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REPORT

Evidence of artisanal fishing impacts and depth refuge in assemblages of Fijian reef fish

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Abstract Protection from fishing generally results in an increase in the abundance and biomass of species targeted by fisheries within marine reserve boundaries. Natural refuges such as depth may also protect such species, yet few studies in the Indo Pacific have investigated the effects of depth concomitant with marine reserves. We studied the effects of artisanal fishing and depth on reef fish assemblages in the Kubulau District of Vanua Levu Island, Fiji, using baited remote underwater stereo-video systems. Video samples were collected from shallow (5–8 m) and deep (25–30 m) sites inside and outside of a large old marine reserve (60.6 km^2, 13 years old) and a small new marine reserve (4.25 km^2, 4 years old). Species richness tended to be greater in the shallow waters of the large old reserve when compared to fished areas. In the deeper waters, species richness appeared to be comparable. The difference in shallow waters was driven by species targeted by fisheries, indicative of a depth refuge effect. In contrast, differences in the abundance composition of the fish assemblage existed between protected and fished areas for deep sites, but not shallow. Fish species targeted by local fisheries were 89% more abundant inside the large old reserve than surrounding fished areas, while non-targeted species were comparable. We observed no difference in the species richness or abundance of species targeted by fisheries inside and outside of the small new reserve. This study suggests that artisanal fishing impacts on the abundance and species richness of coral reef fish assemblages and effects of protection are more apparent with large reserves that have been established for a long period of time. Observed effects of protection also vary with depth, highlighting the importance of explicitly incorporating multiple depth strata in studies of marine reserves.

Keywords Artisanal fishing · Depth refuge · Baited video · Marine reserves · Relative abundance · Fijian reef fish

Introduction

Exploitation of the marine environment is decreasing the ocean's biodiversity and increasingly impairing the ocean's capacity to provide food for human consumption (Worm et al. 2006). Pauly (2007) predicts that the present exploitation patterns are unsustainable. Evidence available for tropical marine ecosystems demonstrates that an increase in fishing pressure can cause shifts in species composition (Jennings and Polunin 1996; Dulvy et al. 2004; Jones et al. 2004), a decline in species richness (Dulvy et al. 2004; McClanahan and Mangi 2004), depletion of carnivorous species, and an increase in the dominance of fish from lower trophic levels (Jennings and Polunin 1997; Russ and Alcala 1998). Such effects have been shown to occur not only within highly fished

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ecosystems, but also in areas subject to relatively low artisanal fishing activity (Jennings and Polunin 1996; McClanahan and Arthur 2001; Dulvy et al. 2004; Campbell and Pardede 2006). This suggests artisanal fishing may be having a greater impact than first predicted.

Most small communities in the Indo Pacific lack information on fisheries yields or in situ fish abundance (Pauly et al. 1998; Pet-Soede et al. 2001; Jones et al. 2009). Artisanal fishers target many more species and employ a greater variety of catching techniques than commercial fishers (Cinner and McClanahan 2006). They are also being increasingly recognized as a potential threat to coastal fish stocks (Pet-Soede et al. 2001; McClanahan and Mangi 2004; Mangi and Roberts 2006; Jones et al. 2009). Depletion of fish stocks may impact heavily on artisanal communities in the Indo Pacific, as fisheries resources are generally essential for nutrition and employment (Pet-Soede et al. 2001; McClanahan and Mangi 2004; Jones et al. 2009).

The implementation of no-take reserves can be an efficient and inexpensive method to maintain fisheries and preserve the biodiversity and abundance of biota contained within them (Allison et al. 1998; Bohnsack 1998; Adams et al. 2010). Reviews of empirical studies suggest that no-take reserves generally enhance biodiversity and increase the abundance, biomass and size of fish species targeted by fisheries (herein, referred to as targeted species), which may lead to increased recruitment and spillover of adult species into neighbouring areas (Trexler and Travis 2000; Russ 2002; Halpern 2003; Russ and Alcala 2004; Claudet et al. 2008; Lester et al. 2009).

The composition of fish assemblages has been shown to change over depth gradients of hundreds to thousands of metres (McGehee 1994; Friedlander and Parrish 1998; Brokovich et al. 2006, 2008). A number of studies have also investigated changes in fish assemblage structure in shallow waters (<20 m) (Bell 1983; Suarez et al. 2004; Tyler et al. 2009; Friedlander et al. 2010; Electronic Supplemental Material, ESM Appendix 1). However, few studies have investigated how fish assemblages change between shallow (<20 m) and deep (>20 m) waters, in part due to limitations of conventional SCUBA below 20 m. This has also limited the number of studies that have looked at the effect of depth concomitant with the effect of protection on reef fish assemblages, with only ~35% of empirical studies on protected areas in the Indo Pacific incorporating multiple depth strata (ESM Appendix 1). Studies that have investigated depth and protection have mostly found a greater effect of protection in shallow waters than in deep, attributing this finding to an increased fishing pressure in shallow waters (Polunin and Roberts 1993; Ashworth and Ormond 2005; Tyler et al. 2009). Only four studies on marine reserves in the Indo Pacific have incorporated depths greater than 15 m (Galal et al. 2002; Alcala et al. 2005; Aswani et al. 2007; Friedlander et al. 2010, ESM Appendix 1) and only one greater than 20 m (Friedlander et al. 2007, ESM Appendix 1). This leaves a gap in the knowledge on the effectiveness of tropical marine reserves at depths greater than 20 m.

