



THE UNIVERSITY OF WESTERN AUSTRALIA

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



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ABSTRACT

Protection from fishing generally results in an increase in the abundance and biomass of targeted fishes within marine reserve boundaries. Natural refuges such as depth may also protect targeted species, yet few studies have looked at the effects of depth concomitant with marine reserves. There is also limited research into the effects of protection on assemblages of coral reef fish in developing countries where fishing is mostly small-scale and artisanal. The effects of protection and depth on assemblages of reef fish in the Kubulua district off Vanua Levu Island, Fiji were studied using stereo Baited Remote Underwater Video systems. Videos were collected from shallow (5-8 m) and deep (25-30 m) sites inside and outside of the Namena reserve (60.6 km², 13 years old) and Namuri reserve (4.25 km², 4 years old). The relative abundances of 341 species and biomass of 258 species was recorded. In the shallow waters of the Namena reserve species richness was 34% greater than surrounding fished areas, while in deep waters of the reserve, species richness was only 9% greater than comparable fished areas. For the Namena reserve, differences in the assemblage composition of fishes existed between protected and fished areas in the deep, but not in the shallow, indicating no effect of a depth refuge on the biomass or abundance of fishes. Targeted fish species belonging to the food fish grades A, B and C (highest price to lowest) of the Kubulua district were more abundant in the Namena reserve than surrounding fished areas, while the remaining non-targeted species were not. There were no differences in the species richness, abundance or biomass of targeted and non-targeted species inside and outside of the Namuri reserve. This is most likely due to its smaller size and age when compared to the Namena reserve. This study suggests that artisanal fishing may impact on the structure of assemblages of fishes, but differences may only be detected in large reserves that have been established for a long period of time. This effect of protection also appears to vary with depth, highlighting the importance of incorporating multiple depth strata in the design of marine reserves and sampling over this full depth range when monitoring.

Table of Contents

ABSTRACT	2
List of figures	5
List of tables	7
ACKNOWLEDGEMENTS	9
1. INTRODUCTION	10
2. MATERIALS AND METHODS	17
Study Area	17
Sampling Design	17
Sampling Technique	20
Data Collection and Measurements	21
Habitat	21
Species richness	21
Abundance and length	21
Biomass	22
Data Analysis	22
Habitat	23
Univariate Analysis	23
Multivariate Analysis	23
3. RESULTS	25
Assemblage Description	25
Habitat	25
Species Richness	25
Assemblage composition (abundance)	26

Univariate abundance.....	29
Targeted Species.....	30
Non-targeted Species.....	31
Food fish grades.....	35
Assemblage composition (biomass).....	38
Univariate Biomass	41
Targeted Species.....	42
Non-targeted Species.....	43
Food fish grades.....	44
4. DISCUSSION	50
REFERENCES	60
APPENDIX 1	68
Abbreviations list	70
Definitions.....	70

List of figures

- Figure 1:** Map of the Kubulua qoliqoli off Vanua Levu Island. The pink shading shows the no-take Marine Protected Areas introduced by the FLMMA initiative. Squares represent sampling sites inside and out of the Namena MPA and circles represent sites inside and out of the Namuri MPA. Filled symbols represent shallow (5-8 m) sampling sites and open symbols represent deep (25-30 m) sites..18
- Figure 2:** Diagram of a stereo Baited Remote Underwater Video system (Courtesy of Dr Timothy Langlois).....20
- Figure 3:** The mean (+ 1SE) number of species per stereo BRUV drop is shown for deep and shallow sites inside and outside of the Namuri and Namena reserves. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found.26
- Figure 4:** (a) Principle coordinate ordination (PCO) and (b) Canonical analysis of principal coordinates (CAP) ordination based on Modified Gower Log 2 dissimilarities for status (*shaded vs. unshaded symbols*) and depth (*squares vs. triangles*) in the Namena reserve. Species correlations with the canonical axis are represented as vectors for species with Pearson R values greater than 0.6; e.g. *Lethrinus erythracanthus* is positively correlated with Deep Protected sites. Choice of m = 12.28
- Figure 5:** (a) Principle Coordinate ordination (PCO) and (b) Canonical analysis of principal coordinates (CAP) ordination based on Modified Gower Log 2 dissimilarities for status (*shaded vs. unshaded symbols*) and depth (*squares vs. triangles*) in the Namuri reserve. Choice of m = 14. The maximum number of PCO axes was set at 2.29
- Figure 6:** Total number of individuals from the MaxN per stereo BRUV drop is shown for deep and shallow sites in the Namuri and Namena reserves. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found. ..30
- Figure 7:** Mean abundance of targeted (right column) and non targeted (left column) species inside (*black*) and outside (*white*) of each reserve for deep and shallow sites. Error bars = +SE. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found. The food fish grade for each species is shown in brackets (A, B or C) with NT representing the non-targeted species.....32

Figure 8: The mean abundance for each food fish grade A, B, C and Non-target species is shown for deep and shallow sites in the Namena reserve. Error bars = +SE. The species *Lethrinus harak* has been removed from the Grade A category. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found. 36

Figure 9: The mean abundance for each food fish grade A, B, C and non-target species is shown for deep and shallow sites in the Namuri reserve. Error bars = +SE. The species *Lethrinus harak* has been removed from the grade A category. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found. 37

Figure 10: (a) Principle Coordinate Ordination (PCO) and (b) Canonical analysis of principal coordinates (CAP) ordination based on Modified Gower Log 10 dissimilarities for status (*shaded* vs. *unshaded* symbols) and depth (*squares* vs. *triangles*) for the Namena reserve. Species correlations with the canonical axis are represented as vectors for species with Pearson R value greater than 0.4; e.g. *Cephalopholis microprion* is positively correlated with Deep Protected sites. Choice of m = 6. The maximum number of PCO axes was set at 2. 40

Figure 11: (a) Principle Coordinate Ordination (PCO) and (b) Canonical analysis of principal coordinates (CAP) ordination based on Modified Gower Log 10 for status (*shaded* vs. *unshaded* symbols) and depth (*squares* vs. *triangles*) for the Namuri reserve. Choice of m = 12. The maximum number of PCO axes was set at 2. 41

Figure 12: Mean biomass per stereo BRUV drop is shown for deep and shallow sites in the Namuri and Namena reserves. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found. 42

Figure 13: Mean biomass of targeted (right column) and non targeted (left column) species inside (*black*) and outside (*white*) of each reserve for deep and shallow sites. Error bars = +SE. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found. The food fish grade for each species is shown in brackets (A, B or C) with NT representing the non-targeted species. 45

Figure 14: The mean abundance for each food fish grade A, B, C and non-target species is shown for deep and shallow sites in the Namena reserve. Error bars = +SE. The species *Lethrinus harak* has been

removed from the grade A category. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found.48

Figure 15: The mean abundance for each food fish grade A, B and C and non-target species is shown for deep and shallow sites in the Namena reserve. Error bars = +SE. The species *Lethrinus harak* has been removed from the grade A category. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found.49

List of tables

Table 1: Construction of Pseudo-F ratio(s) from mean squares of abundance data.	19
Table 2: Construction of Pseudo-F ratio(s) from mean squares of biomass data.	19
Table 3: PERMANOVA results on the presence absence data for habitat categories based on a Bray-Curtis similarity matrix.	25
Table 4: PERMANOVA based on Modified Gower Log 2 dissimilarities of the relative abundances of 341 fish species for the Namena and Namuri reserves in response to Status (St), Depth (De), Sites and their interactions.	27
Table 5: PERMANOVA Pairwise tests for the term Status x Depth in the Namena reserve.	27
Table 6: Results of three-factor PERMANOVA examining the abundance of conspicuous species in response to the factors site, status and depth in the Namena reserve.	33
Table 7: Results of three-factor PERMANOVA examining the abundance of conspicuous species in response to the factors site, status and depth in the Namuri reserve.	34
Table 8: PERMANOVA for the univariate abundance of food fish grades A, B and C and non-targeted species in response to Status (St), Depth (De) and Site for the Namena reserve. The species <i>Lethrinus harak</i> has been removed from the grade A category.	35
Table 9: PERMANOVA for the univariate abundance of food fish grades A, B and C and non-targeted species in response to Status (St), Depth (De) and Site for the Namuri reserve. The species <i>Lethrinus harak</i> has been removed from the grade A category.	37

Table 10: PERMANOVA based on Modified Gower Log 10 dissimilarities of the relative biomass of 258 fish species for the Namena and Namuri reserves in response to Status (St), Depth (De) and Sites and their interactions.....	38
Table 11: PERMANOVA Pairwise tests for the term Status x Depth in the Namena reserve.	39
Table 12: Results of three-factor PERMANOVA examining the biomass of single species of importance in response to site, status and depth in the Namena reserve.....	46
Table 13: Results of three-factor PERMANOVA examining the biomass of single species of importance in response to site, status and depth in the Namuri reserve.....	47
Table 14: PERMANOVA for the univariate biomass of food fish grades A, B and C and non-targeted species in response to Status (St), Depth (De) and Sites for the Namena reserve. The species <i>Lethrinus harak</i> has been removed from the grade A category.....	48
Table 15: PERMANOVA for the univariate biomass of food fish grades A, B and C and non-targeted species in response to Status (St), Depth (De) and Sites for the Namuri reserve. The species <i>Lethrinus harak</i> has been removed from the grade A category.....	49

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1. INTRODUCTION

Exploitation of the marine environment is decreasing the ocean's biodiversity and increasingly impairing the ocean's capacity to provide food (Worm *et al.* 2006). Pauly (2007) predicts that the present exploitation patterns are unsustainable. This has implications for areas of the Indo Pacific where the majority of fishing is artisanal and fisheries resources are essential for nutrition and employment (Pet-Soede *et al.* 2001; McClanahan 2004; Jones *et al.* 2009). Most artisanal communities lack information on fisheries yields or *in-situ* fish abundance (Pauly *et al.* 1998; Pet-Soede *et al.* 2001; Jones *et al.* 2009). The data available for tropical marine ecosystems has shown that an increase in fishing pressure in the past has caused shifts in species composition (Jennings and Polunin 1996; Jennings and Polunin 1997; Dulvy *et al.* 2004), a decline in species richness (Dulvy *et al.* 2004; McClanahan 2004), depletion of carnivorous species and the dominance of fish from lower trophic levels (Jennings and Polunin 1997). Such cascading effects have been shown to occur not only within highly fished ecosystems, but also in areas of relatively low fishing intensities such as those targeted by artisanal communities (Jennings and Polunin 1996; McClanahan and Arthur 2001; Dulvy *et al.* 2004; Campbell and Pardede 2006). Although fishing intensity within these areas is generally low, artisanal fishers target many more species and employ a greater variety of catching techniques than commercial fishers and are increasingly believed to threaten coastal stocks (Pet-Soede *et al.* 2001; McClanahan 2004; Mangi and Roberts 2006; Jones *et al.* 2009).

The use of no-take marine reserves to protect assemblages of reef fishes

No-take marine reserves are areas of the sea protected from fishing and other extractive or harmful human uses (also known as no-take marine protected areas, no-take zones and marine sanctuaries, Roberts and Hawkins 2000). The use of no-take reserves for biodiversity conservation and resource protection is becoming increasingly common as a way to combat the historical and recent collapse of many fisheries and ecosystems

(Halpern and Warner 2002; Halpern 2003; Gladstone 2007). The implementation of no-take reserves is seen as an efficient and inexpensive method to maintain fisheries and preserve biodiversity and biomass of biota contained within them (Allison *et al.* 1998; Bohnsack 1998). Reviews summarising previous research suggest that no-take reserves enhance biodiversity and increase the abundance, biomass and size of targeted species which may lead to increased recruitment and immigration 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). At a species level the effects of no-take reserves are often not detected unless they are targeted species. However, the effects on trophic groups are well documented and usually occur in the form of an increase in carnivorous and piscivorous species (Kulbicki *et al.* 2007) and in some cases grazing fish (Mumby *et al.* 2006). Some studies have recorded effects of protection on non-targeted species. These effects usually involve a decline in the abundance and biomass within protected areas, which may be caused by an increase in the abundance and subsequent predation by piscivorous species (Jennings and Polunin 1997; McClanahan *et al.* 1999; Watson *et al.* 2007; Watson *et al.* 2009).

Within the large body of evidence demonstrating the positive effects of reserves on the diversity, abundance and biomass of the biota contained within them, results of protection vary both in direction and magnitude (Halpern and Warner 2002). The most likely reason for this heterogeneity in results is the varying size and age of reserves (Botsford *et al.* 2003). A number of theoretical studies suggest that large reserves should be more effective for conservation purposes than small reserves (Botsford *et al.* 2001; Botsford *et al.* 2003; Hastings and Botsford 2003; Roberts *et al.* 2003). Some empirical studies have not supported this hypothesis (Cote *et al.* 2001; Halpern 2003; Guidetti and Sala 2007) suggesting either a failure of the theory or synthesis of the data. However, a recent study suggests the theory is correct and the response to protection is reserve size-dependent (Claudet *et al.* 2008). The same argument is apparent within the literature on the effect of age of reserves. Some empirical studies within newly established no-take reserves of 1-3 years have documented increases in the abundance, size and biomass of

fishes and a possible increase in their diversity (Dufour *et al.* 1995; Halpern and Warner 2002; Denny and Babcock 2004; Ashworth and Ormond 2005). Other studies suggest a much longer time frame is necessary, in excess of 10 years (Micheli *et al.* 2004; Russ and Alcala 2004; Claudet *et al.* 2008). These conflicting results may be due to differences in the life history characteristics of fish species, suggesting that the size and age requirements of marine reserves may change for different fish assemblages.

The effects of depth

The composition of assemblages of fishes has been known to change over large depth gradients of hundreds or thousands of metres (McGehee 1994; Friedlander and Parrish 1998; Brokovich *et al.* 2006; Brokovich *et al.* 2008). However, few studies have revealed strong relationships between fish assemblage characteristics and depth over much smaller scales of tens of metres (Suarez *et al.* 2004; Tyler *et al.* 2009). There are few studies that have looked at the effect of depth concomitant with the effect of protection on assemblages of reef fish (Polunin and Roberts 1993; Ashworth and Ormond 2005; Watson *et al.* 2007; Tyler *et al.* 2009; Watson *et al.* 2009). Natural refuges in the marine environment may be created by the limitation of artisanal communities to fish, in deep water, far from shore, in difficult habitats or adverse weather conditions (Tyler *et al.* 2009). Given these premises targeted species occurring in the deep may not be effected to the same extent by fishing, giving a „depth refuge“ effect in artisanal communities yet only one study has quantified this explicitly (Tyler *et al.* 2009). Tyler *et al.* (2009) examined evidence for a depth refuge effect in Tanzania. The authors found that the species richness of targeted fish was depleted by 15% in shallow fished reefs when compared to protected reefs, but there was no difference between protected and fished reefs deeper than seven metres (Tyler *et al.* 2009). This suggests that a depth refuge effect can be detected by comparing protected and fished areas in deep sites with protected and fished sites in shallow sites. However, the majority of studies on marine reserves are limited to very shallow waters with only two studies in the Indo-pacific incorporating depths greater than 15 m, explaining the lack of evidence on the effects of depth refuge (Galal *et al.* 2002; Aswani *et al.* 2007). In

addition the sole study on the effects of depth refuge Tyler *et al.* (2009) provides no information on how this phenomenon may affect the relative abundance and biomass of targeted species.

