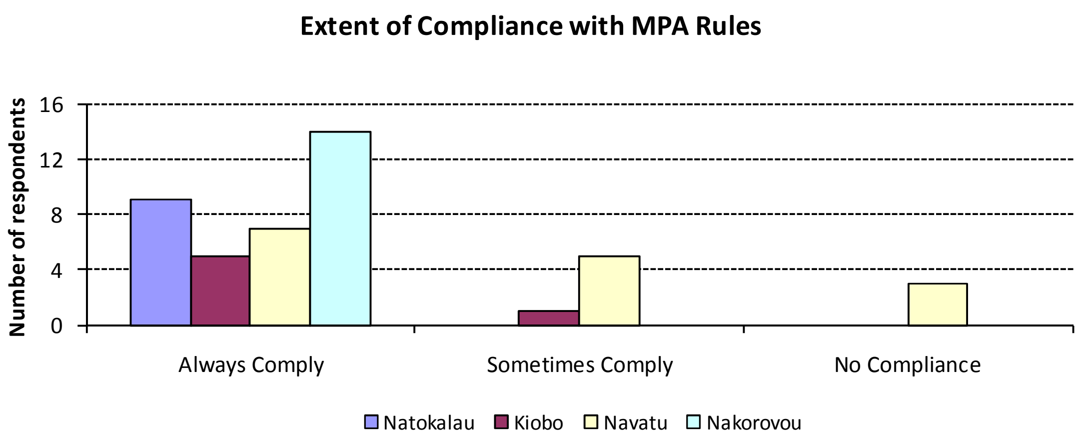


Figure 14. Responses of heads of households in Navatu (n = 15), Kiobo (n = 6) and Nakorovou (n = 14) to the question: "To what extent do you comply with the protected area rules, including respecting boundaries?"

Across all villages surveyed, the responses showed a high degree of general community management participation (both meeting and women participation, Figure 15). The chiefly village (Kiobo) showed the highest level of participation and also satisfaction regarding the representation of the household's interests. In contrast, Navatu stands out as the only village where a few individuals indicated that they are not taking part in meetings but also were unhappy about their interests being represented (Figure 15). In Navatu, only 33% and

20% of heads of households reported that they usually agree with decisions by the Bose Vanua and KRMC, respectively (Figure 16).

Table 8. Preferred fishing gear types used by fishers before and after the marine protected area network was established, based on responses from household surveys in Kubulau in 2009. Illegal/destructive gear includes: fish poison, fine gill nets, and use of SCUBA. Gear requiring management includes: larger gill nets, speargun, and Hawaiian sling. Minimally destructive gear includes: hand nets, hand spear, and hook and line.

	Fishing Gear Class		
Village	**Illegal/Destructive**	**Requires Management**	**Minimally Destructive**
Before management			
Natokalau	13.3%	33.3%	53.3%
Kiobo	30.0%	10.0%	60.0%
Navatu	37.9%	24.2%	37.9%
Nakorovou	3.7%	25.9%	70.4%
After management			
Natokalau	0.0%	31.3%	68.5%
Kiobo	0.0%	22.2%	77.8%
Navatu	13.8%	27.6%	58.6%
Nakorovou	0.0%	25.9%	74.1%

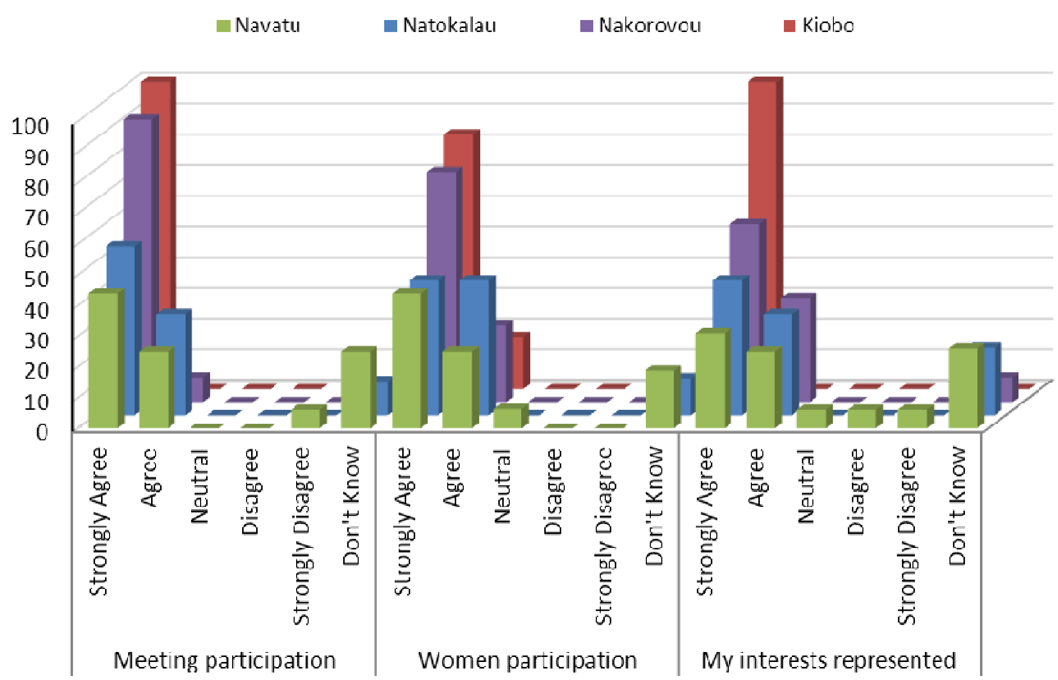


Figure 15. Responses from four villages on their perceived participation and representation in the community decision process.