In Kubulau District, Fiji, the majority of fishing effort is artisanal using nets, fishing lines, spearguns and handspears (Adams et al. 2010). As fishing with SCUBA is prohibited, and dive fins are rarely used by local fishermen, the impact from spear and snorkel fishing is limited to a depth of around 15 m. Nets used in the area are predominantly “hand”, “cast”, or “wading”, also limiting them to shallow waters (Adams et al. 2010). This is expected to restrict the effects of fishing on targeted species to shallow habitats from 0 to 15 m. Fishing lines can easily access depth beyond 15 m, but are mostly used in fine weather conditions (Adams et al. 2010). Upon capture, fish in Kubulau District are sold to the local fish market in Savusavu, with unsold fish kept for local consumption. In Kubulau District, 84% of households in coastal villages reported fishing as a source of income, making the resource essential to the economic viability of the community (WCS 2009). The fish species targeted and sold by the villagers are separated into three grades with different values: high (FJD ~ 3.50), medium (FJD ~ 3.00) and low (FJD ~ 2.00) per kilogram.

Our study examined the effects of artisanal fishing and depth on the coral reef fish assemblages of the Kubulau qoliqoli, a fishing ground with multiple marine reserves in Fiji. We tested the hypotheses that (1) there will be a different fish assemblage structure in protected areas with a greater abundance of targeted species and greater species richness than in fished areas, (2) there will be differences in the fish assemblage between deep (25–30 m) and shallow (5–8 m) sites and (3) there will be an interaction between depth and protection with a greater abundance of targeted species and greater species richness in shallow protected areas compared with fished areas and no difference between deep sites, suggesting a depth refuge effect.

Materials and methods

Study area

The survey was carried out at the “Kubulau qoliqoli”, Vanua Levu, Fiji, from the 4th–28th July 2009. The total area of Kubulau’s qoliqoli is 262 km^2 and contains a network of 17 community-managed marine protected areas and three permanent no-take marine reserves, totalling approximately 80 km^2 or 30% of the qoliqoli (Fig. 1). The largest no-take marine reserve is Namena (herein, referred to as the large old reserve) which was established in 1997 with a total area of 60.6 km^2. The Namuri reserve (herein, referred to as the small new reserve) is considerably smaller at 4.25 km^2 and

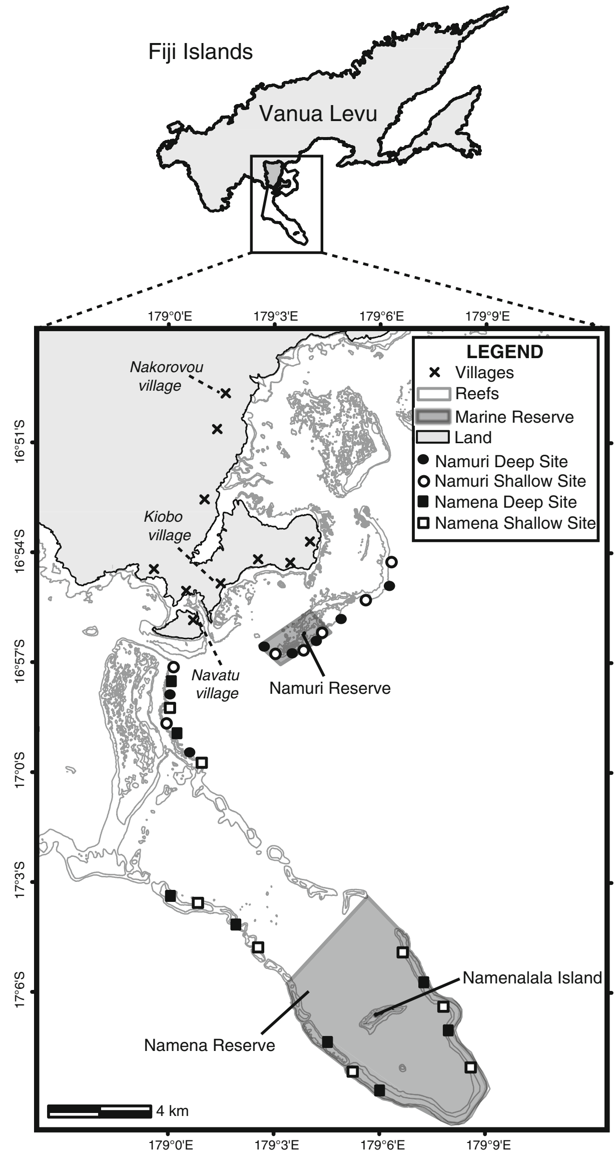

Fig. 1 Map of the Kubulau qoliqoli off Vanua Levu, Fiji. The *dark grey* shading shows the no-take marine reserves. *Squares* represent sampling sites inside and out of the large old (Namena) reserve, and *circles* represent sites inside and out of the small new (Namuri) reserve. *Filled symbols* represent shallow (5–8 m) sampling sites, and *open symbols* represent deep (25–30 m) sites

was established in 2005 (Clarke and Jupiter 2010). Each of these reserves is strictly no take, prohibiting the removal of any living organisms from within their boundaries. Compliance is self-enforced by the local communities.