Fiji

In Fiji, an inshore coastal area belonging to a certain community (normally a district or province) is called a qoliqoli. Qoliqolis are traditionally owned fishing grounds that are passed down from generation to generation and are managed by the local communities. Traditionally, when the chief of a village dies a portion of the community's fishing ground is set aside as temporary no-take, or tabu area as a token of respect to the chief. After 100 days the area is re-opened and the community harvests the potentially increased biomass of fish to hold a feast that ends the mourning period. Tabu areas have recently been applied with a more permanent time frame and independent of the death of a chief, under the Fiji Locally Managed Marine Area (FLMMA) initiative (Aalbersberg *et al.* 2005). The establishment of these permanent no-take reserves in Fiji is based around a modern version of such tabu areas and has been implemented in nearly 60 sites around Fiji (Aalbersberg *et al.* 2005). No rigorous and quantitative data are available on what effect the prohibition of fishing has had on the composition and size structure of the assemblages of fishes in these areas, and in particular on the relative abundance and size of exploited species. In the Kubulau qoliqoli, located off the island of Vanua Levu, a conglomerate of 14 traditional tabu areas and three relatively large no-take reserves were established, providing an ideal opportunity to investigate the functionality of these management measures. These reserves extend from inter-tidal areas to depths of 50 m.

In the Kubulua district of Fiji the majority of fishing effort is artisanal with the most common fishing gear being nets, fishing lines and spear and snorkel (WCS 2009). As fishing with SCUBA is prohibited and flippers are generally not used by local fishermen, the fishing impact from spear and snorkel is most likely limited to a depth of around 15 m, which only experienced free divers can reach (WCS 2009). Nets used in the area, are predominantly "hand", "cast" or "wading" nets, limiting them to shallow

waters. This may focus the effects of fishing on targeted fish species to shallow habitats from 0-15 m. Fishing lines are not limited by depth and can easily access depths in excess of 15 m, but are generally used in fine weather conditions only. In the Kubulua district fish are sold through a “middle man” in the Navatu village to the local fish market in Savusavu and those that are not sold are kept for local consumption. In the Kubulau district 84% of households in coastal villages reported fishing as a source of income, making the resource essential to the wellbeing of the community (WCS 2009). The fish species which are sold by the villages are broken up into three grades: A, B and C. Each grade attracts a different price with the species from grade A, selling at \$3.50 per kg, grade B at \$3.00 per kg and grade C at \$2.00 per kg. These grades therefore strongly influence which species are targeted in the Kubulua district, as a much greater amount of fish is sold than consumed by the villages (WCS 2009). Fish consumed in the village include most species which can be consumed safely, but are not included within the grades, as they do not attract a market price. There is, however, no quantitative record available on the species which locals from the Kubulua district consume, so they cannot be added to the list of targeted species.

Sampling techniques

To test the effectiveness of no-take reserves it is fundamentally important to have the ability to make accurate estimates of the relative abundance, and size structure of the biota contained within them (Roberts 1993; Jennings and Kaiser 1998; Halpern 2003). There are a number of methods which can be used to obtain such data from no-take reserves and determine their effectiveness in protecting ecosystems and exploited species. The most commonly used method when monitoring fish populations is Underwater Visual Census (UVC), where a diver using a self contained breathing apparatus (SCUBA) or snorkeler identifies, counts and estimates the lengths of fishes within a predefined area (Harmelin-Vivien *et al.* 1985; Kingsford and Battershill 1998; Russ *et al.* 2005). The advantages of UVC methods are that they are non-destructive, relatively rapid and cost effective, and do not require subsequent lab work. However, the limitations of UVC techniques include: variability in the response of fish to a diver

(Stobart *et al.* 2007; Watson and Harvey 2007); variation in diver-swimming speed (Smith 1988); failure to correctly identify and estimate the length of individual fish (Harvey *et al.* 2000; Harvey *et al.* 2001); variability within and between observers (Thompson and Mapstone 1997); and limitation on the depth and duration of surveys done by SCUBA (Stobart *et al.* 2007). In Fiji, UVC surveys have been carried out in three of the large no-take reserves of the Kubulau qoliqoli (Figure 1) to compare the abundance and size structure of targeted species of fish. However, due to observer variability no conclusions about the effects of protection have been drawn from the data (Daniel Egli Pers comm.).

Stereo Baited Remote Underwater Video systems (stereo BRUVs) have emerged as a potential technique for overcoming biases associated with UVC techniques. The method eliminates the need for SCUBA divers, reduces the risk of incorrect fish identifications, reduces observer and inter-observer variability, and produces highly accurate length measurements (Harvey and Shortis 1996; Harvey *et al.* 2000; Harvey *et al.* 2001; Harvey *et al.* 2002; Harvey *et al.* 2004; Watson *et al.* 2005; Watson *et al.* 2007). Video techniques provide a permanent record of the fish observed and can access depths beyond limits to divers (Cappo *et al.* 2004; Stobart *et al.* 2007).

Baited video is a very effective tool when sampling carnivorous fish inside and outside of reserves, as they provide non-destructive data on predatory species that are often targeted by fishers (Willis and Babcock 2000; Willis *et al.* 2000; Westera *et al.* 2003). The use of bait increases the numbers of predatory and scavenging species recorded when compared with both UVC and unbaited Remote Underwater Video (RUV) (Harvey *et al.* 2007). Some studies have shown that the attraction of predatory species to BRUVs does not decrease the abundance of herbivorous or omnivorous fishes recorded during sampling when compared to un-baited RUV or UVC techniques (Watson *et al.* 2005; Harvey *et al.* 2007). However, like UVC, stereo-video techniques have biases, such as reliance on good visibility, conservative relative abundance and biomass measures and complexities in determining the area sampled due to variability in the bait plume (Priede and Merrett 1998; Bailey and Priede 2002). The variability in the distance

the bait plume travels and the response from different species limits stereo BRUVs to measures of relative abundance (Harvey *et al.* 2007). Given the differences in limitations between baited video and UVC, a combination of these techniques may be required to achieve the most complete description of assemblages of reef fish (Willis and Babcock 2000; Watson *et al.* 2005).

Aims and research questions

By sampling inside and out of two no-take reserves, this study aims to investigate the effects that artisanal fishing has on the assemblages of reef fishes in the Kubulau qoliqoli. This study will investigate the differences in the relative abundance and biomass of assemblages of reef fishes between two permanent no-take marine reserves and adjacent fished areas. By sampling at two different depths, I will be able to examine the differences in assemblages of targeted and non-targeted fishes across a depth gradient inside and out of these reserves and determine if there is evidence of a depth refuge effect occurring in the area. Key research questions are:

- a) Is there a greater abundance of targeted fish inside the marine reserves than outside?
- b) Is there an interaction of depth and protection, where there is a greater abundance of targeted fish in protected areas than fished areas in the shallow but not the deep?
- c) Does the reef fish assemblage structure differ between the deep and shallow sites sampled within the study?

These three research questions will also be tested on the species richness, assemblage composition (abundance and biomass) and the biomass of conspicuous targeted and non-targeted species.

2. MATERIALS AND METHODS

Study Area

The survey was carried out at the Kubulau fishing ground (qoliqoli), Vanua Levu Island Fiji from the 4th - 28th of July 2009. The largest reserve is Namena Island with a total area of 60.6 km². This reserve was established in 1997 and surrounds the island of Namena where an eco-resort is located. The Namuri reserve is considerably smaller than the Namena reserve at 4.25 km². This reserve was established in 2006 and is situated close to the Navatu village. Each of these reserves is strictly no-take, prohibiting the removal of any living organisms from within their boundaries. The third no-take reserve, the Nasue, was not directly comparable as it is situated close to an estuary and was not sampled during this study. The total area of Kubulau's qoliqoli is 262 km² and is comprised of a network of 17 reserves, totalling approximately 80 km², or approximately 30% of the qoliqoli (Figure 1).

Sampling Design

Sampling was carried out inside and outside of the Namuri and Namena reserves in deep and shallow sites. Four sampling sites were chosen inside the Namena reserve and four outside in fished areas (Figure 1). Due to the small size of the Namuri reserve, only three sampling sites were chosen inside the reserve and four outside in fished areas (Figure 1). This sampling pattern was repeated for shallow sites 5-8 m and deep sites 25 - 30 m. Six baited remote underwater video systems (stereo BRUVs) were deployed at each site at least 150 m apart, giving a total of 180 drops. Only three of these replicate drops were filmed at each site at the same time to prevent the attraction of the same fish to multiple stereo BRUVs. This ensured that the drops were at least 300 m apart whilst in the water and prevented a whole site from being sampled at the same time of day. The full 180 drops were not used in the final analysis of the abundance or biomass data (Tables 1,2) as some drops were removed due to an insufficient field of view as discussed below.

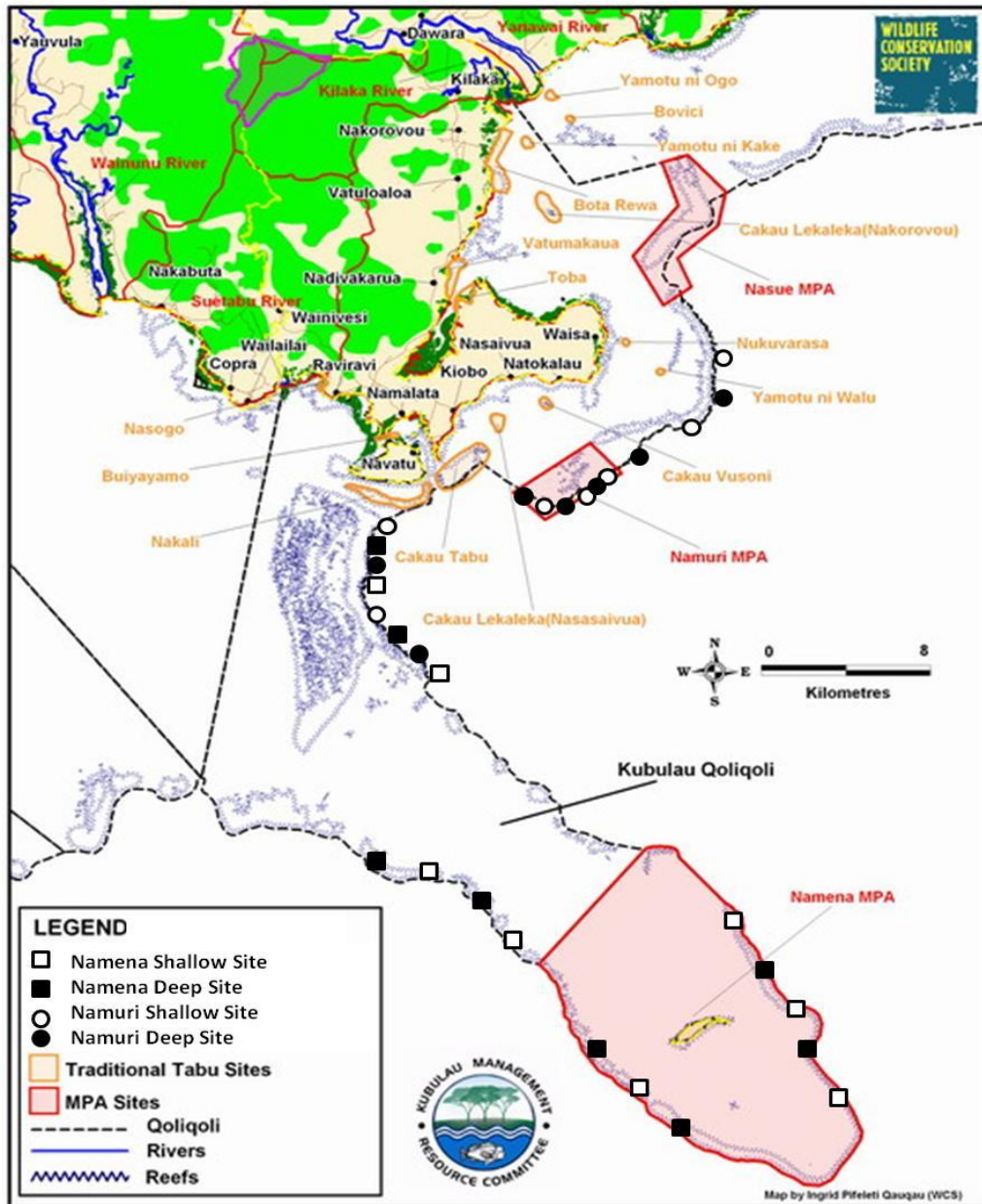


Figure 1: Map of the Kubulua qoliqoli off Vanua Levu Island. The pink shading shows the no-take Marine Protected Areas introduced by the FLMMA initiative. Squares represent sampling sites inside and out of the Namena MPA and circles represent sites inside and out of the Namuri MPA. Filled symbols represent shallow (5-8 m) sampling sites and open symbols represent deep (25-30 m) sites.

The two reserves Namena and Namuri were separated in the design due to their contrast in size and age. The sampling design for each reserve consists of three factors. Status (two levels, fixed: protected vs. fished), depth (two levels, fixed: Shallow, 5-8 m and

Deep, 25-30 m) and site (random, nested in status $\times$ depth, 4 levels at each depth) (Table 1, 2). Due to a lack of suitable habitat close to the Namena reserve, fished sites were placed in-between the fished sites of the Namuri reserve closest to the Navatu village (Figure 1). The design for the biomass and abundance data was separated as biomass could not be calculated for some stereo BRUV drops, causing differences in the number or replicates.

Table 1: Construction of Pseudo-F ratio(s) from mean squares of abundance data.

Namena				
Source	Numerator	Denominator	Num.df	Den.df
<u>Status</u>	St	$0.991 * Si(StxDe) + 9.197E-3 * Res$	1	12.17
<u>Depth</u>	De	$0.991 * Si(StxDe) + 9.197E-3 * Res$	1	12.17
StxDe	StxDe	$0.991 * Si(StxDe) + 9.197E-3 * Res$	1	12.17
Si(StxDe)	Si(StxDe)	$1 * Res$	12	76

Namuri				
Source	Numerator	Denominator	Num.df	Den.df
<u>Status</u>	St	$0.975 * Si(StxDe) + 2.5218E-2 * Res$	1	10.4
<u>Depth</u>	De	$0.975 * Si(StxDe) + 2.5218E-2 * Res$	1	10.4
StxDe	StxDe	$0.975 * Si(StxDe) + 2.5218E-2 * Res$	1	10.4
Si(StxDe)	Si(StxDe)	$1 * Res$	10	64

Table 2: Construction of Pseudo-F ratio(s) from mean squares of biomass data.

Namena				
Source	Numerator	Denominator	Num.df	Den.df
<u>Status</u>	St	$0.978 * Si(StxDe) + 0.022 * Res$	1	12.49
<u>Depth</u>	De	$0.978 * Si(StxDe) + 0.022 * Res$	1	12.49
StxDe	StxDe	$0.978 * Si(StxDe) + 0.022 * Res$	1	12.49
Si(StxDe)	Si(StxDe)	$1 * Res$	12	68

Namuri				
Source	Numerator	Denominator	Num.df	Den.df
<u>Status</u>	St	$0.951 * Si(StxDe) + 0.05 * Res$	1	10.92
<u>Depth</u>	De	$0.951 * Si(StxDe) + 0.05 * Res$	1	10.92
StxDe	StxDe	$0.951 * Si(StxDe) + 0.05 * Res$	1	10.92
Si(StxDe)	Si(StxDe)	$1 * Res$	10	61

Sampling Technique

This study used stereo BRUVs to sample the fish communities inside and outside of the reserves in the Kubulua qoliqoli. Stereo BRUVs consist of a trestle shaped, galvanized frame, with a base bar running horizontally within, holding two water proof camera housings (Figure 2). Each of these housings are inwardly converged at 7° to enable a three dimensional calibration used to estimate the size of fish. Sony Mini-DV HandiCams (Model HC15) with wide-angle lens adapters ($0.6\times$) situated inside of the aluminium housings were used to record the fish populations. The camera setting exposure was set to „Auto“, focus set to „Infinity/Manual“, and „Standard Play“ mode was selected. Bait arms with a plastic coated mesh canister containing 1 kg of pilchards as bait were attached to the front of the frame and lie just off the seabed in plain view of the cameras (Figure 2). A diode is attached to the bait arm to enable the synchronisation of the stereo images. Ropes with 2 surface floats were attached to the stereo BRUVs for deployment, re-location and retrieval. Retrieval was assisted by a manual winch and davit arm.