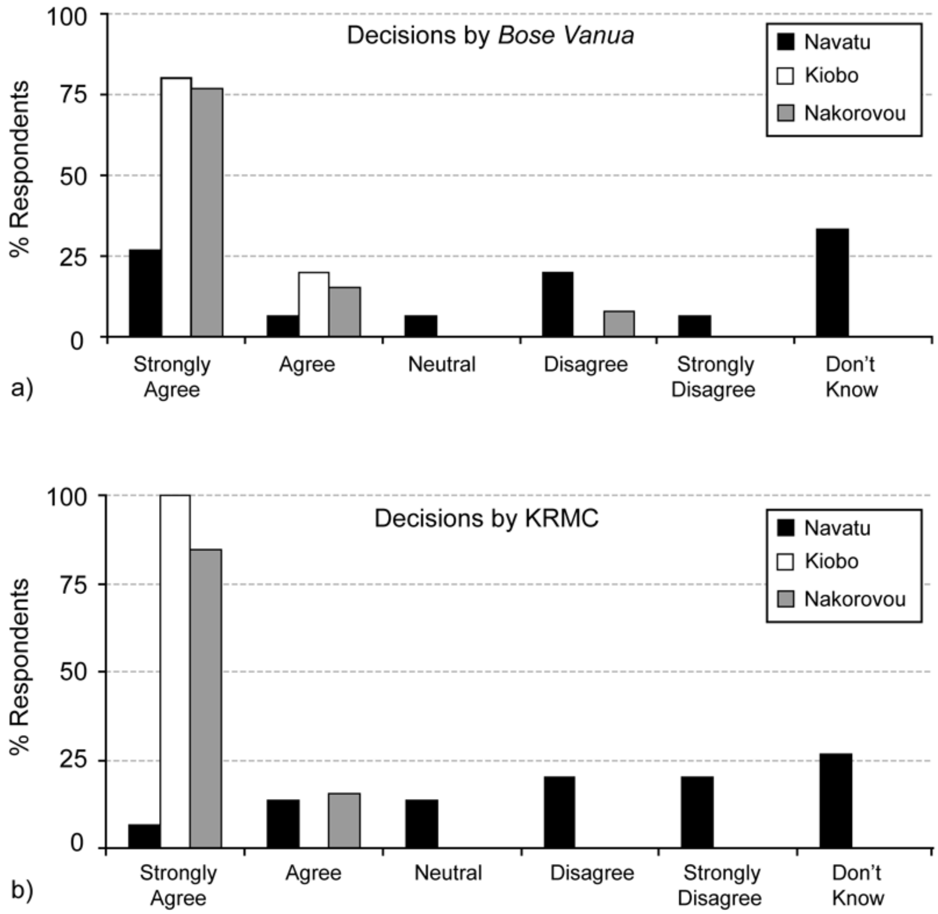


Figure 16. (a) Proportion of responses by village in 2009 household surveys of Kubulau to the statement: "I usually agree with the decisions by the council of chiefs (Bose Vanua). (b) Proportion of responses by village to the statement: "I usually agree with decisions by the Kubulau Resource Management Committee (KRMC)". (Number of households surveyed per village: Navatu: n = 15 of 18; Kiobo: n = 5 of 8; Nakorovou: n = 13 of 18).

Discussion

Factors influencing MPA effectiveness

Many different factors can potentially influence whether or not marine protected areas and MPA networks are effective in reaching their conservation and management goals. These factors can include, but are not limited to: degree of protection (no-take, permanent, periodic opening, partial); awareness of and degree of compliance with MPA rules; visibility from land; design of MPAs and MPA networks; benthic habitat condition; frequency and intensity of current and historical disturbance (e.g. land-based pollution, bleaching, tropical cyclones, crown-of-thorns outbreaks); and longevity of protection. As the goals of the Kubulau MPAs were primarily to increase stock of food fish, we evaluate the results of our fish surveys in the context of the above factors to determine where management has been effective and where there needs to be improvements.

The results from the MPAs located <10 km offshore in Kubulau (Nasue, Namuri) are equivocal. Although there was more total fish and primary fish biomass inside the Nasue

MPA in 2008, there was significantly greater abundance of fish outside the MPA (particularly scarids) in 2009. Long-term coral proxy records from the region indicated potential extreme disturbance from land-based runoff when the nearby Mt. Kasi gold mine was operational between 1996 and 1998. Nevertheless, current surveys of benthic habitat condition indicate no significant differences between Nasue and adjacent fished areas in factors that may indicate recent disturbance (e.g. macroalgal cover, rubble) and influence fish assemblages (e.g. live coral cover, branching coral cover, reef topographic complexity) (Jupiter et al. 2010). This suggests that neither proximity to runoff nor benthic characteristics are driving broad differences in reef fish assemblages between Nasue MPA and the adjacent Drokana reef. Instead, both external and internal poaching is likely to play a major role. Proximity to Wailevu district was one of the major factors which contributed significantly to reef fish biomass structure at the site level. The Nasue MPA shares a boundary with the neighbouring Wailevu qoliqoli and Wailevu fishers have been repeatedly caught fishing in the MPA, a problem compounded by the fact that the MPA is not visible from any of the villages in Kubulau. Internal poaching is also a problem, as indicated by the catch locations of fishers in Figure 12. Lack of awareness of MPA boundaries may additionally be a strong contributor to non-compliance in Nasue as fishers from Nakorovou reported fishing in every single one of their tabu areas as well as the Nasue MPA, despite their reported high level of self-compliance (Figure 14).

The Namuri MPA appeared to be effectively protecting marine resources in 2008, with significantly higher total fish and primary food fish biomass inside compared with adjacent fished. The opposite pattern was observed from 2009 surveys, provoking some concern that when Kubulau fishers were made aware of the exceptionally high biomass inside Namuri MPA during a management planning workshop in February 2009, they may have proceeded to covertly fish the area. Indeed, the monitoring sites within Namuri all had exceptionally low consumption-weighted distance-to-village scores (ω), indicating that they are near numerous villages whose residents frequently consume fish. Thus, in an attempt to use the monitoring data to foster discussions related to management implementation, its public presentation may have had detrimental consequences for the fishery (e.g. Maurstad 2002). Customary management rules rely on respect for traditional authority (Aswani 2005; Hoffman 2002), which may be weakened through access to markets (Cinner et al. 2007). For example, the high dependency of Navatu residents (and to a lesser extent Kiobo residents) on income from fishing (Figure 17) has been facilitated by the presence the middle man living in their village. Such opportunities for financial gain can create loss of respect for traditional authority that may cause people to commit acts in open violation of community rules.