Experimental design

The two reserves, large old and small new, were separated in the design due to their contrasting size and age. The sampling design consisted of three factors: *Status* (two levels, fixed: protected versus fished), *Depth* (two levels, fixed: shallow, 5–8 m and deep, 25–30 m) and *Site* (random, nested in Status × Depth, 4 sites at each depth). Fished sites were placed in areas adjacent to the reserves where high levels of fishing are known to occur (Adams et al. 2010). All deployments were randomly stratified over coral reef habitat along the exposed reef edge. Due to a lack of comparable coral reef habitat directly adjacent to the eastern side of the large old reserve, suitable fished sites were selected as close as possible (Fig. 1).

Sampling technique

Baited remote underwater stereo-video systems (stereo BRUVs) have emerged as a useful technique for surveying fish assemblages in deeper waters (>20 m) and provide a permanent record of the fish observed (Cappo et al. 2003). Stereo BRUVs have also been found to be cost-efficient compared to other video-based methods (Langlois et al. 2010).We used stereo BRUVs to sample the coral reef fish assemblages inside and outside of the reserves in the Kubulau qoliqoli. Information on the design and calibration of the stereo BRUVs can be found elsewhere (Harvey and Shortis 1996, 1998; Harvey et al. 2001, 2002). Stereo-video imagery was calibrated using CAL V1.33.1 (http://www.seagis.com.au/bundle.html). Our systems used two SONY HC 15E handy-cams with 0.6 wide angle lenses in underwater housings. The housings and cameras were separated on a base bar by 0.7 m and inwardly converged to provide an overlapping field of view from approximately 0.5 m in front of the cameras. Importantly, the use of stereo-video allows accurate estimates of distance (Harvey et al. 2004). The standardized field of view sampled by the stereo BRUV system in this study was from 0.5 to 8 m. Six stereo BRUVs were deployed by boat at each site and left to film for 60 min on the seafloor. Bait consisted of 800 g of pilchards (*Sardinops* sp.) in a plastic-coated wire mesh basket that was suspended 1.2 m in front of the two cameras. The pilchards were crushed to promote dispersal of the fish oil and flesh. Adjacent deployments were separated by 250–400 m to reduce the likelihood of fish moving between replicates within the sampling period (see Cappo et al. 2001).

Image analysis

All video footage was captured using Adobe Premiere Pro 2 in an avi (Audio Video Interleaved) format. We used the right hand video of each stereo-pair to determine the relative abundance of the fish seen on video. The right hand avi file was imported into *EventMeasure* (http://www.seagis.com.au/event.html). *EventMeasure* is a program used for logging and reporting events occurring in digital video imagery. It is specifically designed to allow fast, efficient analysis of movie sequences when recording biological information and animal behaviour in underwater movie sequences. This software enabled us to manage data collected from the field operations and video, to record the timing of events and capture reference images of the seafloor and fish in the field of view. We used the stereo-photocomparator software *PhotoMeasure* (http://www.seagis.com.au/photo.html) to analyse the stereo-video imagery for the range of fish from the cameras.

Data collection and measurements

Visual habitat classification

The habitat observed in each camera deployment was initially classified into three benthic categories: the top of coral outcrops, the bottom of coral outcrops, or sand inundated reef. Next, the major biotic classification described the growth forms of coral which made up the highest percentage of the benthos and was classified as massive, rubble, branching or tabulate coral or sand. Finally, the minor biotic classification was the coral type which made up the next highest percentage of the benthos and was classified using the same categories. An estimate of the field of view was made for each deployment. Sites where benthos obscured over 35% of the view were removed from the analysis. Water visibility was consistently good at all sites and greater than 8 m. These measures were obtained to ensure that stereo BRUV deployments were done in comparable habitats and to ensure that there were no systematic differences in habitat between reserve and fished locations.

Species richness and abundance

Species richness was measured as the total number of species observed per 60 min stereo BRUV deployment. Species that could not be distinguished from similar species were grouped together at the genus level. Identification and abundance estimates of species were made by reviewing captured footage in the laboratory. The maximum number of individuals for each species viewed at any one time (MaxN; Priede et al. 1994) was recorded from viewing 60 min of footage and used as a measure of relative abundance. The use of this 'MaxN' as an estimator of relative abundance has been reviewed in detail by Cappo et al. (2003). Interrogation of each tape was conducted by a single experienced analyst.

Data analysis

Permutational multivariate analysis of variance (PERMANOVA with 4999 permutations) was used to examine differences in the habitat, species richness and abundance of fish species using the PERMANOVA + add on (Anderson et al. 2008) to PRIMER (Plymouth Routines in Multivariate Ecological Research; PRIMER-E 2009). Each dataset was appropriately transformed and analysed for all factors including interactions. Where main effects or interactions were significant, a posteriori comparisons were explored (Anderson 2001). As many species within the pelagic genus *Pterocaesio* could not be distinguished, formed very large schools and appeared to mask the patterns of other demersal species, this group was removed from all analyses.