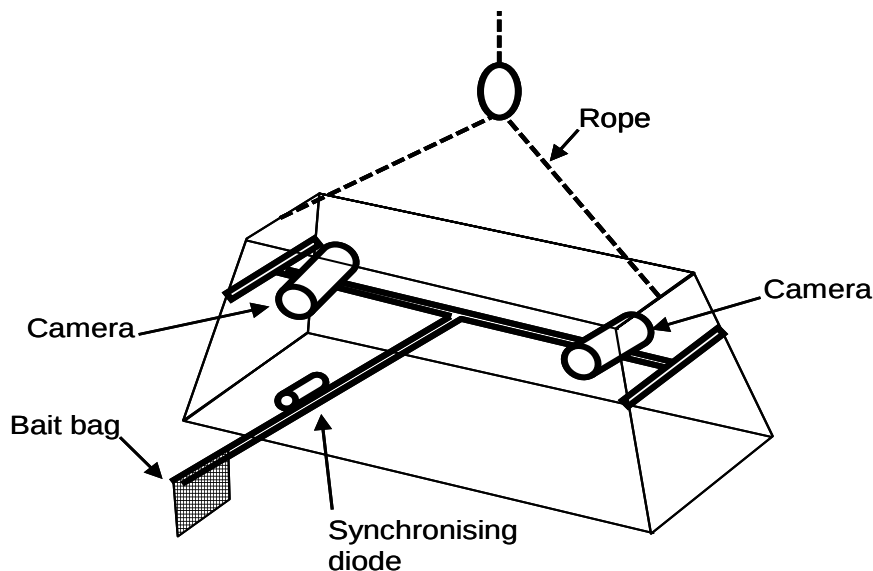


Figure 2: Diagram of a stereo Baited Remote Underwater Video system (Courtesy of Dr Timothy Langlois).

Calibration of the Stereo BRUVs allows for measurements to be made and ensures the accuracy and precision of this data. Calibration of the cameras followed the methods outlined by (Harvey and Shortis 1996) and (Shortis and Harvey 1998). Video imagery was captured in Audio Video Interlace (AVI) format using Adobe Premier Pro 2.0.

Data Collection and Measurements

Habitat

All drops were randomly stratified over coral reef habitat on the exposed reef edge. Initially drops were classified into three categories, the top or bottom of coral bommies and sand inundated reef. Secondary classification involved the form of coral which made up the highest percentage of the benthos and was classified as Massive, Rubble, Branching or Tabulate coral and Sand. The tertiary 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 and drops with benthos obscuring over 35% of the view were removed from the analysis. Water visibility was consistently good at all sites and greater than 8 m.

Species richness

Species richness was measured as the total number of species per stereo BRUV drop. This allows comparison of the average species richness per drop between protected and fished areas and deep and shallow sites. Species which could not be distinguished from similar species of the same genus were lumped together and labelled spp. for the analysis.

Abundance and length

Identification and abundance estimates of species were made by reviewing captured footage in the laboratory. The maximum number of species at any time (MaxN) was recorded from viewing 60 minutes of footage, and used as a measure of relative abundance. The use of MaxN as an estimator of relative abundance has been reviewed in detail by (Cappo *et al.* 2003). Interrogation of each tape was conducted using the

custom interface (Eventmeasure, SeaGIS 2008). The stereo component of the BRUVs allowed for the collection of length measurements for the majority of fish recorded in the MaxN for each species. Length measurements were calculated by locating the snout and the caudal fork of the focal fish within the synchronised video footage in Photomeasure (SeaGIS 2008). These measurements were recorded in (mm) and used to calculate the biomass of fish between sites. The range from the snout of the fish to the central point between the camera lenses was also automatically computed. No measurements of fish length were made at distances greater than 8 m from the camera. Length measurements were not made for some stereo BRUV drops due to one camera being obscured by reef substrate or technical errors preventing recording.

Biomass

Length-to-weight regressions have been calculated for a number of fish species from previous extractive studies and/or commercial catches and can be found in the literature (Letourneur *et al.* 1998) and (FishBase, Froese and Pauly 2007). These values combined with the length measurements allowed the calculation of biomass (grams) for each individual measured using the standard equation $W = a \times L^b$ described in (Cinco 1982). In total 258 out of the 341 species recorded were used to calculate the relative biomass of fish for each stereo BRUV drop. There were 84 drops used from a possible 96 in the Namena reserve and 75 drops used from a possible 84 in the Namuri reserve.

Data Analysis

Permutational multivariate analysis of variance (herein referred to as PERMANOVA, Anderson *et al.* 2008) with 4999 permutations was used to analyse the habitat, species richness, abundance and biomass data sets using Plymouth Routines in Multivariate Ecological Research (PRIMER-e) package (Clarke and Gorley 2006). Each data set was appropriately transformed and analysed for all factors including interactions of the model. Where main effects or interactions were significant, *a posteriori* comparisons were explored (Anderson 2001). The group *Pterocaesio* spp. was removed from all analysis as there were a number of species within the group which could not be

identified. These are also pelagic species which formed very large schools and so might mask the patterns of other demersal species.

Habitat

The minor biota category in the habitat presence-absence data was given a value of 0.5 compared with 1 for the benthos and major biota so to reduce its importance. A Bray-Curtis similarity matrix was used for the subsequent PERMANOVA. The Bray-Curtis similarity matrix was chosen as it does not count joint absences as similarities making it more ecologically relevant (Anderson *et al.* 2008).

Univariate Analysis

A PERMANOVA using dissimilarity matrices constructed with Euclidean distance was performed on the species richness, average number of individuals and biomass per drop, the abundance and biomass of conspicuous species, targeted species of the food fish grades A, B and C and non-targeted species. Sites were pooled when a $P(\text{perm})$ value greater than 0.25 was found and the factors protection and depth were not already significantly different. Sites were left un-pooled if the factors status and depth did not become significantly different because of the pooling.

Multivariate Analysis

Abundance

A Log 2 Modified Gower dissimilarity matrix was used for the analysis of the multivariate abundance data set. The type of similarity measure used is critical as each choice can highlight specific aspects of the assemblage (Anderson *et al.* 2008). A Log 2 Modified Gower is better suited for comparisons of assemblage structure between two areas as it is more powerful in detecting the average rate of change in species composition between populations sampled as it uses a less severe transformation (Anderson *et al.* 2008).

Biomass

Length measurements were not made for some drops due to technical faults, thereby resulting in an unbalanced model for biomass data. However, PERMANOVA is able to analyse variance in unbalanced multi-factorial designs (Anderson *et al.* 2008). The multivariate biomass data used a Log 10 Modified Gower similarity matrix. The variation in biomass values between sites was much greater than with the abundance data which called for the increase in Log within the Modified Gower similarity matrix.

Ordination analysis (Biomass and Abundance)

A Principle Coordinate analysis (PCO) was produced to show the unconstrained grouping of sites and help visualize any broad patterns in the abundance and biomass data. A Constrained Canonical Analysis of Principal coordinates (CAP) was used to investigate significant factors within these data and to identify the species primarily responsible for the dispersions (Anderson and Robinson 2003; Anderson and Willis 2003). The square of the first canonical correlation (δ^2) will provide an indication of the strength of the observed differences among sites in the data set 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 miss-classification error (see Anderson and Willis 2003). Pearson's product moment correlations of the complete data set 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 and 0.4 for the biomass data, to show only the dominant species which are driving the patterns as there were many species with a high correlation with the canonical axis.

3. RESULTS

Assemblage Description

The stereo BRUVs recorded 11722 individuals of 341 species from 44 families over the two week study. The number of species seen per drop varied from 8 to 83 species. Out of the 341 species, 128 were targeted according to the food fish grades of the Kubulua district. There were 48 species from grade A, 23 species from grade B and 57 in grade C (Appendix 1). The remaining 213 species were classified as non-targeted species for this study because they cannot be sold to local fish markets.

Habitat

Habitat did not vary greatly throughout the study as all drops were on the exposed edge of the reef and contained coral as the major benthos. Habitat did not differ between fished and protected areas for the Namena or the Namuri reserve (Table 3). However, there was a significant difference in habitat between shallow and deep sites for the Namena and the Namuri data sets (Table 3). It was more common for drops to land on top of coral bommies at shallow sites, while drops which landed at the bottom of coral bommies or on flat ground were more prevalent with the deep sites.

Table 3: PERMANOVA results on the presence absence data for habitat categories based on a Bray-Curtis similarity matrix.

Source	Namena				Namuri			
	<i>df</i>	MS	<i>Pseudo-F</i>	<i>P(perm)</i>	<i>df</i>	MS	<i>Pseudo-F</i>	<i>P(perm)</i>
<u>Status</u>	1	2021	0.744	0.494	1	6572.4	2.431	0.085
<u>Depth</u>	1	16514	6.076	0.005	1	11605	4.293	0.015
StxDE	1	5774.8	2.125	0.16	1	1719.8	0.636	0.588
Site (StxDE)	12	2719.5	1.065	0.39	10	2726.4	1.503	0.084
Residual	76	2554.6			64	1814.1		
Total	91				77			

Species Richness

Species richness was 34% greater in protected areas than fished areas for the shallow sites and 9% greater in protected areas than fished areas for the deep sites of the Namena

reserve (Figure 3). The average number of species per drop in the Namena reserve were 22% richer than surrounding fished areas ($Pseudo-F = 5.371$, $P = 0.042$). For the Namuri reserve there was a 3% greater species richness outside of the reserve than inside (Figure 3). There was no significant difference between fished and protected areas ($P > 0.05$). Species richness did not differ with depth in the Namena or Namuri reserves (both $P > 0.05$).

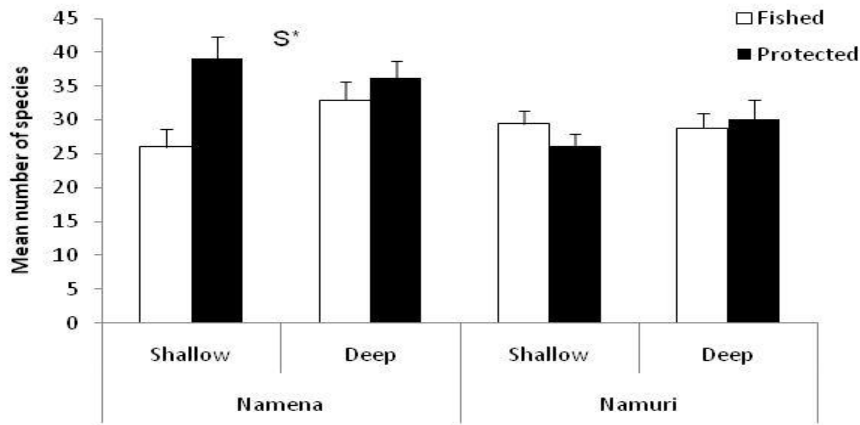


Figure 3: The mean (+ 1SE) number of species per stereo BRUV drop is shown for deep and shallow sites inside and outside of the Namuri and Namena reserves. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found.

Assemblage composition (abundance)

There was high variability in the structure of assemblages of fish between sites, shown by the significant Site (Status x Depth) term in the model (Table 4). A significant interaction was found with the factors status and depth in the Namena reserve (Table 4). Pairwise tests in PERMANOVA were used to examine this significant interaction. A difference between protected and fished assemblages was found in the deep sites but not between shallow sites (Table 5). A significant difference in the assemblages of fishes between deep and shallow sites was found in both the protected and fished areas (Table 5). There was a significant difference in the structure of assemblages of fishes between deep and shallow sites in the Namuri reserve (Table 4). There were no significant

differences in the abundance and composition of fish assemblages between protected and fished sites of the Namuri reserve (Table 4).

Table 4: PERMANOVA based on Modified Gower Log 2 dissimilarities of the relative abundances of 341 fish species for the Namena and Namuri reserves in response to Status (St), Depth (De), Sites and their interactions.

Source	Namena				Namuri			
	<i>df</i>	MS	<i>Pseudo-F</i>	<i>P(perm)</i>	<i>df</i>	MS	<i>Pseudo-F</i>	<i>P(perm)</i>
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			

Table 5: PERMANOVA Pairwise tests for the term Status x Depth in the Namena reserve.

Protected vs. Fished			Deep vs. Shallow		
Groups	t	<i>P(perm)</i>	Groups	t	<i>P(perm)</i>
Deep	1.48	0.02	Protected	1.945	0.018
Shallow	1.219	0.089	Fished	2.08	0.028

A PCO and CAP analysis of Namena showed evidence of the interaction between status and depth (CAP analysis: $\delta^2 = 0.847$; total correct $70/92 = 76.087\%$ using 12 axes). The canonical test statistic was highly significant ($P < 0.001$ using 4999 permutations). The protected and fished sites in the deep were separated into groups indicating a difference in the structure of assemblages of fishes (Figure 4). Numerous species of fish contributed to the observed difference in structure of assemblages of fish, for the Namena reserve, as indicated by Pearson's correlations with canonical axis. Species highly correlated with the canonical axis of Status ($|r| > 0.6$) are displayed as vectors in (Figure 4). The species correlated positively with deep protected sites, *Lethrinus erythracanthus* and *Cephalopholis microprion* are both grade A food fish, and therefore highly targeted (Appendix 1). All species positively correlated with fished deep sites are non-targeted with the exception of *Lethrinus harak*.