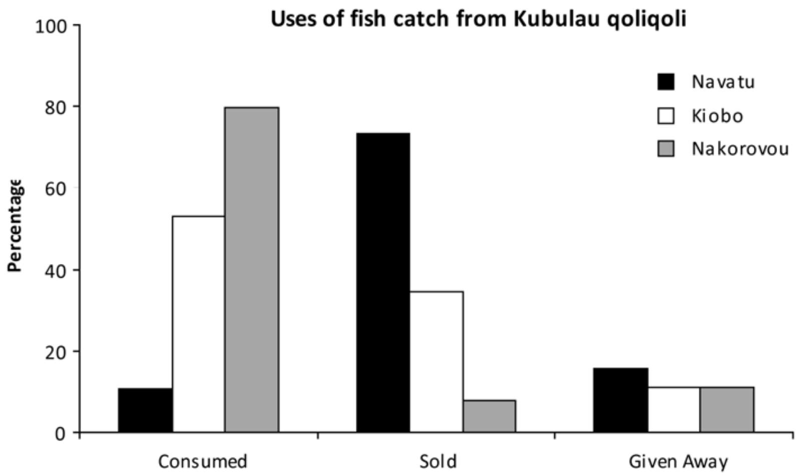


Figure X. Percentage of fish from catch per unit effort surveys consumed (black), sold (white), and given away (striped) for catches by fishers from Navatu, Kiobo, and Nakorovou. Data from Cakacaka et al. (2010).

The Namena MPA demonstrated the strongest results in terms of increasing food fish biomass and abundance. The most likely reasons for its success are: strong commitment to enforcement; natural geomorphic features which promote recovery; longevity of protection; and distance from villages. The Namena MPA has been informally established as a permanent no-take protected area since 1997, when the high council of chiefs both banned commercial fishing from the qoliqoli and set up the reserve around the reefs of Namenalala Island (Clarke and Jupiter in press). The longevity and permanence of the closure has enabled recovery of large-bodied piscivores such as serranids and lutjanids, which have low growth and recruitment rates and are highly vulnerable to overfishing (Russ and Alcala 1998). Increases in biomass of these taxa from growth alone may take a decade to observe, as opposed to biomass increases from successful recruitment ("spill-in") following closure of an MPA, which can occur rapidly over 1-3 years (White 1988; McClanahan and Kaunda-Arara 1996; Russ and Alcala 1996b).

At 60.6 km^2, Namena is the largest MPA in Fiji, covering an extensive barrier reef system that extends outward into the deep waters of the Vatu-i-Ra passage. High currents flush the reef, supporting an abundance of top predators, including schools of hammerhead sharks which draw dive tourists from around the globe. High currents along reef walls additionally provide important fluxes of zooplankton, upon which planktivorous fish feed (Hamner et al. 1988): some of these planktivores (e.g. schooling damselfish) are prey for larger-bodied carnivores, while other large acanthurids (e.g. *Naso* spp) can grow up to 100 cm. These naturally favourable habitats can promote rapid recovery of exploited populations, while unfavourable habitats, such as the backreef of Namena which is dominated by reef pavement, may see temporal increases in fish abundance and size in response to management but may appear to be less effective if the reef fish populations are compared to those from control habitats with higher topographic complexity (Friedlander et al. 2003).

Given that international dive tourism in Namena brings revenue to the communities of Kubulau through the payment of user fees to dive in the MPA, there is high incentive from the communities to enforce the MPA regulations. The chiefs of Kubulau have empowered the owners of Namena Island Resort, located within the reserve, to patrol the area and trained community fish wardens may board vessels suspected of illegal fishing activity (Clarke and Jupiter in press). Due to this vigilance, there has historically been less poaching by fishers coming from the mainland given the high price of boat fuel: fishers would only be attracted to the area if they have guaranteed access to a market to sell their catch.

However, since the biological monitoring surveys in 2009, there have been repeated incidents of poaching within the Namena MPA by members of one of Navatu's two clans who have lost access to their traditional fishing grounds due to the establishment of the MPA. Observational evidence and socioeconomic surveys have indicated that loss of respect for traditional authority and access to markets may be primary drivers of repeated and public incidents of illegal fishing in the Namena. The Namena MPA is not legally gazetted. Its success has largely relied on respect for traditional chiefly authority and, to a lesser extent, a misconception that the reserve is protected under national legislation (Clarke and Jupiter in press).

In the Pacific, compliance with local resource management rules relies to a significant extent on respect for traditional authority and decision-making processes (Aswani 2005). Management planning processes that respect and reinforce the roles of traditional leaders, while providing opportunities for broad community engagement, strengthen long-term prospects for community-based resource governance (Lal 2005). The level of participation of community members in the management process in the Kubulau district appeared to be fairly high, which bodes well for continued management implementation. However, there was notable resistance to participation, and dissension from management decisions, by several residents of Navatu village.

Perceptions of inequity, exclusion from decision-making processes or failure to respect traditional resource rights may result in challenges to traditional authority. It is clear from the responses of Navatu residents that some individuals within the village are unhappy with the level management rules within the Kubulau qoliqoli and decisions by community managers. The clan with traditional fishing rights in Namena strongly feels that they are bearing a larger burden of the costs because they have not been adequately compensated for the loss of their traditional fishing rights. One important lesson learned from these experiences is the importance of ensuring that distribution of costs and benefits is considered early in the management planning process in order to reduce potential conflict (Lal 2005). In addition, mapping tenure boundaries, including overlapping and competing claims, may help to avoid management conflicts. For example, in Kubulau, clearer understanding of the relationship between village fishing areas (*kanakana*) and the district fishing ground (*qoliqoli*) when designing protected area boundaries might have helped to avoid conflict with Navatu village, enhancing the effectiveness of the Namena Marine Reserve while minimizing the opportunity costs to Navatu given its stronger dependence on marine resources than other villages in the district (Klein et al. 2008).

Conclusions and Recommendations

In Kubulau, the factors which appear to have the most influence on the success of management to provide protection of exploited species include: size; placement of reserves in naturally productive habitats; visibility; distance from potential poachers; access to markets; and respect for management rules and community decision makers. Some key recommendations to improve and expand MPA networks to other sites in Fiji include:

- Size: MPAs need to be larger than the home ranges of targeted fish species. Recent fish tagging studies from the Coral Coast of Fiji have shown that *Lethrinus* spp. can move up to 700m and do so mostly at night (Grober-Dunsmore et al. 2009). Therefore, MPAs should be at least double this length on both sides in order to ensure that fish are not caught while foraging.