Habitat

To weight the occurrence of the habitat data, the minor biota category was given a value of 0.5 compared with 1 for the benthos and major biota. To test for any consistent differences in the habitat between reserve and fished areas, a PERMANOVA analysis using a Bray–Curtis similarity matrix was used. The Bray–Curtis similarity matrix was chosen as it does not count joint absences as similarities making it more ecologically relevant for habitat data (Anderson et al. 2008).

Multivariate analysis

A Log 2 Modified Gower dissimilarity matrix was used for the analysis of the multivariate fish abundance dataset as it is more appropriate for dealing with multivariate heterogeneity of variance than the Bray–Curtis measure (Anderson et al. 2006).

A principle coordinate analysis (PCO) was done to show the unconstrained grouping of sites and helped to visualize any broad patterns in the abundance data. A constrained canonical analysis of principal coordinates (CAP) was used to investigate significant factors from the PERMANOVA analysis and to identify the species primarily responsible for causing these differences (Anderson and Robinson 2003; Anderson and Willis 2003). The square of the first canonical correlation (δ^2) provided an indication of the strength of the observed differences among sites in the dataset in relation to an axis. The number of axes (m) was chosen by plotting the residual sum of squares and choosing the first significant drop in relation to the other values. This results in a minimum misclassification error (see Anderson and Willis 2003). Pearson's product moment correlations of the complete dataset and CAP ordinations were used to determine the species that were linearly correlated with the canonical axis and contributing to the observed dissimilarity between sampling units (Anderson and Willis 2003). A Pearson's correlation value of 0.6 was chosen for the abundance data to show only the dominant species that were driving the patterns as there were many species with a high correlation with the canonical axis.

Univariate analysis

A PERMANOVA using dissimilarity matrices constructed with Euclidean distance was performed on measures of species richness and of abundance for the targeted species of the food fish grades high, medium and low and non-targeted species. Sites were pooled when a *P(perm)* value greater than 0.25 was found, and the factors *Status* and *Depth* were not already significantly different (Underwood 1997). Sites were left un-pooled if the factors *Status* and *Depth* did not become significantly different because of the pooling. To indicate which species were primarily responsible for any observed differences in species richness inside and outside of reserves, a CAP on presence absence data was done, using Pearson's correlations ($|r| > 0.4$).

Results

We observed a total of 11,722 individuals from 341 species and 44 families. The number of species seen per stereo BRUV deployment varied from 8 to 83. Of the 341 species, 124 (36%) were considered targeted according to the food fish grades of the Kubulau District. There were 46 species observed from the high value grade, making up 13% of the total number of individuals, 23 species from medium grade making up 7% and 55 in low grade making up 16% (ESM Appendix 2). The remaining 217 species accounting for 64% of the total number of individuals were classified as non-targeted species.

Habitat

Habitat did not vary greatly between the different sites sampled as all stereo BRUVs were deployed on the exposed edge of outer barrier fore reefs dominated by coral. Habitat did not differ between fished and protected areas for both reserves (both $P > 0.05$). However, there was a significant difference in habitat between shallow and deep sites in the large old (*Pseudo-F* = 6.076, $P = 0.005$) and in the small new reserve (*Pseudo-F* = 4.293, $P = 0.015$). It was more common for drops to land on top of coral outcrops at shallow sites, while in the deep sites, drops tended to land at the bottom of coral outcrops or on flat ground.

Species richness

Overall, the species richness in the large old reserve was significantly greater than surrounding fished areas with an average of 8 more species per deployment (Table 1). There was no significant interaction of *Status* and *Depth*; however, there was on average 13 more species per deployment in the large old reserve than fished areas for the shallow sites and only 3 more than fished areas for the deep sites (Table 1; Fig. 2). Although not significant, this result suggests an interaction between *Status* and *Depth* which is indicative of a depth refuge effect. In addition, a CAP on the presence

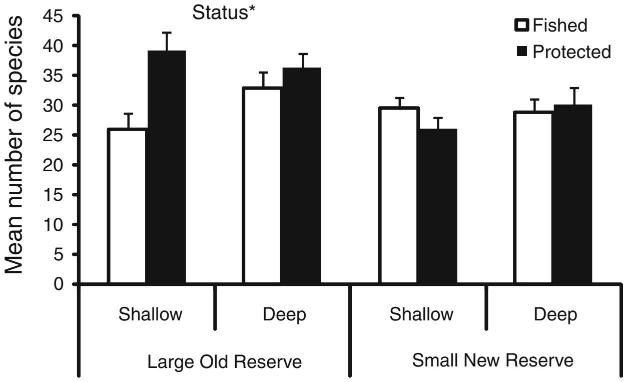

Fig. 2 The mean (+1 SE) number of species per 60 min stereo BRUV deployment for deep and shallow sites inside and outside of the large old and the small new reserves. Any significant term in the model is displayed on the plot with an *asterisk* next to its name e.g., (Status*)