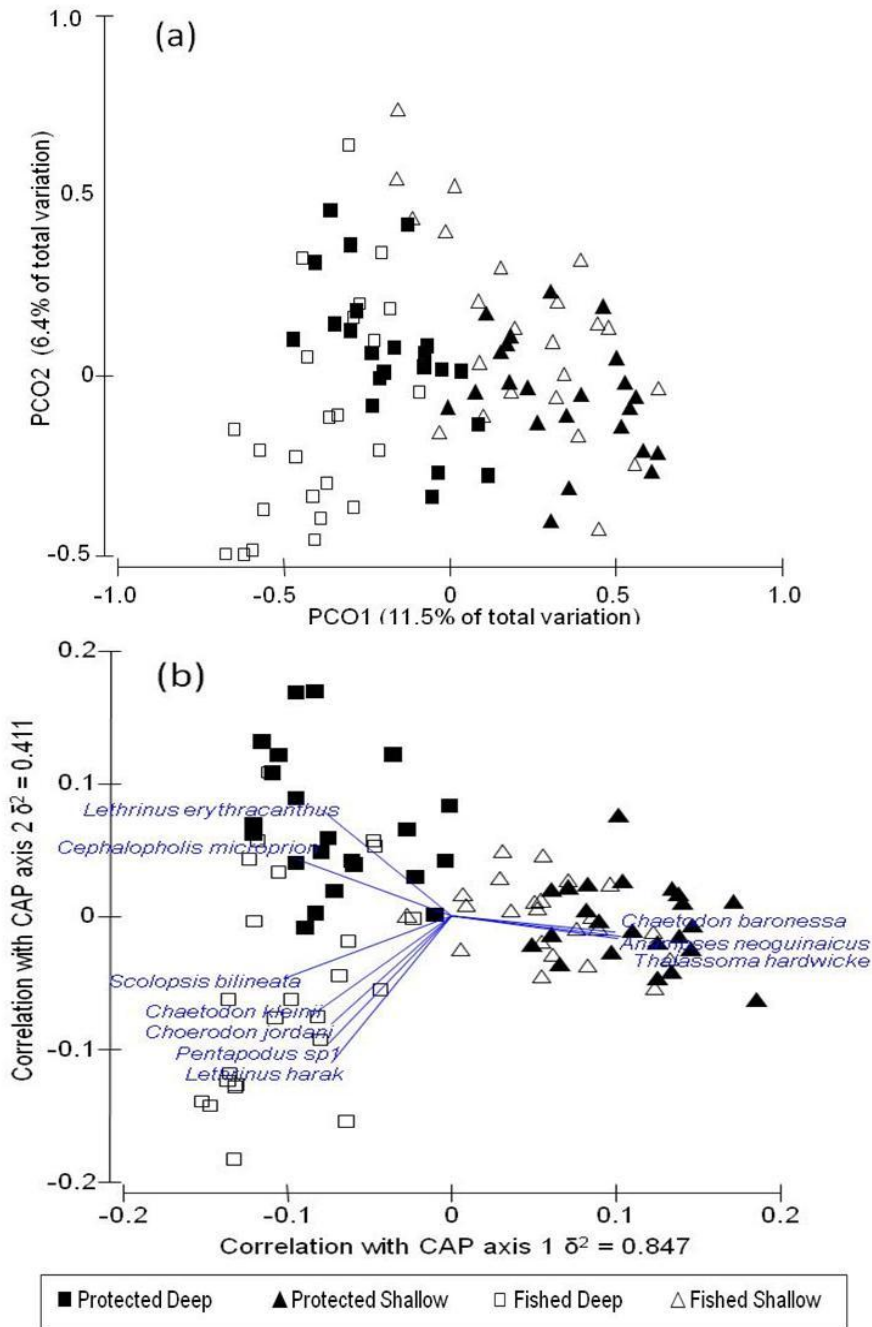


Figure 4: (a) Principle coordinate ordination (PCO) and (b) Canonical analysis of principal coordinates (CAP) ordination based on Modified Gower Log 2 dissimilarities for status (*shaded* vs. *unshaded* symbols) and depth (*squares* vs. *triangles*) in the Namena reserve. Species correlations with the canonical axis are represented as vectors for species with Pearson R values greater than 0.6; e.g. *Lethrinus erythracanthus* is positively correlated with Deep Protected sites. Choice of $m = 12$.

The PCO and CAP analysis for the Namuri reserve displayed a strong separation between deep and shallow sites (CAP analysis: $\delta^2 = 0.85$; total correct 72/78 = 92.31% using 14 axes). The canonical test statistic was highly significant ($P < 0.001$ using 4999 permutations).

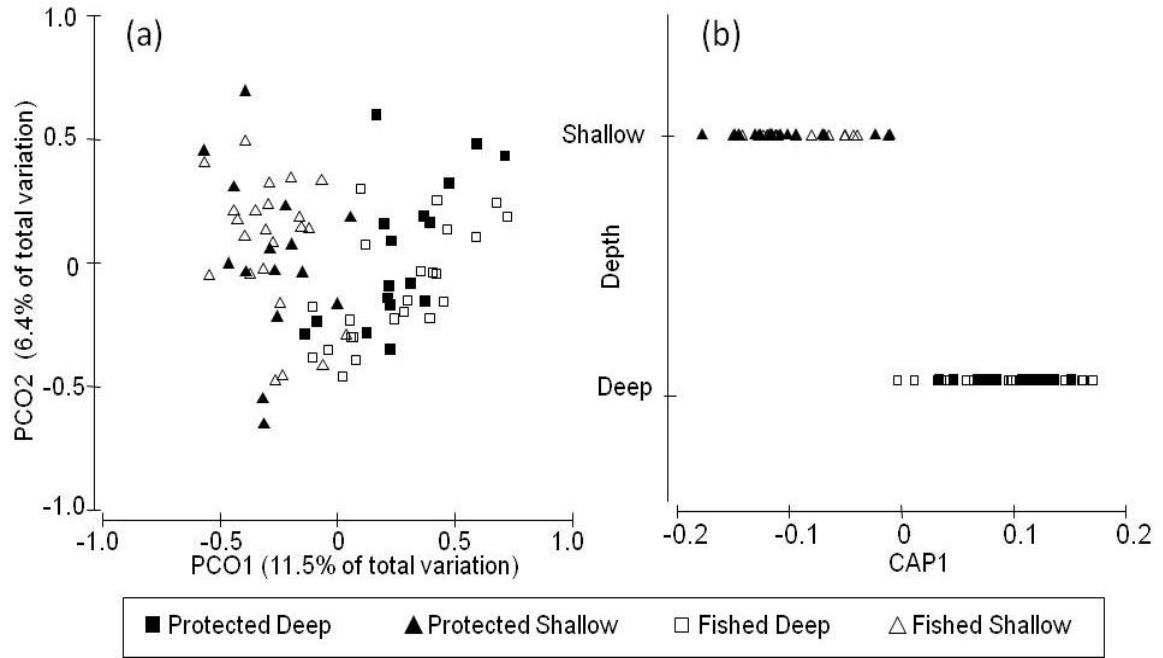


Figure 5: (a) Principle Coordinate ordination (PCO) and (b) Canonical analysis of principal coordinates (CAP) ordination based on Modified Gower Log 2 dissimilarities for status (*shaded* vs. *unshaded* symbols) and depth (*squares* vs. *triangles*) in the Namuri reserve. Choice of $m = 14$. The maximum number of PCO axes was set at 2.

Univariate abundance

There was no significant difference in the average number of all individuals per drop between deep and shallow sites or protected and fished sites for the Namena or Namuri reserve ($P > 0.05$). There were, however, more individuals in the shallow protected sites than the shallow fished sites for the Namena reserve (Figure 6).

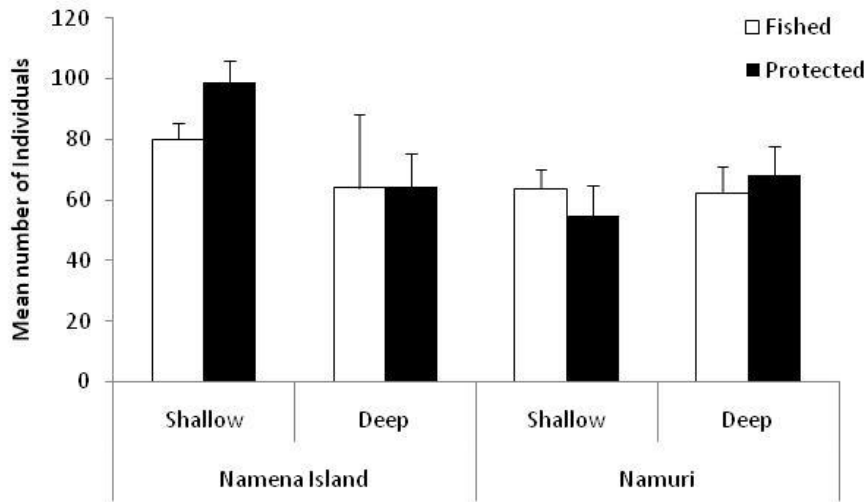


Figure 6: Total number of individuals from the MaxN per stereo BRUV drop is shown for deep and shallow sites in the Namuri and Namena reserves. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found.

Targeted Species

The individual species shown in Figure 7 were found to be conspicuous either because of their abundance or strong correlation in the CAP analysis (Figure 4). The species *Lethrinus erythracanthus* and *Cephalopholis microprion* were both positively correlated with deep protected sites and are grade A food fish. *Cephalopholis microprion* was found only in the deep sites at both reserves. Although not significantly different, they were more abundant in deep protected areas than fished areas for the Namena reserve and the opposite for the Namuri reserve (Figure 7, Table 7). *Lethrinus erythracanthus* showed a significant effect of status and depth for the Namena reserve (Table 6). This species was more abundant in the deep sites than the shallow and in protected areas than fished areas. A significant interaction was found between status and depth for the Namuri reserve with no individuals recorded in the shallow protected areas (Table 7).

Cephalopholis urodeta, a grade A targeted species and *Chlorurus sordidus*, a grade C targeted species were both more abundant in protected sites than fished sites in the deep and shallow for the Namena reserve (Figure 7). *Cephalopholis urodeta* showed a

significant effect of status and depth for the Namena reserve (Table 6). Both species showed a significant effect of status and depth in the Namuri reserve, however, there were more *Cephalopholis urodeta* in fished areas than protected (Figure 7, Table 7). The genus *Macolor* spp. includes *Macolor niger* and *Macolor macularis*, as they could not be distinguished unless very close to the stereo BRUV. These grade B, targeted species showed a much greater abundance in protected areas than fished, for the Namena reserve and the opposite for the Namuri reserve although not significantly different (Figure 7). This may be due to a rare school with a large number of individuals increasing the variation around the mean.

Lethrinus harak is a grade A, targeted species. *L. harak* showed the opposite pattern to all other grade A food fish with more in the deep fished areas than protected areas for the Namena reserve (Figure 7). There were very few *Lethrinus harak* recorded in shallow areas, giving a significant interaction between status and depth in the Namena reserve (Table 6). There was also a greater abundance of *Lethrinus harak* in the fished than protected areas for the Namuri reserve, although there was only a significant difference with the factor depth (Figure 7, Table 7). The average fork length of all *Lethrinus harak* recorded was 18.8 cm with a maximum of 34.3 cm. It is possible that *Lethrinus harak*, being a much smaller predator, has increased in abundance due to the removal of much larger predatory species from fished areas. For this reason it has been removed from the fish food grade analysis which follows.

Non-targeted Species

None of the non-targeted species differed significantly between protected and fished areas for the Namena or Namuri reserves (Figure 7, Tables 6, 7). However, there were more *Chromis ternatensis*, *Chromis viridis* and *Pomacentrus imitator* showed in shallow fished areas than in shallow protected areas for the Namena reserve. These species also showed a greater abundance in shallow sites than deep sites for both reserves (Figure 7). The species *Scolopsis bilineata* and *Pentapodus* sp. were much more abundant in deep sites than shallow and also showed greater abundance in fished areas than protected with the Namena reserve, which again may be due to predation (Figure 7). *Chaetodon*

baronessa showed no effect of status, with a very similar abundance between fished and protected areas. The species did however, show a significant difference between deep and shallow sites in both reserves (Figure 7, Tables 6, 7).

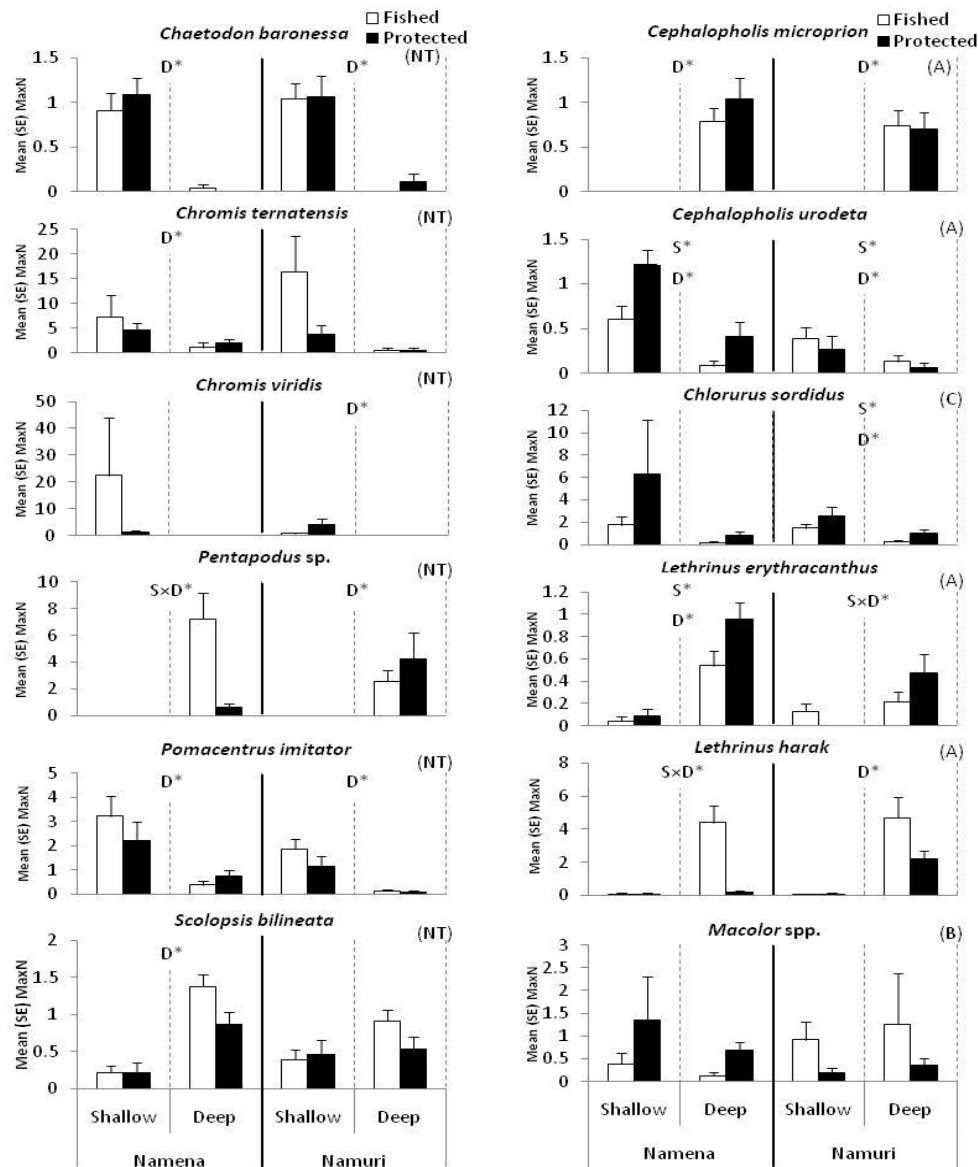


Figure 7: Mean abundance of targeted (right column) and non targeted (left column) species inside (black) and outside (white) of each reserve for deep and shallow sites. Error bars = +SE. The symbol D* represents a significant difference between depths, S* a significant difference between status, SxD* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found. The food fish grade for each species is shown in brackets (A, B or C) with NT representing the non-targeted species.

Table 6: Results of three-factor PERMANOVA examining the abundance of conspicuous species in response to the factors site, status and depth in the Namena reserve.