- Permanence and placement: Though some studies have observed limited increases in fish biomass and abundance despite periodic opening (Cinner et al. 2005; Bartlett et al. 2009), the ability of fish populations to recover from harvests is likely to depend both on the frequency and intensity of harvest events (Seidel 2009). Permanently closed areas provide the maximum level of protection and degree of recovery. They also depend on other factors relating to placement such as, natural geomorphology and oceanographic features of the region and the life-history patterns of targeted species. Ideally, MPAs should be placed in highly resilient locations. For other cases, Russ and Alcala (2003) make a strong argument for permanent closures as a precautionary principle because the “benefits accrue slowly but are lost quickly” with repeated fishing event.

- Visibility: Visibility of MPAs need not always imply that they be placed within direct sight of villages. In the case of the Macuata tabus established around mangrove islands, although the landward side is visible, the trees impede the view of the seaward-facing reef which can be easily targeted by poachers by day or by night. Visibility can be improved by frequent enforcement patrols, though resourcing is required for boats and fuel. Resource management committees must therefore place priority on financing enforcement activities through their varied sources of revenue.

- Management planning: The emerging conflicts associated with the Namena MPA present instructive lessons for design of new MPA networks in the region. Before any closures are enforces, there needs to be an open discussion of costs and benefits with equitable distribution of compensation for lost access to resources. Mapping traditional kanakana boundaries may help eliminate potential conflict by identifying actual opportunity costs associated with each village or clan.

The data collected here can provide important baselines for future comparisons with other sites across Fiji and the Pacific. The lessons learned are being shared with the communities of Kubulau and Macuata and the broader Fiji Locally Managed Marine Area network to help inform adaptive management of inshore fisheries resources.

Acknowledgments

The authors gratefully acknowledge the support of the chiefs and communities of Kubulau and in particular the Kubulau Resource Management Committee, for the commitment they have shown to protecting their marine resources. Since 2008, WCS has received assistance from many scientists, staff and volunteers to collect data, including: Deborah Blaik (Greenforce), Steve Fitzpatrick (Greenforce), Unaisi Mara (Navatu village), Alana Murphy (Greenforce), Yashika Nand (Department of Fisheries), Alex Patrick (WCS), Willie Saludrau (Department of Fisheries), Paul Veileqe (Navatu village), and Heidi Williams (CORAL). Greenforce staff and volunteers provided much needed assistance with equipment. The EBM team is particularly grateful to: David Olson and Linda Farley, who initially conceived of the project with assistance from Michael Marnane; Kathy Walls, who initiated the NOAA CRCP project; and Martin Callow, who led the WCS team from 2008 to March 2009 with a strong emphasis on management and communication.

References

Adams AJ, Dahlgren CP, Kellison GT, Kendall MS, Layman CA, Ley JA, Nagelkerken I, Serafy JE (2006) Nursery function of tropical back-reef systems. Marine Ecology Progress Series 318:287-301

Alcala A, Russ GR, Maypa AP, Calumpong HP (2005) A long-term, spatially replicated experimental test of the effect of marine reserves on local fish yields. Canadian Journal of Fisheries and Aquatic Sciences 62:98-108

Anderson MJ, Gorley RN, Clarke KR (2008) PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods. PRIMER-E, Plymouth, UK

Aswani S (2005) Customary sea tenure in Oceania as a case of rights-based fishery management: Does it work? Reviews in Fish Biology and Fisheries 15:285-307

Bartlett CY, Manua C, Cinner JE, Sutton S, Jimmy R, South R, Nilsson J, Raina J (2009) Comparison of outcomes of permanently closed and periodically harvested coral reef reserves. Conservation Biology doi: 10.1111/j.1523-1739.2009.01293.x

Cakacaka A, Jupiter SD, Egli DP, Moy W (2010) Status of fin fisheries in a Fijian traditional fishing ground, Kubulau District, Vanua Levu. Wildlife Conservation Society-Fiji Technical Report no. 06/10. Suva, Fiji, 21 pp.

Campbell SJ, Pardede ST (2006) Reef fish structure and cascading effects in response to artisanal fishing pressure. Fisheries Research 79:75-83

Care JC, Zorn JG (2001) Legislating pluralism - statutory developments in Melanesian customary law. Journal of Legal Pluralism & Unofficial Law 46:49-101

Cinner JE, Marnane MJ, McClanahan TR, Almany GR (2005) Periodic closures as adaptive coral reef managment in the Indo-Pacific. Ecology and Society 11:31. http://www.ecologyandsociety.org/vol11/iss31/art31

Cinner JE, Sutton SG, Bond TG (2007) Socioeconomic thresholds that affect use of customary fisheries management tools. Conservation Biology 21:1603-1611

Clarke KR, Warwick RM (2001) Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. Primer-e, Plymouth, UK

Clarke P, Jupiter SD (in press) Law, custom and community-based natural resource management in Kubulau District, Republic of Fiji Islands. Environmental Conservation

Denny CM, Willis TJ, Babcock RC (2004) Rapid recolonisation of snapper *Pagrus auratus*: Sparidae within an offshore island marine reserve after implementation of no-take status. Marine Ecology Progress Series 272:183–190

Dulvy NK, Freckleton RP, Polunin NVC (2004) Coral reef cascades and the indirect effects of predator removal by exploitation. Ecology Letters 7:410-416

English S, Wilkinson C, Baker V (1997) Survey manual for tropical marine resources. Australian Institute of Marine Science, Townsville, Australia, 390 pp

Evans RD, Russ GR, Kritzer JP (2008) Batch fecundity of *Lutjanus carponotatus* (Lutjanidae) and implications of no-take marine reserves on the Great Barrier Reef, Australia. Coral Reefs 27:179-189

Friedlander AM, Parrish JD (1998) Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. Journal of Experimental Marine Biology and Ecology 224:1-30

Friedlander AM, Brown EK, Jokiel PL, Smith WR, Rodgers KS (2003) Effects of habitat, wave exposure, and marine protected area status on coral reef fish assemblages in the Hawaiian archipelago. Coral Reefs 22:291-305