Table 1 Results of three-factor PERMANOVA examining the species richness in response to factors *Status* (St), *Depth* (De) and *Site* in the large old and small new reserves

Source	Large old reserve				Small new reserve			
	df	MS	*Pseudo-F*	*P(perm)*	*df*	MS	*Pseudo-F*	*P(perm)*
Status	1	1,637.6	5.371	**0.042**	1	13.82	0.191	0.681
Depth	1	147.51	0.484	0.493	1	49.32	0.682	0.433
StxDe	1	420.54	1.379	0.257	1	102.9	1.423	0.261
Site (StxDe)	12	306.3	1.989	**0.035**	10	71.65	0.724	0.694
Residual	76	154			64	99.04		
Total	91				77			

Bold value indicates a significant $P > 0.05$

Table 2 PERMANOVA based on Modified Gower Log 2 dissimilarities of the relative abundances of 341 fish species for the large old and small new reserves in response to *Status* (St), *Depth* (De), *Sites* and their interactions

Source	Large old reserve				Small new reserve			
	df	MS	*Pseudo-F*	*P(perm)*	*df*	MS	*Pseudo-F*	*P(perm)*
Status	1	2.336	1.914	**0.013**	1	1.197	1.058	0.391
Depth	1	7.804	6.393	**<0.001**	1	6.003	5.31	**<0.001**
StxDe	1	2.09	1.712	**0.017**	1	1.11	0.982	0.473
Site (StxDe)	12	1.223	1.312	**<0.001**	10	1.137	1.313	**<0.001**
Residual	76	0.932			64	0.866		
Total	91				77			

Bold value indicates a significant $P > 0.05$

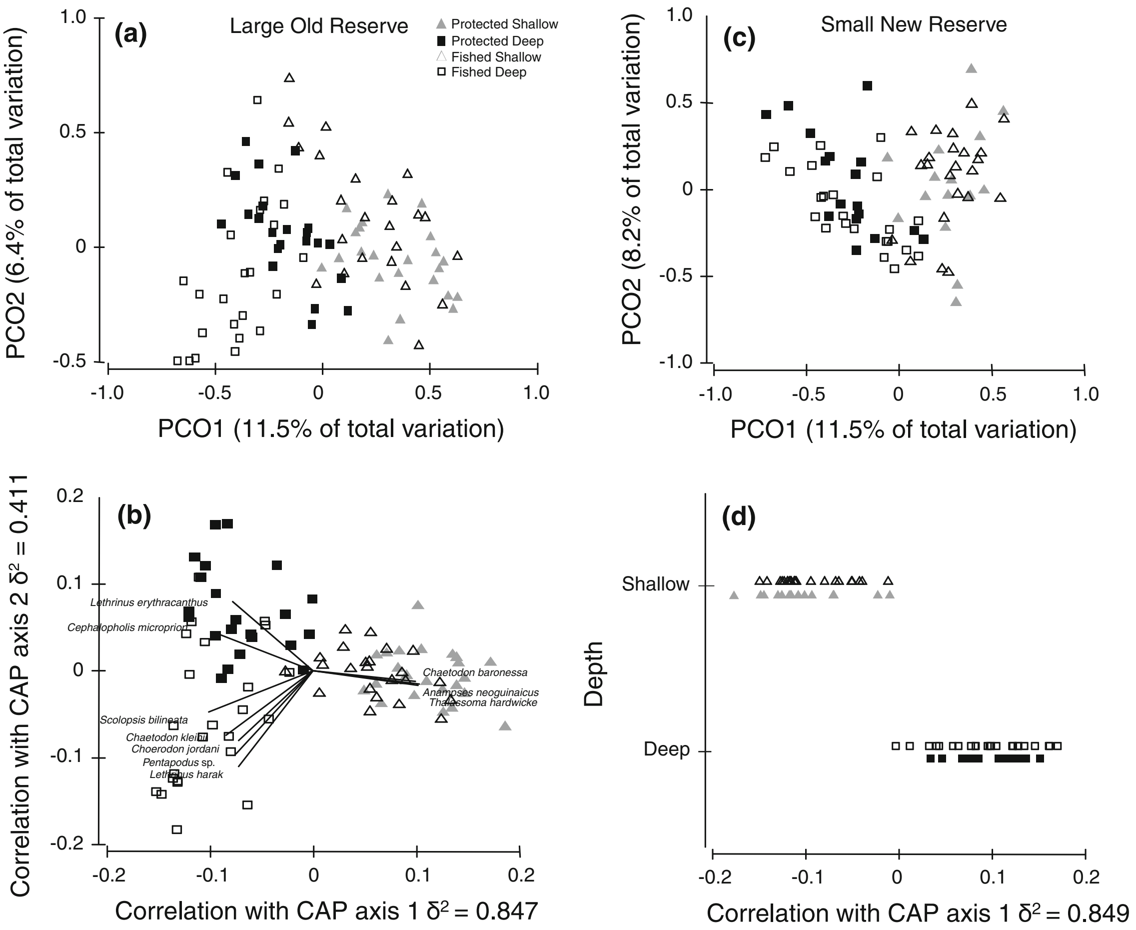

Fig. 3 **a**, **c** Principle coordinate ordination (PCO) and (**b**, **d**) Canonical analysis of principal coordinates (CAP) ordination based on Modified Gower Log 10 dissimilarities for Status (*shaded* versus *unshaded symbols*) and Depth (*black squares* versus *grey triangles*) for the large old and young new reserves. Species correlations with the canonical axis are represented as vectors for species with Pearson *R* value greater than 0.6; e.g. *Cephalopholis microprion* is positively correlated with deep protected sites. Choice of $m = 6$ for the large old reserve and $m = 12$ for the small new reserve