Namena		<i>Cephalopholis microprion</i>			<i>Cephalopholis urodeta</i>			<i>Chlorurus sordidus</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
Status	1	0.355	1.086	0.324	5.172	9.154	0.012	204.21	1.249	0.331
Depth	1	19.1	58.375	<0.001	9.295	16.45	0.003	331.35	2.026	0.119
StxDE	1	0.355	1.086	0.317	0.343	0.608	0.445	108.52	0.663	0.623
Site (StxDE)	12	0.326	0.751	0.702	0.566	1.275	0.254	163.77	1.156	0.176
Res	76	0.434			0.444			141.62		
Total	91									

Namena		<i>Lethrinus erythracanthus</i>			<i>Lethrinus harak</i>			<i>Macolor spp.</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
Status	1	1.447	5.598	0.018	100.6	7.025	0.021	13.156	2.279	0.064
Depth	1	11.441	44.272	<0.001	112.07	7.825	0.014	4.993	0.865	0.497
StxDE	1	0.989	3.826	0.051	100.6	7.025	0.021	0.918	0.159	0.917
Site (StxDE) ^a	12	0.235		0.542	14.402	2.582	0.007	5.645		0.468
Res	76	0.262			5.578			5.794		
Pooled ^a	88	0.258			-	-	-	5.774		
Total	91									

^a Pooled mean-squares used when p > 0.25 and results not already significant (see Underwood 1997)

Namena		<i>Chaetodon baronessa</i>			<i>Chromis ternatensis</i>			<i>Chromis viridis</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
Status	1	0.048	0.067	0.813	12.499	0.121	0.769	2304.5	0.876	0.496
Depth	1	21.05	29.35	<0.001	501.93	4.855	0.031	2929.2	1.114	0.391
StxDE	1	0.174	0.243	0.657	59.386	0.574	0.519	2304.5	0.876	0.49
Site (StxDE)	12	0.72	1.958	0.048	103.08	0.762	0.785	2629.7	0.965	0.517
Res	76	0.368			135.34			2725.7		
Total	91									

Namena		<i>Pentapodus sp.</i>			<i>Pomacentrus imitator</i>			<i>Scolopsis bilineata</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
Status	1	252.47	3.481	0.057	2.525	0.443	0.53	1.771	3.269	0.091
Depth	1	348.56	4.806	0.022	104.2	18.28	0.002	17.89	33.039	0.001
StxDE	1	252.47	3.481	0.047	11.4	2	0.202	1.566	2.891	0.122
Site (StxDE)	12	73.049	4.431	<0.001	5.673	0.652	0.803	0.542	1.16	0.335
Res	76	16.487			8.707			0.468		
Total	91									

Table 7: Results of three-factor PERMANOVA examining the abundance of conspicuous species in response to the factors site, status and depth in the Namuri reserve.

Namuri		<i>Cephalopholis microprius</i>			<i>Cephalopholis urodeta</i>			<i>Chlorurus sordidus</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
Status	1	0.0003	0.001	0.966	1.049	5.552	0.021	15.153	4.314	0.043
Depth	1	10.106	39.487	0.001	1.027	5.433	0.022	35.616	10.14	0.001
StxDe	1	0.0003	0.001	0.98	0.68	3.598	0.064	0.47	0.134	0.706
Site (StxDe) ^a	12	0.253	0.691	0.727	0.195		0.422	3.544		0.456
Res	76	0.366			0.188			3.507		
Pooled ^a	74	-	-	-	0.189			3.512		
Total	91									

^a Pooled mean-squares used when p > 0.25 and results not already significant (see Underwood 1997)

Namuri		<i>Lethrinus erythracanthus</i>			<i>Lethrinus harak</i>			<i>Macolor spp.</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
Status	1	0.073	1.15	0.311	25.351	0.997	0.358	10.49	1.003	0.41
Depth	1	1.448	22.938	0.003	204.22	8.035	0.028	1.024	0.098	0.809
StxDe	1	0.653	10.347	0.009	27.191	1.07	0.328	0.151	0.014	0.917
Site (StxDe)	12	0.059	0.267	0.99	25.833	2.767	0.008	10.471	1.064	0.339
Res	76	0.221			9.336			9.841		
Total	91									

Namuri		<i>Chaetodon baronessa</i>			<i>Chromis ternatensis</i>			<i>Chromis viridis</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
Status	1	0.046	0.134	0.736	863.39	1.676	0.231	41.96	1.806	0.219
Depth	1	18.17	52.23	0.001	1647.6	3.198	0.111	102.8	4.426	0.032
StxDe	1	0.069	0.199	0.658	854.96	1.659	0.251	41.96	1.806	0.209
Site (StxDe)	12	0.347	0.919	0.533	519.75	1.527	0.122	23.44	1.506	0.077
Res	76	0.378			340.46			15.57		
Total	91									

Namuri		<i>Pentapodus sp.</i>			<i>Pomacentrus imitator</i>			<i>Scolopsis bilineata</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
Status	1	252.47	3.481	0.057	2.525	0.443	0.53	1.771	3.269	0.091
Depth	1	348.56	4.806	0.022	104.2	18.28	0.002	17.89	33.039	0.001
StxDe	1	252.47	3.481	0.047	11.4	2	0.202	1.566	2.891	0.122
Site (StxDe)	12	73.049	4.431	<0.001	5.673	0.652	0.803	0.542	1.16	0.335
Res	76	16.487			8.707			0.468		
Total	91									

Food fish grades

There was a significant difference with status for the grade, A, B and C, targeted species with a greater abundance of all in the protected areas than fished areas for both shallow and deep sites in the Namena reserve (Table 8, Figure 8). There was a significant difference in the abundance of Grade B species between sites (Table 8). The species included in the non-targeted category showed no significant difference between protected and fished sites for the Namena reserve, although there was a greater abundance in fished areas than protected areas for both shallow and deep sites Table 8, Figure 8). There was a significant difference between the abundance of non-targeted species between deep and shallow sites (Table 8).

Table 8: PERMANOVA for the univariate abundance of food fish grades A, B and C and non-targeted species in response to Status (St), Depth (De) and Site for the Namena reserve. The species *Lethrinus harak* has been removed from the grade A category.

Source	df	Namena Grade A			Namena Grade B		
		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	Namena Grade C			Namena Non Target		
		MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
Status	1	1198.4	4.989	0.039	326.5	0.105	0.915
Depth	1	915	3.809	0.065	9537.1	3.06	0.027
StxDE	1	1013.7	4.22	0.061	8.884	0.003	0.99
Site (StxDE) ^a	12	239.08	0.664	0.833	2714.3		0.678
Res	76	360.16			3180.4		
Pooled ^a	88	-	-	-	3116.8		
Total	91						

^a Pooled mean-squares used when p > 0.25 and results not already significant (see Underwood 1997)

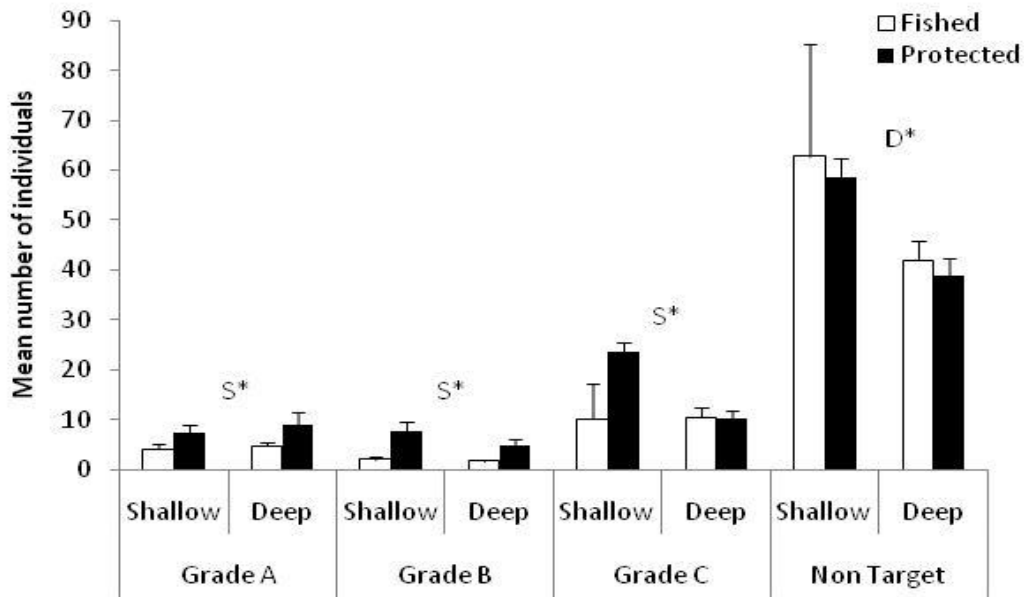


Figure 8: The mean abundance for each food fish grade A, B, C and Non-target species is shown for deep and shallow sites in the Namena reserve. Error bars = +SE. The species *Lethrinus harak* has been removed from the Grade A category. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found.

There was no significant difference with the abundance of grade A, B and C targeted species or non-targeted species between deep and shallow sites or protected and fished sites for the Namuri reserve (Table 9). The plot of average abundance of species for each grade A, B and C and non-targeted species shows that there is very little difference with depth or status in the Namuri reserve (Figure 9).

Table 9: PERMANOVA for the univariate abundance of food fish grades A, B and C and non-targeted species in response to Status (St), Depth (De) and Site for the Namuri reserve. The species *Lethrinus harak* has been removed from the grade A category.

Source	df	Namuri Grade A			Namuri Grade B		
		MS	Pseudo-F	P(pern)	MS	Pseudo-F	P(pern)
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	Namuri Grade C			Namuri Non Targeted		
		MS	Pseudo-F	P(pern)	MS	Pseudo-F	P(pern)
Status	1	75.879	0.747	0.402	164.45	0.094	0.757
Depth	1	96.284	0.948	0.344	0.743	0.001	0.986
StxDE	1	2.952	0.029	0.878	2187.4	1.247	0.273
Site (StxDE)	10	102.46	1.569	0.13	1775.7	1.882	0.062
Res	64	65.322			943.62		
Total	77						

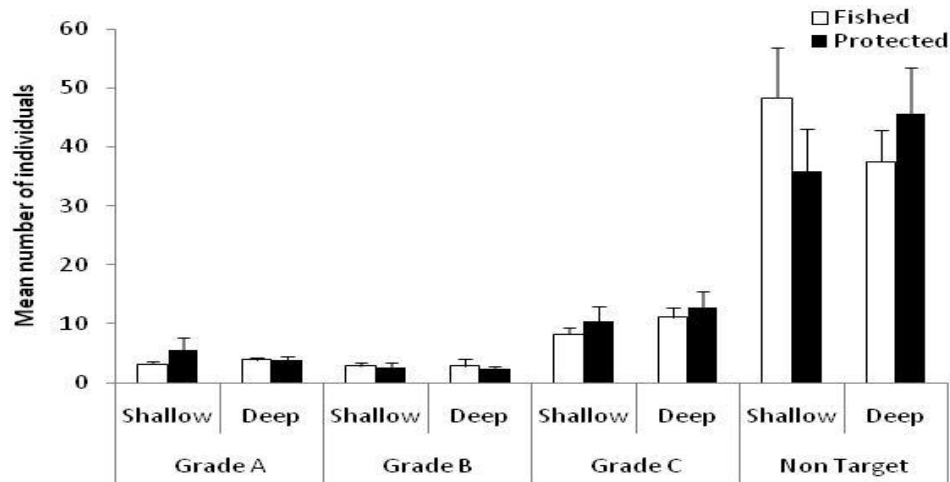


Figure 9: The mean abundance for each food fish grade A, B, C and non-target species is shown for deep and shallow sites in the Namuri reserve. Error bars = +SE. The species *Lethrinus harak* has been removed from the grade A category. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found.

Assemblage composition (biomass)

It was only possible to make estimated of biomass for 6640 of the 11722 individuals used for the analysis of the abundance data. There is high variability in the structure of assemblages of fish with biomass between sites, shown by the significant Site (Status x Depth) term in the model (Table 10). A significant interaction was found with the factors status and depth in the Namena reserve (Table 10). Pairwise tests in PERMANOVA were used to examine this significant interaction. A difference between the biomass of protected and fished assemblages was found in the deep sites, but not between the shallow sites (Table 11). A significant difference in the biomass of fishes between deep and shallow sites was found in both the protected and fished areas (Table 11). There was a significant difference in biomass between deep and shallow sites in the Namuri reserve (Table 10). No significant difference was found in the biomass of fish assemblages between protected and fished sites of the Namuri reserve.

Table 10: PERMANOVA based on Modified Gower Log 10 dissimilarities of the relative biomass of 258 fish species for the Namena and Namuri reserves in response to Status (St), Depth (De) and Sites and their interactions.

Source	Namena				Namuri			
	<i>df</i>	MS	<i>Pseudo-F</i>	<i>P(perm)</i>	<i>df</i>	MS	<i>Pseudo-F</i>	<i>P(perm)</i>
<u>Status</u>	1	8.855	2.163	0.005	1	3.116	0.792	0.768
<u>Depth</u>	1	20.319	4.963	<0.001	1	18.324	4.66	0.001
StxDe	1	5.922	1.446	0.044	1	3.56	0.906	0.594
Site (StxDe)	12	4.104	1.115	0.017	10	3.961	1.176	0.003
Residual	68	3.680			61	3.367		
Total	83				74			

Table 11: PERMANOVA Pairwise tests for the term Status x Depth in the Namena reserve.

Protected vs. Fished			Deep vs. Shallow		
Groups	t	P(perm)	Groups	T	P(perm)
Deep	1.509	0.012	Protected	1.859	0.01
Shallow	1.169	0.095	Fished	1.725	0.022

The PCO and CAP analysis also displayed a strong distinction between deep, fished and protected sites ($\delta^2 = 0.787$; total correct $56/84 = 66.67\%$ using 6 axes) (Figure 10). The canonical test statistic was highly significant ($P < 0.001$ using 4999 permutations). A number of fish species contributed to the observed difference in biomass between the deep protected and fished sites in the Namena reserve, as indicated by Pearson's correlations with canonical axis. Species highly correlated with the canonical axis of status ($|r| > 0.4$) are displayed as vectors in (Figure 10). The species that correlated positively with deep protected sites, *Cephalopholis microprion* is a grade A food fish and therefore highly targeted, while *Naso vlamingii* is a grade C food fish and also targeted (Appendix 1). All species correlated positively with fished deep sites are non-targeted except for *Lethrinus harak*.

The PCO and CAP analysis for the Namuri reserve displayed a strong distinction between deep and shallow sites ($\delta^2 = 0.783$; total correct $68/75 = 90.67\%$ using 12 axes) (Figure 11). The canonical test statistic was highly significant ($P = 0.0002$ using 4999 permutations). The protected and fished sites were not separated into groups while deep and shallow sites were, supporting the results of the PERMANOVA analysis (Figure 11).