Froese R, Pauly D (2009) FishBase. World Wide Web electronic publication www.fishbase.org

Graham NAJ, Wilson SK, Jennings S, Polunin NVC, Bijoux JP, Robinson J (2006) Dynamic fragility of oceanic coral reef systems. Proceedings of the National Academy of Sciences 103:8425-8429

Graham NAJ, Wilson SK, Jennings S, Polunin NVC, Robinson JB, Bijoux JP, Daw TM (2007) Lag effects in the impacts of mass coral bleaching on coral reef fish, fisheries, and ecosystems. Conservation Biology 21:1291-1300

Grober-Dunsmore R, Bonito V, Aalbersberg W, Bogiva A, Comley J (2009) Evaluation and enhancement of marine conservation efforts in Tikina Komave and Navosa Province: CPUE and fish tagging study. In: Jenkins AP, Prasad SR, Bacchiochi J, Skelton P, Yakub N (eds), Proceedings of the Inaugural Fiji Islands Conservation Science Forum

Halpern BS (2003) The impact of marine reserves: Do reserves work and does reserve size matter? Ecological Applications 13:S117-S137

Hamner WM, Jones MS, Carleton JH, Hauri IR, Williams DM (1988) Zooplankton, planktivorous fish, and water currents on a windward reef face: Great Barrier Reef, Australia. Bulletin of Marine Science 42:459-479

Hand T, Davis D, Gillett R (2005) Fisheries sector review: Republic of the Fiji Islands. Asian Development Bank

Hoffman TC (2002) The reimplementation of the Ra'ui: Coral reef management in Rarotonga, Cook Islands. Coastal Management 30:401-418

IAS (2009) A nation-wide survey of village-based fishing pressure in Fiji. In: Jenkins AP, Prasad SR, Bacchiochi J, Skelton P, Yakub N (eds), Proceedings of the Inaugural Fiji Islands Conservation Science Forum, Wetlands International-Oceania, Suva, Fiji.

IUCN (2009) Accelerating progress to establish marine protected areas and creating marine protected area networks. The World Conservation Union, Gland, Switzerland

Jackson JBC, Kirby MX, Berger WH, Bjorndal KA, Botsford LW, Bourque BJ, Bradbury RH, Cooke R, Erlandson J, Estes JA, Hughes TP, Kidwell S, Lange CB, Lenihan HS, Pandolfi JM, Peterson CH, Steneck RS, Tegner MJ, Warner RR (2001) Historical overfishing and the recent collapse of coastal ecosystems. Science 293:629-638

Jennings S, Polunin NVC (1996) Effects of fishing effort and catch rate upon the structure and biomass of Fijian reef fish communities. The Journal of Applied Ecology 33:400-412

Jennings S, Polunin NVC (1997) Impacts of predator depletion by fishing on the biomass and diversity of non-target reef fish communities. Coral Reefs 16:71-82

Jupiter SD, Tui T, Shah S, Cakacaka A, Moy W, Naisilisili W, Dulunaqio S, Patrick A, Qauqau I, Yakub N, Caginitoba A (2010) Integrating EBM science to assess marine protected area effectiveness: clues from coral proxies of land disturbance, ecological assessments and socioeconomic surveys. Technical report no. 02/10. Wildlife Conservation Society-Fiji, Suva, Fiji, 24 pp

Klein CJ, Steinback C, Scholz AJ, Possingham HP (2008) Effectiveness of marine reserve networks in representing biodiversity and minimizing impact to fishermen: a comparison of two approaches used in California. Conservation Letters 1: 44-51

Lal P (2005) Information, institutions and conflict management in the natural resource sector. Peace Building and Conflict Prevention Workshop

Lester SE, Halpern BS, Grorud-Colvert K, Lubchenco J, Ruttenber BI, Gaines SD, Airame S, Warner RR (2009) Biological effects within no-take marine reserves: a global synthesis. Marine Ecology Progress Series 384:33-46

Maurstad A (2002) Fishing in murky waters - ethics and politics of research on fisher knowledge. Marine Policy 26:159-166

McClanahan TR, Kaunda-Arara B (1996) Fishery recovery in a coral reef marine park and its effect on the adjacent fishery. Conservation Biology 10:1187-1199

McClanahan TR, Arthur R (2001) The effect of marine reserves and habitat on populations of East African coral reef fishes. Ecological Applications 11:559-569

McLeod E, Salm R, Green A, Almany J (2009) Designing marine protected area networks to address the impacts of climate change. Frontiers in Ecology and the Environment 7:362-370

Mumby PJ, Hastings A, Edwards HJ (2007) Thresholds and the resilience of Caribbean coral reefs. Nature 450:98-101

Newton K, Cote IM, Pilling GM, Jennings S, Dulvy NK (2007) Current and future sustainability of island coral reef fisheries. Current Biology 17:655-658