absence data found 10 species to be highly correlated ($|r| > 0.4$) with shallow water protected areas (ESM Appendix 2), whilst no species were correlated with fished areas. Seven out of these 10 species were targeted, suggesting that the difference in species richness was driven by the depletion of these species from shallow fished areas, again supporting the depth refuge hypothesis (ESM Appendix 2). For the small new reserve, there was no significant difference in species richness inside and outside of the reserve or between deep and shallow sites (Table 1; Fig. 2).

Table 3 PERMANOVA for the total abundance of food fish grades high, medium, low and non-targeted species in response to *Status* (St), *Depth* (De) and *Site* for the large old reserve

Source	*df*	Large old reserve					
		High grade			Medium grade		
		MS	*Pseudo-F*	*P(perm)*	MS	*Pseudo-F*	*P(perm)*
Status	1	382.73	6.594	**0.001**	415.26	6.057	**0.019**
Depth	1	66.636	1.148	0.331	62.487	0.911	0.389
StxDe	1	19.97	0.344	0.622	34.563	0.504	0.543
Site (StxDe)	12	58.008	0.94	0.503	68.923	2.399	**0.014**
Res	76	61.714			28.73		
Total	91						

Source	*df*	Low grade			Non-targeted		
		MS	*Pseudo-F*	*P(perm)*	MS	*Pseudo-F*	*P(perm)*
Status	1	1,070.1	4.336	**0.049**	244.57	0.08	0.936
Depth	1	801.04	3.246	0.085	9,814	3.21	**0.018**
StxDe	1	993.52	4.026	0.062	8.47	0.002	0.991
Site (StxDe)[a]	12	245.72	0.679	0.834	32,096		0.677
Res	76	361.71			3,116.8		
Pooled[a]	88	–	–	–	3,056.5		
Total	91						

Bold value indicates a significant $P > 0.05$

[a] Pooled mean squares used when $P > 0.25$ and results not already significant (see Underwood 1997)

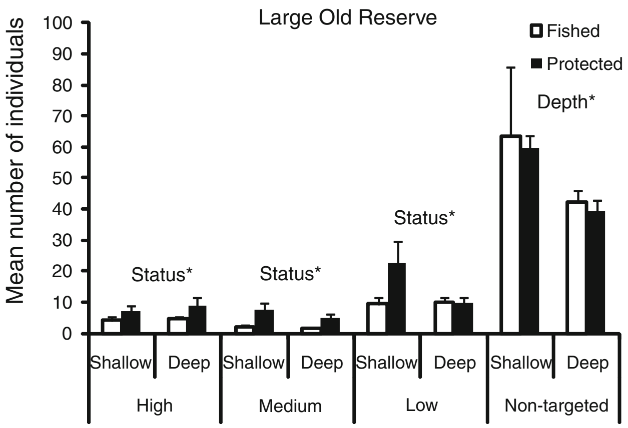

Fig. 4 The mean abundance (+1 SE) for each food fish grade (high, medium, low and non-targeted species) for deep and shallow sites inside and outside the large old reserve. Any significant term in the model is displayed on the plot with an *asterisk* next to its name e.g., (Status*)

Assemblage composition

For the large old reserve, a significant interaction was found between the factors *Status* and *Depth* (Table 2), and pairwise tests found a difference between protected and fished assemblages at deep sites ($t = 1.48$, $P = 0.02$), but not shallow. Further pairwise tests found a significant difference in the assemblage between deep and shallow sites in both protected ($t = 1.954, P = 0.018$) and fished areas ($t = 2.08$, $P = 0.028$). Inside and outside the large old reserve, there was high variability in the fish assemblage structure between sites shown by the significant *Site* term in the model (Table 2). A PCO and CAP analysis of fish assemblages inside and outside the large old reserve showed evidence of the interaction between *Status* and *Depth* (CAP analysis: $\delta^2 = 0.847$; total correct 70/92 = 76.087% using $m = 6$, Fig. 3a, b). The protected and fished sites in the deep were separated into groups indicating a difference in the structure of the assemblage. For the large old reserve, numerous species of fish contributed to the observed difference in assemblage structure, as indicated by Pearson's correlations with the canonical axis. Species highly correlated with the canonical axis of *Status* ($|r| > 0.6$) are displayed as vectors on Fig. 3b. The species *Lethrinus erythracanthus* and *Cephalopholis microprion* correlated positively with deep protected sites. They are both high-grade food fish, and therefore highly targeted (ESM Appendix 2). All species positively correlated with fished deep sites were non-targeted with the exception of *Lethrinus harak*.