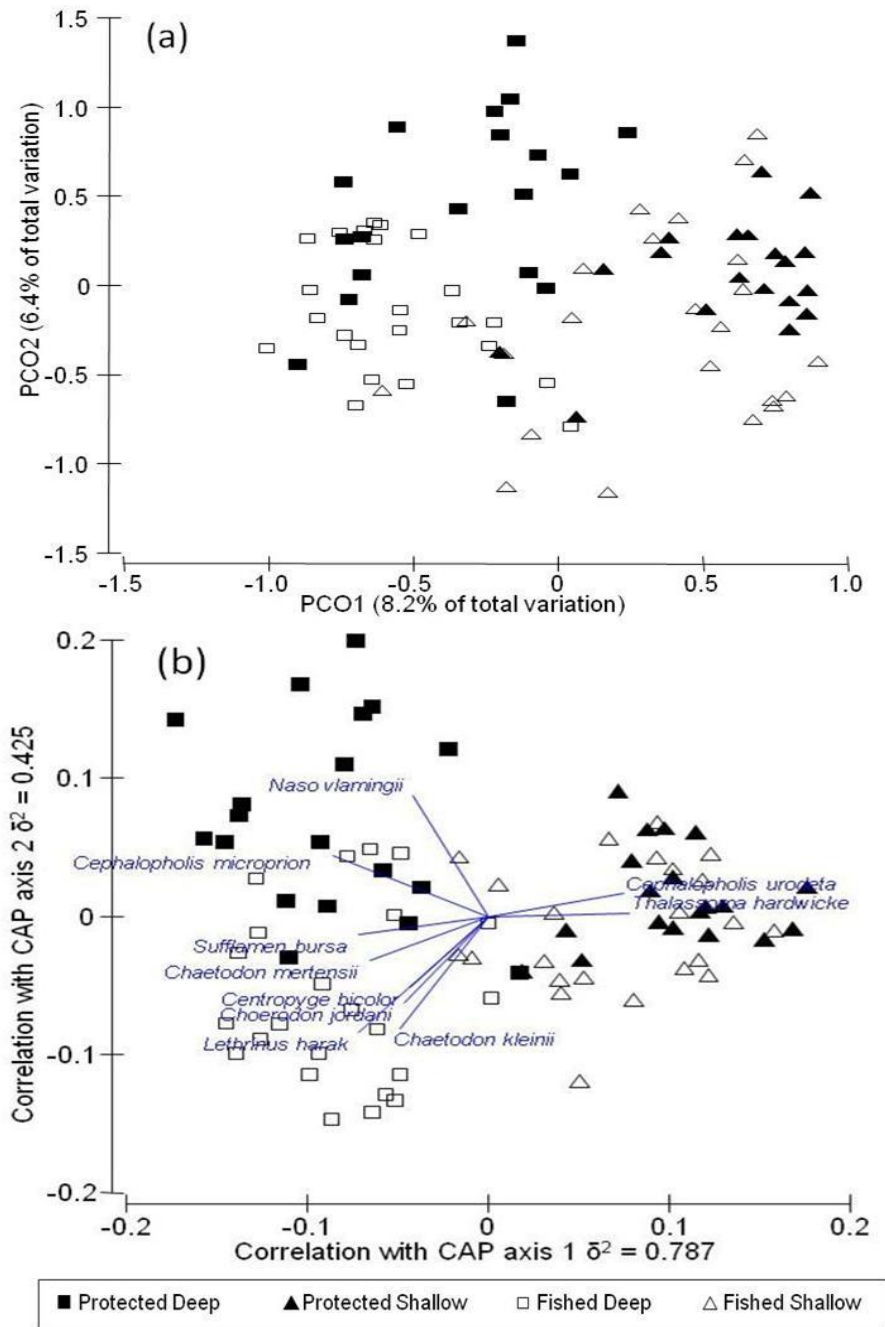


Figure 10: (a) Principle Coordinate Ordination (PCO) and (b) Canonical analysis of principal coordinates (CAP) ordination based on Modified Gower Log 10 dissimilarities for status (*shaded* vs. *unshaded* symbols) and depth (*squares* vs. *triangles*) for the Namena reserve. Species correlations with the canonical axis are represented as vectors for species with Pearson R value greater than 0.4; e.g. *Cephalopholis microprion* is positively correlated with Deep Protected sites. Choice of $m = 6$. The maximum number of PCO axes was set at 2.

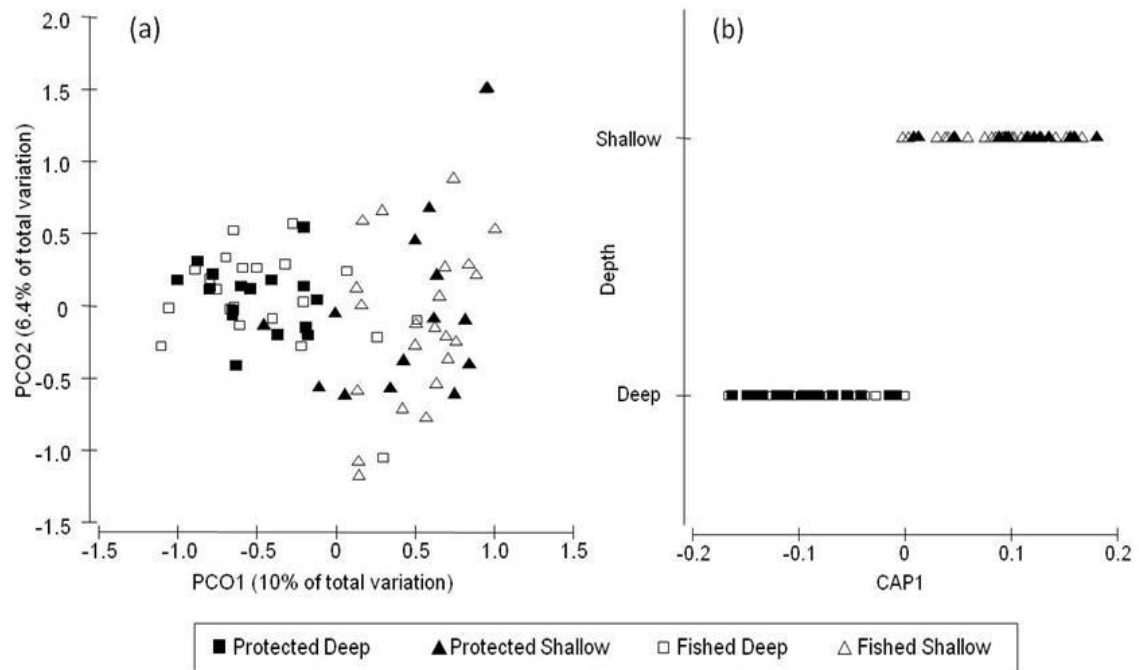


Figure 11: (a) Principle Coordinate Ordination (PCO) and (b) Canonical analysis of principal coordinates (CAP) ordination based on Modified Gower Log 10 for status (*shaded vs. unshaded symbols*) and depth (*squares vs. triangles*) for the Namuri reserve. Choice of $m = 12$. The maximum number of PCO axes was set at 2.

Univariate Biomass

There was no significant difference between deep and shallow sites or fished and protected sites for the Namena or Namuri reserve ($P > 0.05$). However, in the deep sites of the Namena reserve there was a much greater biomass of fish in the protected areas than the fished areas, supporting the multivariate results of an effect of status in the deep but not the shallow (Figure 12). For the shallow sites there was a greater biomass in the fished areas than the protected areas, which is not analogous with the univariate abundance data. There is, however, a very high standard error value which has been caused by a number of large sharks. These sharks have very large individual biomasses, which have increased the biomass and variance around the mean in this area dramatically, without an effect on the abundance data. For the Namuri reserve, on

average there is very little difference with status in the deep sites and a slightly higher biomass in fished areas than protected areas in the shallow sites (Figure 12).

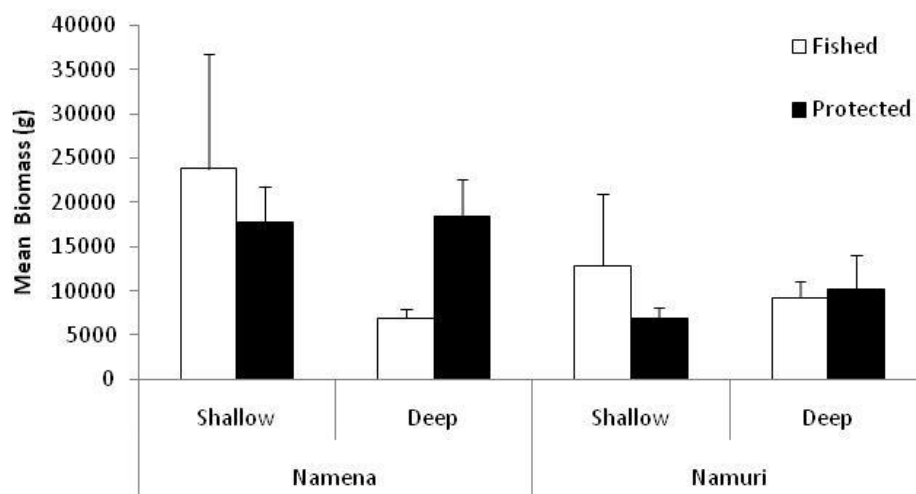


Figure 12: Mean biomass per stereo BRUV drop is shown for deep and shallow sites in the Namuri and Namena reserves. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found.

Targeted Species

The species *Cephalopholis argus* and *Cephalopholis urodeta* are both grade A, targeted species (Appendix 1). Both of these species showed a significant difference in biomass between protected and fished areas for the Namena reserve (Table 12). They have a much greater biomass inside protected areas than fished areas (Figure 13). *Cephalopholis urodeta* also showed a significant difference with the factor depth, where it had a greater biomass in shallow sites than deep sites for the Namena reserve (Figure 13, Table 12). This species showed no differences with depth or status in the Namuri reserve. *Cephalopholis argus* however, showed a significant difference with status and depth for the Namuri reserve. It had a greater biomass in protected areas compared to fished areas and shallow areas compared to deep areas (Figure 13, Table 13).

The species *Cephalopholis microprion*, a grade A food fish and *Macolor* spp., a grade B food fish showed the same pattern as with the abundance results. *Cephalopholis*

microprius which correlated with deep protected sites was only found in deep sites giving a significant result with the depth factor for both reserves (Table 13). Although not significantly different, there was a greater biomass in deep protected areas than fished areas for the Namena reserve and the opposite for the Namuri reserve (Figure 13, Table 13). There were significantly more *Macolor* spp. in protected areas than fished areas for the Namena reserve and the opposite for the Namuri reserve although not significantly different (Figure 13, Table 13). This was due to the occurrence of a rare school with large numbers resulting in large variance around the mean.

The grade C food fish, *Chlorurus sordidus* did not show the same results as the abundance data. It was more abundant in the shallow protected areas for the Namena reserve but has shown a much greater biomass in the shallow fished areas (Figure 13). This was due to a large school which could not be measured as it was positioned behind a coral outcrop in one camera. This counted in the abundance data and not the biomass data. This species showed a significant difference with depth for the Namena reserve and no difference with depth or status for the Namuri reserve (Table 13).

The species *Lethrinus harak* has shown the same results as the abundance data, the opposite result to all other grade A species. There is a much greater biomass in the deep fished areas than protected areas for the Namena reserve (Figure 13). There were very few *Lethrinus harak* recorded in shallow areas giving a significant interaction between status and depth in the Namena reserve (Table 13). There is also a greater biomass of *Lethrinus harak* in the fished areas than protected areas for the Namuri reserve, although there is only a significant difference with depth (Figure 13, Tables 12, 13). Once again it is possible that *Lethrinus harak*, being a much smaller predator has increased in abundance outside of the reserves due to the removal of much larger predatory species from fished areas.

Non-targeted Species

Similar to the abundance data, there were no non-targeted species which showed a significant difference between protected and fished areas for either the Namena or

Namuri reserve (Tables 12, 13). The species *Pygoplites diacanthus*, *Chaetodon ulietensis* and *Pomacentrus imitator* showed a greater biomass in fished areas than protected areas for the Namena reserve (Figure 13). The species *Pomacentrus imitator*, *Chaetodon ephippium* and *Chaetodon baronessa* had a much greater biomass in shallow sites than deep, supported by the significant difference with depth for both the Namena and Namuri reserves (Figure 13, Tables 12, 13). *Chaetodon ulietensis* were much more abundant in deep sites than shallow for the Namena reserve (Figure 13). *Scolopsis bilineata* showed no effect of status or depth with a very similar biomass in fished and protected areas for both reserves apart from the deep sites of the Namena reserve (Figure 13).

Food fish grades

Results of the biomass food grade analysis for the Namena reserve are not consistent with the abundance results. None of the three grades A, B or C showed any effect of status on the biomass of their species (Table 14, Figure 14). The only significant difference found with biomass was for grade A fish between the deep and shallow sites where there was a greater biomass in the deep than the shallow (Table 14, Figure 14). Although not significant, there was a greater biomass in protected areas than fished areas for each grade at each depth apart from the deep sites for grade A species which were very similar (Figure 14). The inconsistency with grade A was due to a number of large Camouflage Grouper, *Epinephelus polyphekadion*, which greatly increased the biomass in the deep fished areas with little effect on the abundance data. There was no significant difference in biomass with the factors depth or status for non-targeted species (Table 14). There was however, a much greater biomass of non-targeted species in the shallow fished areas than protected while in the deep sites the opposite was apparent (Figure 14).

No significant differences were found in the biomass of grade A, B and C or non-targeted species with depth or status for the Namuri reserve (Table 15). There are also no consistent patterns with the biomass data of each food grade and non-targeted species (Figure 15).

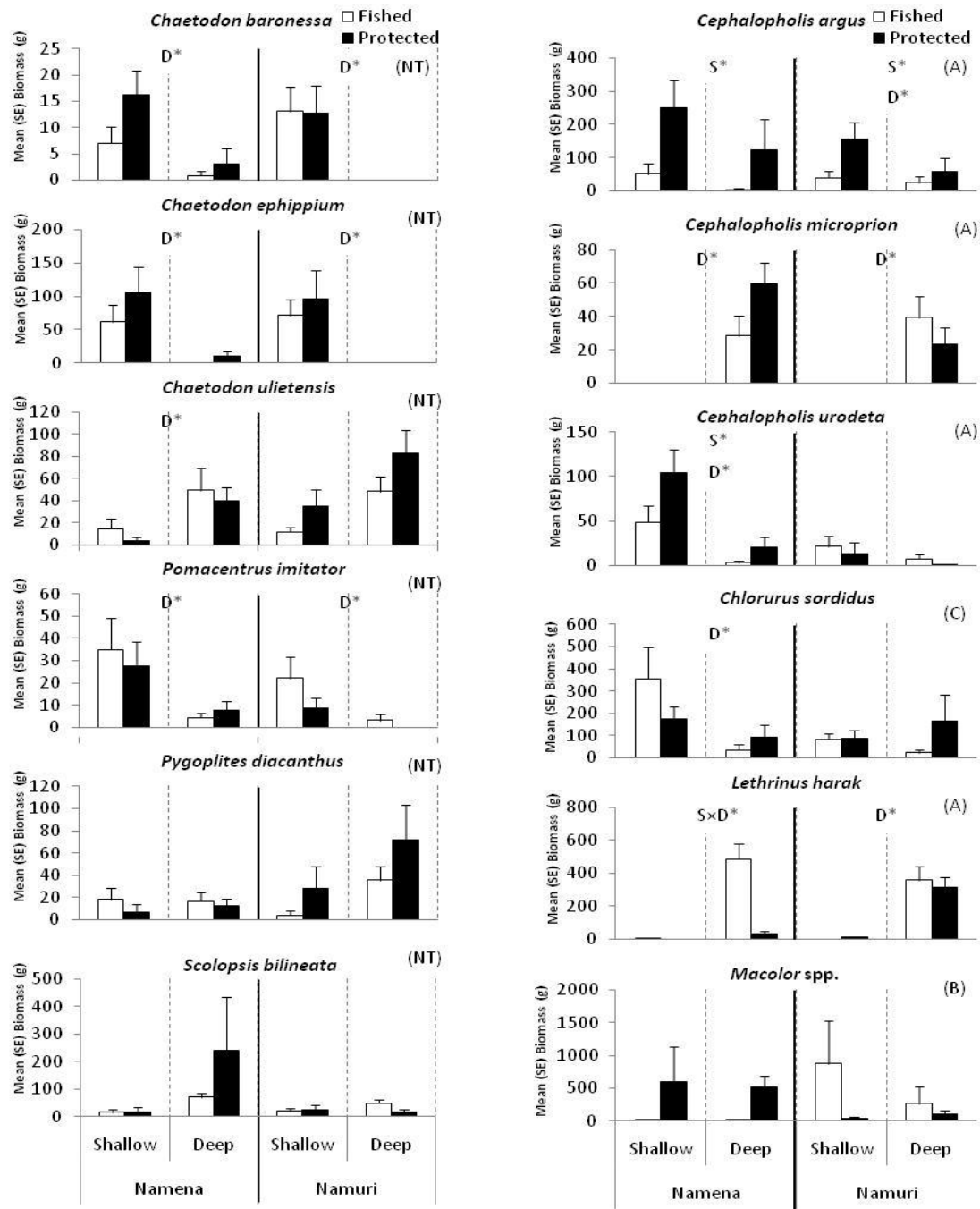


Figure 13: Mean biomass of targeted (right column) and non targeted (left column) species inside (*black*) and outside (*white*) of each reserve for deep and shallow sites. Error bars = +SE. The symbol D* represents a significant difference between depths, S* a significant difference between status, SxD* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found. The food fish grade for each species is shown in brackets (A, B or C) with NT representing the non-targeted species.