NZLC (2006) Converging currents: Custom and human rights in the Pacific. Study Paper 17. New Zealand Law Commission, Wellington, New Zealand.
Pauly D, Watson R, Alder J (2005) Global trends in world fisheries: impacts on marine ecosystems and food security. Philosophical Transactions of the Royal Society B 360:5-12
Pet Soede C, Van Dansen WLT, Pet JS, Machiels MAM (2001) Impact of Indonesian coral reef fisheries on fish community structure and the resultant catch composition. Fisheries Research 5:35-51
Raj J, Evans N (2004) The role of trade in fisheries production and consumption in Fiji. Background paper. Pacific Islands Regional Ocean Forum, 15 pp
Russ GR (2002) Yet another review of marine reserves as reef fishery management tools. In: Sale PF (ed) Coral reef fishes: Dynamics and diversity in a complex ecosystem. Academic Press, San Diego, USA, pp421-443
Russ GR, Alcala AC (1996a) Do marine reserves export adult fish biomass? Evidence from Apo Island, central Philippines. Marine Ecology Progress Series 132:1-9
Russ GR, Alcala AC (1996b) Marine reserves: rates and patterns of recovery and decline of large predatory fish. Ecological Applications 6:947-961
Russ GR, Alcala AC (1998) Natural fishing experiments in marine reserves 1983-1993: roles of life history and fishing intensity in family responses. Coral Reefs 17:399-416
Russ GR, Alcala AC (2003) Marine reserves: rates and patterns of recovery and decline of predatory fish, 1983-2000. Ecological Applications 13:1553-1565
Russ GR, Alcala AC, Maypa AP, Calumpong HP, White AT (2004) Marine reserve benefits local fisheries. Ecological Applications 14:597-606
Scaglion. R. (1999) Law. In: Rappaport M (ed), The Pacific Islands: Environment and Society, Bess Press, Honolulu, USA
Seidel H (2009) Evaluating the role of science in Community Based Adaptive Management of coastal resources in Fiji. University of Bremen, 101 pp
Teh LCL, Teh LSL, Starkhouse B, Sumaila UR (2009) An overview of socio-economic and ecological perspectives of Fiji's inshore reef fisheries. Marine Policy 33:807-817
Tetreault I, Ambrose RF (2007) Temperate marine reserves enhance targeted but not untargeted fishes in multiple no-take MPAs. Ecological Applications 2251-2267
Trexler JC, Travis J (2000) Can marine protected areas restore and conserve stock attributes of reef fishes? Bulletin of Marine Science 66:853-873
Veitayaki J (1997) Traditional marine resource management practices used in the Pacific Islands: an agenda for change. Ocean & Coastal Management 37:123-136
WCS (2009) Ecosystem-Based Management Plan: Kubulau District, Vanua Levu, Fiji. Wildlife Conservation Society, Suva, Fiji, 121 pp
White AT (1988) The effect of community-managed marine reserves in the Philippines on their associated coral reef fish population. Asian Fisheries Science 2:27-41
Wilson SK, Fisher R, Pratchett MS, Graham NAJ, Dulvy NK, Turner RA, Cakacaka A, Polunin NVC, Rushton SP (2008) Exploitation and habitat degradation as agents of change within coral reef fish communities. Global Change Biology 14:2796-2809
Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, Jackson JBC, Lotze HK, Micheli F, Palumbi SR, Sala E, Selkoe KA, Stachowicz JJ, Watson R (2006) Impacts of biodiversity loss on ocean ecosystem services. Science 314:787-790
WWF (2004) Setting priorities for marine conservation in the Fiji Islands Marine Ecoregion. WWF South Pacific Programme, Suva, Fiji, 79 pp

Appendix 1. Locations of survey sites in Kubulau

The maps below indicate the location of baseline and monitoring survey sites in Kubulau and Macuata qoliqolis from which data on fish assemblages and benthic communities were collected to assess MPA effectiveness.

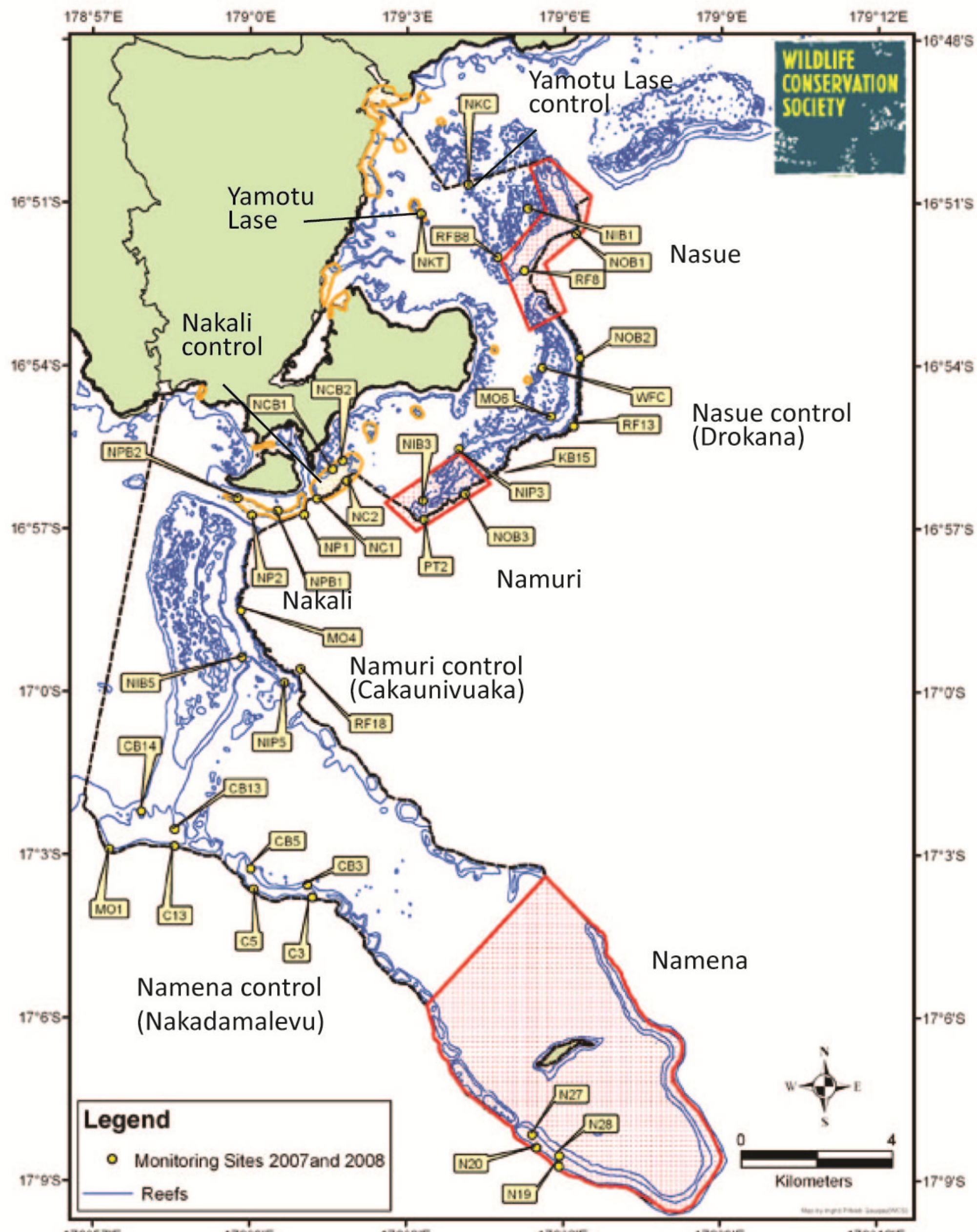


Figure 1. Location of forereef and backreef sites surveyed within Kubulau qoliqoli during Program I monitoring between April-May 2008.