Inside and outside the small new reserve, there was a significant difference in the structure of the fish

Table 4 PERMANOVA for the total abundance of food fish grades high, medium, low and non-targeted species in response to *Status* (St), *Depth* (De) and *Site* for the small new reserve

Source	*df*	Small new reserve					
		High grade			Medium grade		
		MS	*Pseudo-F*	*P(perm)*	MS	*Pseudo-F*	*P(perm)*
Status	1	37.951	1.477	0.281	2.632	0.217	0.679
Depth	1	10.803	0.42	0.615	0.101	0.008	0.939
StxDe	1	43.923	1.71	0.229	0.079	0.007	0.941
Site (StxDe)	10	25.912	1.505	0.118	12.115	0.938	0.508
Res	64	17.223			12.912		
Total	77						
Source	*df*	Low grade			Non-targeted		
		MS	*Pseudo-F*	*P(perm)*	MS	*Pseudo-F*	*P(perm)*
Status	1	57.446	0.571	0.468	124	0.076	0.781
Depth	1	158.67	1.578	0.237	16.867	0.01	0.924
StxDe	1	2.204	0.021	0.882	2,040.9	1.256	0.278
Site (StxDe)	10	101.55	1.645	0.105	1,775.7	1.84	0.069
Res	64	61.743			893.82		
Total	77						

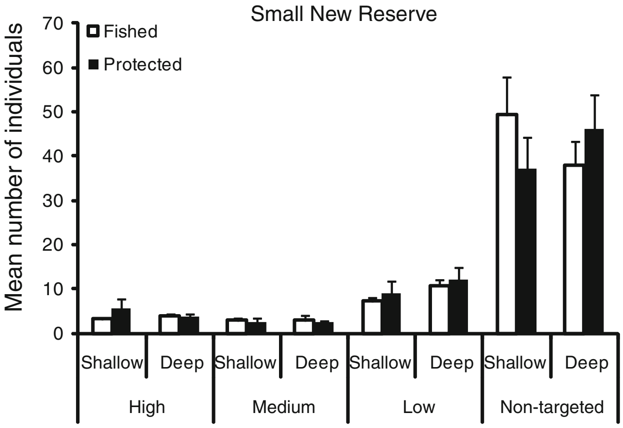

Fig. 5 The mean abundance (+1 SE) for each food fish grade (high, medium, low and non-targeted species) for deep and shallow sites inside and outside the small new reserve. The absence of any symbols indicates no significant terms in the model

assemblage between deep and shallow sites (Table 2). However, no significant differences were found between the assemblages inside the small new reserve and comparable fished sites (Table 2). There was, however, high variability in the fish assemblage structure between sites shown by the significant *Site* term in the model (Table 2). The PCO and CAP analysis for the small new reserve displayed a strong distinction between deep and shallow sites ($\delta^2 = 0.849$; total correct $68/75 = 90.67\%$ using $m = 12$, Fig. 3c, d).

Food fish grades

Inside the large old reserve, significantly greater abundances of high-, medium- and low-grade species were observed, when compared to fished areas for both shallow and deep sites (Table 3; Fig. 4). High value species were on average 84.2% more abundant inside protected areas than fished areas, medium value species 238.8%, low value species 64.8%, and all grades combined 89.9% (Fig. 4). However, for medium value species, there was significant site-to-site variability (Table 3). Non-targeted species showed no significant difference between protected and fished areas for the large old reserve (Table 3; Fig. 4). There was a significant difference in the abundance of non-targeted species with depth, with a greater abundance in the shallow sites (Table 3; Fig. 4).

Within the small new reserve, there was no significant difference with the abundance of high-, medium- and low-grade species or non-targeted species between deep and shallow or protected and fished sites (Table 4; Fig. 5).

Discussion

We observed differences in the composition of coral reef fish assemblage structure between protected and fished areas in a large old reserve. Protected areas had a greater species richness and abundance of targeted species compared to nearby areas open to fishing. This suggests that the artisanal fishing practices in Kubulau District are impacting the fish assemblages and supports the hypothesis that artisanal fishing techniques are capable of decreasing both the species richness and abundance of fish species they target (Jennings and Polunin 1996, 1997; Dulvy et al. 2004; McClanahan and Mangi 2004). These results are also consistent with the shallow water, diver-based studies, conducted in 2007 and 2009, which found that the total reef fish biomass was higher at sites within the large old reserve compared to fished areas (Jupiter and Egli 2011). A number of other studies support these results by documenting the effects of protection on the abundance of targeted species within artisanal areas, including marine reserves in New Caledonia (Chateau and Wantiez 2005), the Philippines (Russ and Alcala 2003; Alcala et al. 2005; Russ et al. 2005), Papua New Guinea (Jones et al. 2004; McClanahan et al. 2006) and the Solomon Islands (Aswani et al. 2007).