Table 12: Results of three-factor PERMANOVA examining the biomass of single species of importance in response to site, status and depth in the Namena reserve.

Namena		<i>Cephalopholis argus</i>			<i>Cephalopholis micropion</i>			<i>Cephalopholis urodeta</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
<u>Status</u>	1	540620	11.482	0.004	4258	2.457	0.151	23602	6.43	0.026
<u>Depth</u>	1	140240	2.979	0.108	35558	20.517	0.001	80836	22.024	0.002
StxDe	1	32182	0.684	0.413	4258	2.457	0.145	6715	1.83	0.202
Site (StxDe)	12	46462	0.621	0.855	1736	1.083	0.385	3622	0.625	0.813
Res	68	74840			1602			5793		
Total	83									

Namena		<i>Chlorurus sordidus</i>			<i>Lethrinus harak</i>			<i>Macolor spp.</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
<u>Status</u>	1	82264	0.528	0.505	1117000	13.857	0.002	6822200	3	0.061
<u>Depth</u>	1	830800	5.333	0.016	1341700	16.645	0.003	311970	0.137	0.873
StxDe	1	307430	1.973	0.165	1085100	13.462	0.006	290080	0.128	0.878
Site (StxDe) ^a	12	41044		0.998	81135	1.426	0.17	2298200	1.935	0.016
Res	68	176050			56914			1187500		
Pooled ^a	80	155800			-	-	-	-	-	-
Total	83									

^a Pooled mean-squares used when p > 0.25 and results not already significant (see Underwood 1997)

Namena		<i>Chaetodon baronessa</i>			<i>Chaetodon ephippium</i>			<i>Chaetodon ulietensis</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
<u>Status</u>	1	712.63	3.279	0.096	14517	1.637	0.224	2585.3	0.733	0.405
<u>Depth</u>	1	1940.6	8.929	0.013	123390	13.911	0.004	25106	7.121	0.023
StxDe	1	303.49	1.396	0.26	7122.6	0.803	0.395	82.525	0.023	0.883
Site (StxDe)	12	217.71	1.082	0.39	8834.5	0.844	0.615	3516.8	0.898	0.549
Res	68	201.18			10466			3916.3		
Total	83									

Namena		<i>Pomacentrus imitator</i>			<i>Pygoplites diacanthus</i>			<i>Scolopsis bilineata</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
<u>Status</u>	1	83.093	0.082	0.779	1348.4	1.709	0.216	137360	0.847	0.489
<u>Depth</u>	1	14716	14.563	0.003	95.131	0.121	0.733	371460	2.292	0.098
StxDe	1	480.21	0.475	0.513	153.88	0.195	0.664	133940	0.826	0.509
Site (StxDe)	12	987.11	0.479	0.954	770.19	0.474	0.947	162050	0.987	0.431
Res	68	2059.5			1626			164240		
Total	83									

Table 13: Results of three-factor PERMANOVA examining the biomass of single species of importance in response to site, status and depth in the Namuri reserve.

Namuri		<i>Cephalopholis argus</i>			<i>Cephalopholis microprius</i>			<i>Cephalopholis urodeta</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
<u>Status</u>	1	101390	11.486	0.01	1079	1.083	0.332	197.49	0.119	0.747
<u>Depth</u>	1	57611	6.527	0.003	16630	16.697	0.003	5206.9	3.143	0.094
StxDe	1	33950	3.846	0.075	1079	1.083	0.334	126.65	0.076	0.813
Site (StxDe)	10	8362.7	0.472	0.915	968.19	0.633	0.791	1663.4	1.091	0.353
Res	61	17729			1528.9			1524.6		
Total	74									

Namuri		<i>Chlorurus sordidus</i>			<i>Lethrinus harak</i>			<i>Macolor spp.</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
<u>Status</u>	1	116830	1.441	0.31	6468.6	0.088	0.808	4195600	1.377	0.31
<u>Depth</u>	1	5401.4	0.067	0.794	1934200	26.411	0.001	1334700	0.438	0.598
StxDe	1	38256	0.472	0.517	12435	0.17	0.697	2109000	0.692	0.477
Site (StxDe)	10	82545	1.574	0.089	73929	1.233	0.279	3021400	0.85	0.65
Res	61	52449			59960			3554500		
Total	74									

Namuri		<i>Chaetodon baronessa</i>			<i>Chaetodon ephippium</i>			<i>Chaetodon ulietensis</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
<u>Status</u>	1	1.74	0.006	0.955	2360.8	0.272	0.616	13664	1.903	0.203
<u>Depth</u>	1	3089.7	11.19	0.013	118640	13.654	0.009	26055	3.629	0.087
StxDe	1	1.74	0.006	0.943	2360.8	0.272	0.618	34.453	0.005	0.945
Site (StxDe)	10	279.28	1.299	0.229	8670.2	0.958	0.49	7419.5	2.857	0.005
Res	61	215.08			9053.1			2596.7		
Total	74									

Namuri		<i>Pomacentrus imitator</i>			<i>Pygoplites diacanthus</i>			<i>Scolopsis bilineata</i>		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
<u>Status</u>	1	1626.2	2.608	0.131	13412	1.182	0.303	3177.5	0.969	0.338
<u>Depth</u>	1	3224.6	5.171	0.032	20537	1.81	0.25	2315	0.706	0.424
StxDe	1	782.53	1.255	0.326	9.136	0.001	0.976	4294.7	1.31	0.284
Site (StxDe)	10	615.36	0.789	0.687	11709	2.64	0.01	3305.9	1.198	0.299
Res	61	780.29			4435.7			2760.3		
Total	74									

Table 14: PERMANOVA for the univariate biomass of food fish grades A, B and C and non-targeted species in response to Status (St), Depth (De) and Sites for the Namena reserve. The species *Lethrinus harak* has been removed from the grade A category.

Source	df	Namena Grade A			Namena Grade B		
		MS	Pseudo-F	P(pern)	MS	Pseudo-F	P(pern)
Status	1	1111300	0.272	0.601	24233000	2.184	0.172
Depth	1	21498000	5.254	0.043	22462000	2.024	0.182
StxDE	1	2442000	0.597	0.45	1776900	0.16	0.694
Site (StxDE)	12	4095700	1.044	0.412	11178000	1.49	0.136
Res	68	3924300			7501200		
Total	83						

Source	df	Namena Grade C			Namena Non Target		
		MS	Pseudo-F	P(pern)	MS	Pseudo-F	P(pern)
Status	1	28876000	0.499	0.531	26916000	0.019	0.961
Depth	1	88427000	1.528	0.36	1443500000	1.031	0.413
StxDE	1	98893	0.002	0.956	1799700000	1.286	0.323
Site (StxDE)	12	58781000	3.571	0.001	1407200000	1.304	0.176
Res	68	16461000			1079300000		
Total	83						

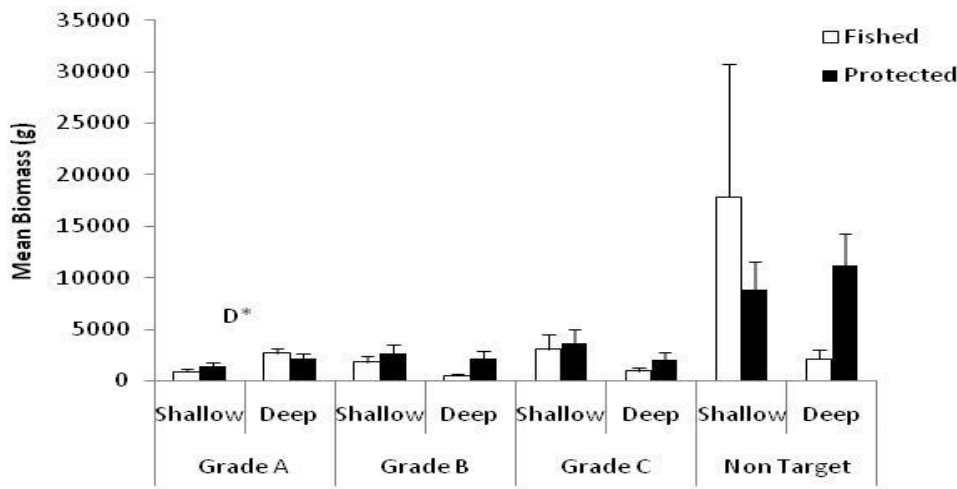


Figure 14: The mean abundance for each food fish grade A, B, C and non-target species is shown for deep and shallow sites in the Namena reserve. Error bars = +SE. The species *Lethrinus harak* has been removed from the grade A category. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found.

Table 15: PERMANOVA for the univariate biomass of food fish grades A, B and C and non-targeted species in response to Status (St), Depth (De) and Sites for the Namuri reserve. The species *Lethrinus harak* has been removed from the grade A category.

Source	df	Namuri Grade A			Namuri Grade B		
		MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
Status	1	21521	0.004	0.963	31186000	2.634	0.147
Depth	1	168200	0.028	0.9	3937100	0.333	0.584
StxDe	1	1282200	0.21	0.752	6226500	0.526	0.513
Site (StxDe)	12	6024000	0.8	0.704	11608000	0.712	0.764
Res	68	7533400			16294000		
Total	83						

Source	df	Namuri Grade C			Namuri Non Target		
		MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
Status	1	7450400	4.169	0.07	6759500	0.042	0.862
Depth	1	2533400	1.418	0.267	2815000	0.017	0.913
StxDe	1	2761100	1.545	0.241	126610000	0.781	0.444
Site (StxDe)	12	1731200	0.606	0.852	158740000	0.696	0.819
Res	68	2857000			228070000		
Total	83						

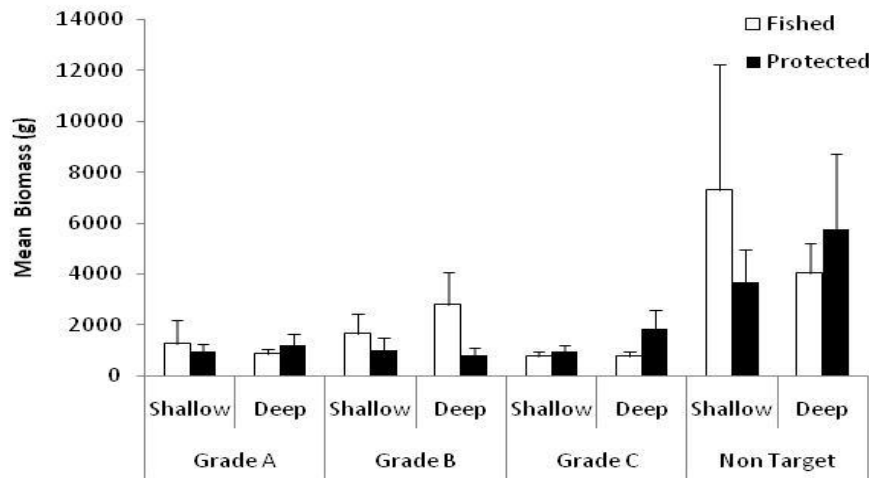


Figure 15: The mean abundance for each food fish grade A, B and C and non-target species is shown for deep and shallow sites in the Namena reserve. Error bars = +SE. The species *Lethrinus harak* has been removed from the grade A category. The symbol D* represents a significant difference between depths, S* a significant difference between status, S×D* for the interaction between the factors status and depth and the absence of a symbol indicates no significant difference was found.

4. DISCUSSION

For the Namena reserve there was a difference in the reef fish assemblage structure, which was associated with an increase in species richness and the abundance of targeted fish inside the reserve when compared to outside. This suggests that the artisanal fishing practices in the Kubulau district may be impacting on the assemblages of fishes by reducing the abundance of targeted species in fished areas. This supports the hypothesis that, artisanal fishing techniques decrease the species richness and abundance of targeted fish species (Jennings and Polunin 1996; Jennings and Polunin 1997; Dulvy *et al.* 2004; McClanahan 2004). Other studies which have documented effects of protection on the abundance of targeted species within artisanal areas are limited, but include marine reserves in New Caledonia (Chateau and Wantiez 2005), and the Philippines, (Russ and Alcala 2003; Alcala *et al.* 2005; Russ *et al.* 2005). This study provides evidence that artisanal fisheries in Fiji may be reducing the abundance of targeted species and that, large marine reserves such as the Namena reserve may increase the abundance of these targeted species.

In the Namuri reserve there was no detectable difference in the composition of assemblages of fishes inside and outside the reserve. The major differences between the Namuri reserve and the Namena are age (4 vs. 13 years) and size (4.25 km² vs. 60.6 km²). The lack of an effect of protection for the Namuri reserve is consistent with the results found by Claudet *et al.* (2008), who suggest that reserves need to be of sufficient size and age, to increase the diversity and abundance of targeted species within their boundaries. However, the number of reserves which were sampled in this study is not sufficient to draw any conclusions on the effects of the size and age of marine reserves on their degree of protection. I therefore recommend that future studies on the no-take marine reserves of Fiji, incorporate multiple reserves of varying size and age to further explore this pattern. This will provide important information that may improve the design of no-take marine reserves so they effectively protect the fish assemblages targeted by artisanal fisheries in Fiji.

Effects of status and depth on species richness

The exposed reef edges of the Kubulau district were found to be extremely rich in species. The Namena reserve was 22% richer in species than surrounding fished areas while there was no difference between the Namuri reserve and nearby fished areas. The increased species richness in the Namena reserve may be due to the extended period of time it has been protected from fishing and the large area it protects, allowing the area to become more diverse with rarer species. However, the Namena reserve may have been historically richer in species than surrounding areas due to differences in topographic complexity, making it difficult to identify the true cause of this difference without “before and after” data. If the observed differences in species richness are in fact caused by the depletion of species from fishing, these results suggest that reserves in Fiji need to encompass a large area for a long period of time in order to increase the species richness within their boundaries. By monitoring the species richness of both reserves over time, a better understanding of the mechanisms which have caused these differences may be uncovered.

Species richness was 34% greater in protected areas than fished areas for the shallow sites and only 9% greater in protected areas than fished areas for the deep sites of the Namena reserve. This result is similar to the depth refuge effect found by Tyler *et al.* (2009). The authors found a 15% greater species richness in shallow protected areas than fished areas but no difference with depths greater than 7 m. This decrease in the number of species from shallow fished areas may be caused by the limitation of artisanal fishing techniques (such as spearing) to depths less than 15 m. These fishing techniques may have removed rare species from shallow fished sites and had little effect on the species in the deep. Although there is evidence of a depth refuge effect, it cannot be linked directly to the effects of fishing as these differences in species richness may have occurred historically.