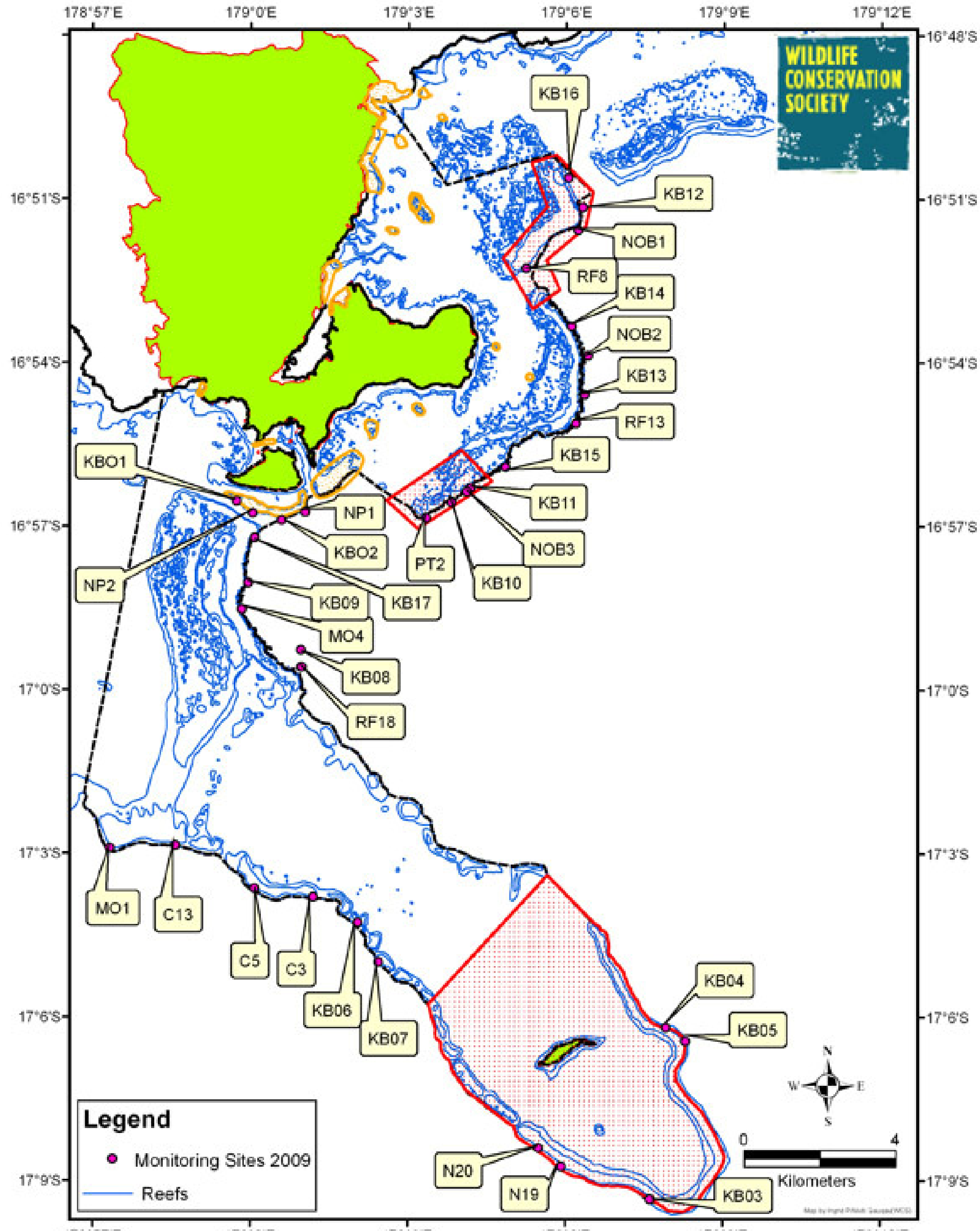
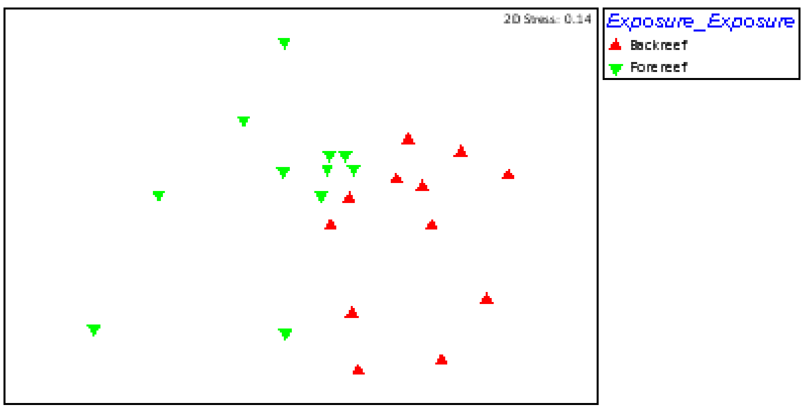


Figure 2. Location of forereef sites surveyed within Kubulau qoliqoli during Program II monitoring between April-May 2009. Controls for Nasue were site: KB13, KB14, NOB2, RF13; controls for Namuri were: KB09, KB15, KB17, RF13; and controls for Namena were: C13, C3, C5, KB06, MO1.

Appendix 2. Revision of experimental design for monitoring MPAs

Variation in fish assemblages across exposure (forereef, backreef) and protection (open, closed) from Kubulau 2007 data was explored with multivariate tests using PRIMER-e version 6 software.

A Modified Gower similarity matrix with a log10 was used to compare the biomass of reef fish assemblages at each site from inside and adjacent to the district MPAs (Anderson et al. 2008). A multidimensional scaling (MDS) plot of the matrix shows distinct separation between forereef and backreef sites (Figure 1), while no clear separation is evident related to protection status (Figure 2). This suggests that the observed pattern of reef fish assemblages is more likely driven by exposure gradients that override potential management effects; therefore focus on one exposure factor only will reduce the influence of additional variables and likely improve our ability to detect differences related to management.