In contrast, there was no significant difference in the composition of fish assemblages inside and outside the small new reserve, which does not support our original artisanal fishing hypothesis. This likely relates to the young age (4 years) and small size (4.25 km^2) of this reserve compared with the large old reserve (13 years, 60.6 km^2). The lack of an observable effect of protection for the small new reserve is consistent with the results found by Claudet et al. (2008) in the Mediterranean, who found that a greater size and age of marine reserves will lead to an increase in diversity and abundance of targeted species within their boundaries. However, the number of reserves that were sampled in this study is not sufficient to draw any generalized conclusions as to the effect of the size and age of marine reserves around Fiji. In the same small new reserve, Jupiter and Egli (2011) found a greater biomass of reef fishes when compared to fished areas in 2007 and 2008. However, in 2009, they found the pattern was reversed and suggested that this was caused by an increase in poaching resulting from a presentation to local communities in 2008, highlighting the increase in fish biomass within this reserve (Jupiter and Egli 2011). This pattern of inconsistent differences over time is possibly attributed to the reserve being more susceptible to the effects of poaching given its small size.

The exposed reef fronts of Kubulau District were found to be extremely rich in species, with the large old reserve having on average 8 more species per deployment than the surrounding fished areas. Species richness tended to be greater in protected areas than fished areas for the shallow sites, but appeared to be similar between the deep sites of the large old reserve. The majority of species driving the greater species richness in the shallow protected areas were targeted species. This result is indicative of a depth refuge effect, which may have been caused by the limitation of artisanal fishing techniques (such as spearing) to fish at depths greater than 15 m and supports our depth refuge hypothesis (Adams et al. 2010). These fishing techniques may have removed rarer species targeted by fisheries from shallow fished sites and had little effect on these species in the deep. These results are supported by Tyler et al. (2009) who found evidence of a depth refuge in fished areas, also indicated by greater species richness with increasing depth.

In contrast, differences in the abundance composition between protected and fished areas were observed in deep sites, but not in shallow sites. This contradicts both our original depth refuge hypothesis and our species richness results but suggests that marine reserves in the area are effectively protecting fish assemblages at greater depths (25–30 m) than first predicted. Overall, these contradicting results suggest that shallow water artisanal fishing techniques may reduce species richness by removing rare targeted species from the shallows, but have little effect on the abundance composition of reef fishes. It may also be that the line fishing techniques used in Kubulau District are having a greater effect on the more common targeted species than first predicted, resulting in the differences found in deep water between protected and fished areas. Information on the frequency and depth range for each of the artisanal fishing techniques is needed to further investigate the existence of any depth refuge effect on the abundance of these fish assemblages.

There were significant changes in the fish community with depth changes ($>$ 20 m) supporting our original depth hypothesis. These changes were driven by species such as *Thalassoma hardwicke, Chaetodon baronessa* and *Anampses neoguinaicus* which were associated with shallow sites and *Lethrinus harak, Cephalopholis microprion* and *Choerodon jordani* which were associated with deep sites. A number of studies has documented changes in fish assemblages over such small depth scales supporting our results (Bell 1983; Polunin and Roberts 1993; Ashworth and Ormond 2005; Watson et al. 2007, 2009; Tyler et al. 2009; Friedlander et al. 2010).

In Kubulau District, villages such as Navatu are dependent on the sale of fish as a major source of income (WCS 2009). Thus, the food fish grades that set the prices for fish species in the area should reflect the species targeted by the Kubulau District. The species within food fish grades high, medium and low were all more abundant within the large old reserve than fished areas, supporting our hypothesis that there would be a greater abundance of targeted species within protected areas. In contrast, there was no difference in the abundance of any of the three grades between the small new reserve and comparable fished areas. Two of the main families which make up the high-grade category Lethrinidae and Serranidae were also found to be the major contributors to the differences described by Jennings and

Polunin (1996) in a study of highly and rarely fished areas in Fiji. The current study found that species from the families Siganidae and Scombridae (high grade), Carangidae, Lutjanidae and Haemulidae (medium grade) and Labridae, Mullidae, Acanthuridae, Scaridae and Sphyraenidae (low grade) may also be affected by artisanal fishing with a significant decrease in their abundance in fished areas compared to the large old reserve.

The present study found that artisanal fishing in Kubulau District has reduced the species richness and abundance of targeted species in fished areas. The higher species richness and abundance of targeted species within the large old reserve, but not the small new reserve, suggests that large no-take marine reserves are more effective at protecting these species from fishing given sufficient time and are less likely to be susceptible to the effects of poaching. The lack of data from before the implementation of these marine reserves makes it difficult to distinguish the effects of artisanal fishing from other factors influencing the fish assemblage. However, our study controlled for differences in habitat and found significant results consistent with the effects of fishing, reducing the likelihood of other factors influencing the results. This highlights the importance of obtaining baseline data in areas where marine reserves are proposed. Given that an effect of protection on the abundance structure of fish assemblages was found in the deep and not the shallow, sampling methods not restricted by depth, such as the stereo BRUVs, may be important to complement conventional UVC techniques which are limited by depth. Future monitoring of the no-take marine reserves within Kubulau District will provide insight into any temporal patterns with protection and will help to distinguish the effects of artisanal fishing from any natural changes in the fish community. The further establishment of large no-take marine reserves will be important for ensuring the economic and nutritional well-being of artisanal communities by protecting representative populations of the fish species they target.

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