)S plot of
wer
: matrix of 2007
nass for all
ed by exposure
eef sites; green
tes).

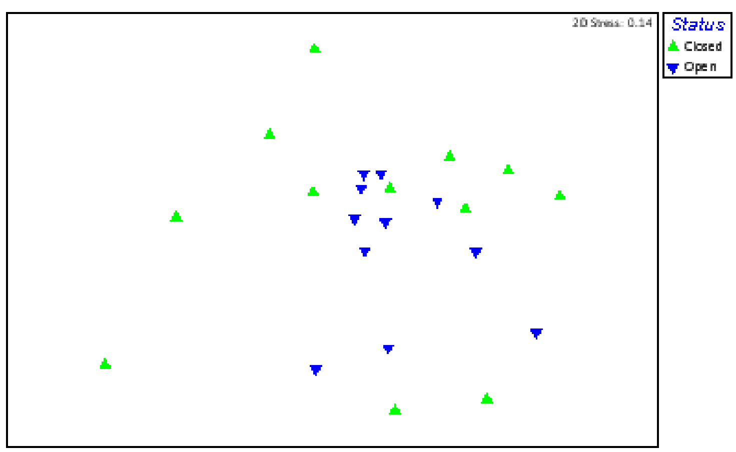
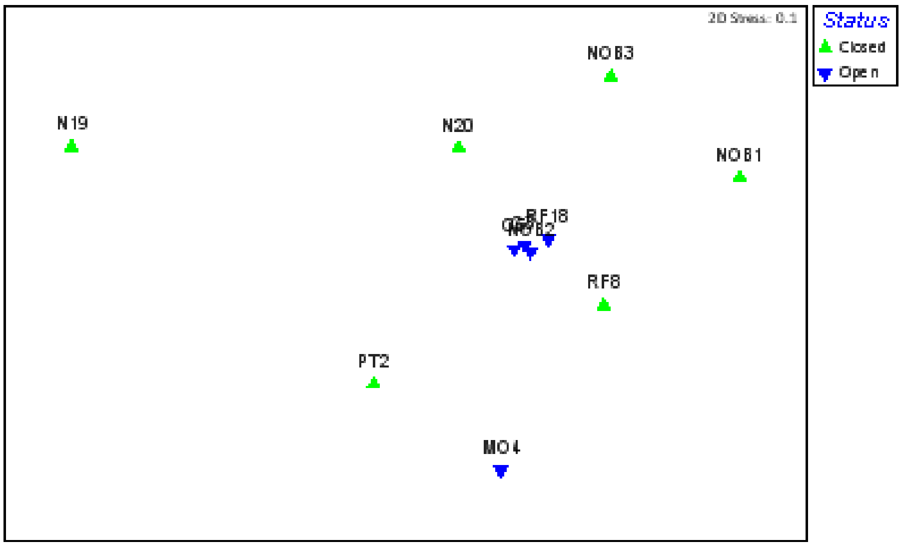


Figure 2. MDS plot of Modified Gower resemblance matrix of 2007 reef fish biomass for all sites identified by protection status (blue = sites open to fishing; green = closed MPA sites.)

When only forereef sites are considered, there is strong clustering of fish assemblages by species biomass for sites open to fishing (Figure 3). The large variability within MPA sites is likely due to the different responses of individual sites to protection, which can strongly influence the biomass of protected species and also the composition of fish assemblages.



ıDS plot of
ıower
ce matrix of 2007
ef fish biomass
identified by
status (blue =
to fishing; green
PA sites.) Sites
n Namena MPA:
sites from within
ᴾA: PT2, NOB3;
ı Nasue MPA:

Power analysis of experimental design showed a reduction in critical F-statistic values when sites are pooled across exposure (Table 1a,b) and when higher replicates of forereef only sites are surveyed (Table 2a,b). The main improvements were an expected increase of power to detect an effect of status (crit F reduced from 12.2 to 7.57), which was the main question addressed by the original experimental design.

Table 1. Critical F-statistics needed to conclude significant differences at $p < 0.05$ level for experimental design of Kubulau 2007 and 2008 surveys where (a) exposure, site and depth are considered as separate factors; and (b) sites are pooled across exposure categories.

Factor	Levels	Nesting	Fixed/ Random	Numerator	Denominator	Critical F-statistic
(a) Exposure, Site and Depth as factors						
Status	2 (open, closed)		fixed	1	4	12.2
Exposure	2 (back-, forereef)		fixed	1	4	12.2
Site	2	status x exposure	random	4	96	2.93
Depth	3 (top, shallow, deep)	status x exposure x site	fixed	2	8	6.06
N	5					
Sample size	120					
(b) Site and Depth as factors						
Status	2 (open/closed)		fixed	1	6	8.81
Site	4	status	random	6	96	2.55
Depth	3 (top, shallow, deep)	status x site	fixed	2	12	5.1
N	5					
Sample size	120					

Table 2. Critical F-statistics needed to conclude significant differences at $p < 0.05$ level for experimental design of Kubulau 2009 surveys for (a) Namena MPA with 5 closed sites and 5 open sites surveyed; and (b) Namuri and Nasue MPAs with 4 closed sites and 4 open sites each surveyed.

Factor	Levels	Nesting	Fixed/ Random	Numerator	Denominator	Critical F-statistic
(a) Namena MPA (n = 10 sites total)						
Status	2 (open, closed)		fixed	1	8	7.57
Site	5	status	random	8	80	2.35
Depth	2	status & site	fixed	1	8	7.57
N	5					
Sample size	100					
(b) Namuri/Nasue MPA (n = 8 sites total)						
Status	2 (open, closed)		fixed	1	6	8.81
Site	4	status	random	6	64	2.63
Depth	2	status & site	fixed	1	6	8.81
N	5					
Sample size	80					

Based on the results of the above sets of analyses, a decision was made to survey forereef sites only in Kubulau in April-May 2009 and to increase the number of sites surveyed in closed and open areas to improve the statistical power to detect differences related to management and depth. Results from pre-2009 are reported from forereef sites only in the body text.