Effects of status and depth on the composition of assemblage

The same results were found for the assemblage composition with both the abundance and biomass data sets. The Namena reserve showed an effect of protection with significantly different assemblages in the deep protected areas than the deep shallow areas while the Namuri showed none. The patterns found in the CAP analysis suggest that the differences found in the assemblage composition between protected and fished areas in the deep were driven by the depletion of targeted species from fished areas and succession of non-targeted species in fished areas. This suggests an effect of protection in the Namena reserve, supporting the reviews on marine reserves, which suggest that fishing effects the composition of fish assemblages through depletion of targeted species (Pauly *et al.* 1998; Halpern 2003; Lester *et al.* 2009).

The abundance and biomass data sets collected in this study suggested that there is an interaction between depth and status. However, the differences in assemblage structure with status occurred in deep sites but not the shallow sites, the opposite of the result predicted by the depth refuge hypothesis. This result also contradicts the species richness results of Tyler *et al.* (2009) and my own, which suggest there is a depth refuge effect. Tyler *et al.* (2009) collected only presence absence data using UVC techniques, which gave no measures of abundance or biomass. This severely limits the conclusions which can be drawn from the results of this study. It may be that the differences in species richness found with both studies, occurred before the implementation of the reserves and were therefore not caused by fishing. If this depth refuge effect is caused by fishing, the artisanal fishing techniques may only impact on species richness through the depletion of rarer species in shallow waters. This would have little impact on the abundance and biomass of the more common targeted species and explain the lack of a depth refuge effect with the abundance and biomass data sets. However, without any information on the frequency or depth range for each of the artisanal fishing techniques it is difficult to determine if they are the cause of a depth refuge effect. It may be that the line fishing technique used in the Kubulau district is having a greater effect on the

targeted species than first predicted, resulting in the differences found between protected at fished areas in the deep.

There were distinct changes in the assemblage composition with both the abundance and biomass data sets with depth in the Namena and Namuri reserves. This suggests that there are significant changes in the fish community with small scale depth changes of around 20 metres. These changes were driven by species such as *Thalassoma hardwicke*, which was associated with shallow sites and *Lethrinus harak*, *Cephalopholis microprion* and *Choerodon jordani* which were associated with deep sites for both the abundance and biomass data sets. This change in the assemblage composition of fishes with depth may have been caused by the change in habitat with depth. Very few studies have documented changes in fish assemblages over such small scales (Suarez *et al.* 2004; Tyler *et al.* 2009). These results have important implications for the design of marine reserves as well as the sampling techniques needed to assess their effectiveness. As the communities and habitat change so quickly with depth, reserves need to incorporate a broad range of depth strata to protect the whole fish assemblage. When assessing the performance of these reserves, the full depth range needs to be incorporated within sampling plans as the different assemblages which lie within them may have different responses to protection. This was the case for the Namena reserve, where an effect of status was detected in the deep but not the shallow. Conventional UVC techniques which are often limited to a depth of 20 m may not have found this effect of protection. This highlights the need for fishery independent techniques, which are not constrained by depth, to sample marine reserves with large depth gradients.

Effects of status on targeted species

Five of the most common targeted species (excluding *Lethrinus harak* and *Chlorurus sordidus*) were more abundant and greater in biomass inside the Namena reserve than in surrounding fished areas. These same species either showed no effect of status or a greater abundance and biomass in fished areas for the Namuri reserve. In addition, the two grade A targeted species *Cephalopholis urodeta* and *Lethrinus erythracanthus*

showed significant differences in abundance between protected and fished areas of the Namena reserve while the B and C grade species *Macolor* spp. and *Chlorurus sordidus* showed differences which were not significant. Similarly with the biomass data, grade A, targeted species *Cephalopholis urodeta* and *Cephalopholis argus* showed significant differences with status while *Macolor* spp. and *Chlorurus sordidus* did not. This suggests that species which are sold for a higher price (grade A) may be affected more by artisanal fishing as they are likely to be targeted over species with a lower price (grade B and C). As there are no other published studies in Fiji which have examined the effect of marine reserves on fish assemblages, my results can only be compared to studies on the effects of different fishing intensities. One such study by Jennings and Polunin (1996) found that the more intensively fished fishing grounds (*qoliqoli*) had a reduced number of targeted species compared with less intensively fished *qoliqoli*. They also found that the families Serranidae and Lethrinidae contributed the most to these differences. This is consistent with my results where there was a greater abundance of *Cephalopholis urodeta* and *Lethrinus erythracanthus* and biomass of *Cephalopholis urodeta* and *Cephalopholis argus*, in protected areas compared with fished areas for the Namena reserve. These species belong to the Serranidae and Lethrinidae families which Jennings and Polunin (1996) suggested were affected by fishing. These results suggest that artisanal fishing may be reducing the abundance of some of the most common targeted species in fished areas and that species which attract the highest prices may be the most heavily targeted and therefore depleted in the Kubulau district.

The species *Lethrinus harak* gave the opposite result to all other grade A, targeted species with a higher abundance and biomass in fished areas than protected for the Namena and Namuri reserve. *Lethrinus harak* is a small species from the Lethrinidae family with a maximum size of approximately 50 cm (Froese and Pauly 2007). The largest recorded individual in this study was 34 cm. I suggest that the depletion of large predatory species from fished areas, such as the ones mentioned above has allowed *Lethrinus harak* to succeed as a top predator, giving the increased abundance and biomass in these fished areas. It is also likely that this species is not as heavily targeted

as other grade A species due to its smaller size. For these reasons this species was removed from the analysis of A grade food fish and examined here individually.

Effects of status on non-targeted species

Marine Protected Areas are known not only to protect marine ecosystems against the direct effects of fishing, but also against the indirect effects (Botsford *et al.* 1997; Pauly *et al.* 1998). None of the non-targeted species in the study showed a significant difference with the factor status with the abundance or biomass data sets for the Namena or Namuri reserve. This result suggests that artisanal fishing may not affect the non-targeted species of the area. This is supported by Jennings and Polunin (1996) who also found no effect on the non-targeted species with increasing fishing intensity. This may be due to the fact that the artisanal fishing techniques of the Kubulau district are not highly destructive techniques, resulting in minimal habitat destruction and by-catch of non-targeted species. However, some non-targeted species, although not significant, showed a greater abundance and biomass in fished areas than protected areas. Piscivorous fish species are the most significant consumers of fish biomass on coral reefs, and their removal by fishing can lead to an increase in abundance of prey species (Hixon and Beets 1993). Watson *et al.* (2007), found an increase in a number of non-targeted species within fished area when compared with reserves. Species from the genus, *Pentapodus*, *Pomacentrus*, *Chromis* and *Chaetodon*, were found to increase in fished areas when compared with protected areas in both this study and Watson *et al.* (2007). This suggests that artisanal fishing may have indirect impacts on non-targeted species, by releasing the pressure of predation by piscivorous species. However, a number of species examined showed no difference in protected areas to fished areas, suggesting that the effects of fishing on non-targeted species will depend upon their role in the ecosystem, e.g. whether they are preferred prey species.

Effects of depth on individual species

A number of the single species examined showed significant differences with depth. Some of the species showed a much greater abundance and biomass within deep sites

while others showed a much greater abundance and biomass in shallow sites. These results help to explain the significant difference found in assemblage composition between deep and shallow sites, as it seems certain species are associated with certain depths. These depth associations may have been caused by the different habitats found at each depth. Some species such as *Cephalopholis microprion* and *Pentapodus* sp. were not recorded in shallow sites, yet had a relatively high abundance in deep sites. The species *Chromis viridis* had a high abundance in shallow sites, but was not recorded in deep sites. Only a few studies have recorded changes in fish assemblages over such small scales (Ashworth and Ormond 2005; Watson *et al.* 2007; Tyler *et al.* 2009). Watson *et al.* (2007) found significant difference in the abundance of targeted and non-targeted species with changes in depth of less than 20 m while Ashworth and Ormond (2005) found differences over a 10 m depth change. These results show how small scale changes in depth can greatly affect the species composition of a community. It also highlights the importance of incorporating multiple depths within marine reserve boundaries and subsequent sampling designs as some species can be completely absent if only one depth is incorporated or sampled.

The effects of status on the abundance of food fish grade species

In the Kubulau district, villages such as Navatu village are dependent on the sale of fish as a major source of income (WCS 2009). This means that the food fish grades which set the prices for the species of fish in the area should best reflect the targeted species of the Kubulua district. The species within food fish grades A, B and C were all more abundant within protected areas than fished areas, for the Namena reserve. Again this result was not apparent in the Namuri reserve with no difference in the abundance of any of the three grades between protected and fished areas. Two of the main families which make up the grade A category Lethrinidae and Serranidae were also found to be the major contributors to the differences between highly fished areas and rarely fished areas with Jennings and Polunin (1996) study in Fiji. The results found by this study suggest that species from the families Siganidae and Scombridae (A grade), Carangidae, Lutjanidae and Haemulidae, (B Grade) and Labridae, Mullidae, Acanthuridae, Scaridae

and Sphyraenidae (C grade) may also be affected by artisanal fishing with a significant decrease in their abundance between protected and fished areas for the Namena reserve. These results support reviews of marine reserves, which found that they increase the abundance of targeted species within their boundaries (Roberts and Hawkins 2000; Russ 2002; Halpern 2003; Russ and Alcala 2004; Lester *et al.* 2009)

Biomass of food fish grades species

The results for the biomass of food fish grades were not consistent with those of the abundance data set as no significant differences were found with status. This may have been due to lack of measurements for just under half of the fish within the abundance data, which were obscured by coral structure in one of the cameras. The lack of length to weight relationships for 83 of the species used in the abundance data set, may have also contributed to the differences in results with the biomass data set. These species were mostly obscure non-targeted species but also included some of the targeted species in the food fish grades (Appendix 1). In addition, some large schools could not be measured and very large individuals recorded large biomasses skewing the data from the abundance data. I therefore suggest that the large amount of variation within the biomass data set is masking any effects of protection that may be present. The slight increase in biomass for each of the food grades, except for the deep sites with grade A species, suggests that artisanal fishing may have a negative effect on the biomass of targeted species. However, very few conclusions can be drawn from these results, highlighting the need to refine the methods involved with obtaining biomass data.

Limitations and recommendations

As mentioned above, a large proportion of fish in the abundance data set could not be measured due to coral outcrops obstructing one of the cameras. The stereo BRUVs used in this study had frames designed for the low lying coral reef and sand habitats of Western Australia and therefore sat low to the ground. Special frames which sit higher off the ground have been designed to sample the kelp environments of South-western Australia by sitting above the canopy. As the rugosity of the Fijian coral reefs obstructed

the view of the low lying stereo BRUVs, I suggest future studies use the higher frames to increase the number of fish which can be measured. These frames still encompass the seafloor within their field of view but will sit above small coral outcrops, preventing fish from being hidden behind them.

Due to logistical constraints a number of factors had to be removed from the experimental design of this project. The initial one is the sampling of the Nasue reserve. With future studies in the area, I suggest the Nasue reserve be incorporated, so its effect of protection can be determined and a greater generality of results can be applied. The second factor was the removal of a depth level in between the two used within this study. I suggest at least three depth levels be incorporated with future studies to get a better understanding of the changes in fish assemblages over small scale depth changes and how this interacts with protection. Out of the 341 species recorded within the abundance data only 258 species had length to weight relationship which could be used to calculate biomass. I recommend that the number of species which have length to weight relationships is expanded, in particular those which are endemic to Fiji. This will produce a more complete data set for the calculation of biomass and reflect any differences found with protection more accurately.

I recommend that sampling needs to be repeated across multiple reserves of different age and size. This is particularly important within the Kubulua district as my results found the Namena reserve (13 years old, 60.6 km²) to have an effect of protection and the Namuri (4 years old, 4.25 km²) to have none. By monitoring these reserves and sampling additional reserves, we can determine if my results were a “once off” occurrence or if a temporally consistent pattern occurs and if the size of reserves impacts on their effectiveness of protection. I also recommend that the depth range and frequency of fishing techniques in the Kubulau district be quantified to determine which techniques may be causing the observed differences in fish assemblages. A list of the most common species that are kept for local consumption should also be produced to determine if they are also affected by these fishing techniques.

Conclusions

The results from this study suggest that artisanal fishing in the Kubulau district has reduced the species richness and abundance of targeted species in fished areas. The increase in species richness and abundance of targeted species within the Namena reserve and not the Namuri reserve, suggests that large no-take marine reserves may effectively protect these targeted species from fishing given sufficient time. However, the lack of data from before the implementation of these marine reserves makes it difficult to distinguish the effects of artisanal fishing from natural changes in the assemblages of fishes. This highlights the importance of obtaining baseline data in areas where marine reserves are proposed. This study also found a depth refuge effect, which may have been caused by the depletion of rare species in shallow areas, from artisanal fishing techniques. This depth refuge effect did not impact on the abundance and biomass of fish assemblages, although an interaction with protection and depth was still found. This suggests that the effect of protection can vary with depth and highlights the importance of incorporating multiple depth strata in the design of marine reserves. As the effect of protection was found in the deep and not the shallow, sampling techniques such as the stereo BRUVs used in this study may be more suitable than conventional UVC techniques which are limited by depth. Future monitoring of the no-take marine reserves within the Kubulau district, will provide insight to any temporal patterns with protection and help to distinguish the effects of artisanal fishing from any natural changes in the fish community.

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APPENDIX 1: List of the species used for the analysis of each food fish grade. (*) indicates species which were not used in the biomass data set.

Grade A	Grade B	Grade C
Lethrinidae	Carangidae	Acanthuridae
<i>Gnathodentex aureolineatus</i>	<i>Carangoides plagiotaenia</i>	<i>Acanthurus albipectoralis</i>
<i>Gymnocranius grandoculis</i>	<i>Carangoides</i> sp.	<i>Acanthurus fowleri</i>
<i>Gymnocranius</i> sp.*	<i>Caranx ignobilis</i>	<i>Acanthurus grammoptilus</i>
<i>Lethrinus atkinsoni</i>	<i>Caranx lugubris</i> *	<i>Acanthurus guttatus</i>
<i>Lethrinus erythracanthus</i>	<i>Caranx melampygus</i>	<i>Acanthurus lineatus</i>
<i>Lethrinus erythropterus</i>	<i>Caranx</i> sp.	<i>Acanthurus mata</i>
<i>Lethrinus harak</i>	<i>Elagatis bipinnulata</i>	<i>Acanthurus nigricans</i> *
<i>Lethrinus lentjan</i> *	<i>Gnathanodon speciosus</i>	<i>Acanthurus nigrofuscus</i>
<i>Lethrinus microdon</i>	<i>Scomberoides lysan</i>	<i>Acanthurus olivaceus</i>
<i>Lethrinus obsoletus</i>		<i>Acanthurus pyroferus</i>
<i>Lethrinus olivaceus</i>	Haemulidae	<i>Acanthurus</i> sp.
<i>Monotaxis grandoculis</i>	<i>Plectorhinchus albobittatus</i>	<i>Acanthurus thompsoni</i>
<i>Monotaxis heterodon</i>	<i>Plectorhinchus chaetodonoides</i>	<i>Acanthurus triostegus</i>
		<i>Acanthurus xanthopterus</i>
Scombridae	Lutjanidae	<i>Ctenochaetus binotatus</i>
<i>Acanthocybium solandri</i> *	<i>Aphareus furca</i>	<i>Ctenochaetus striatus</i>
<i>Grammatorcynus bilineatus</i>	<i>Aprion virescens</i>	<i>Ctenochaetus tominiensis</i>
<i>Gymnosarda unicolor</i>	<i>Lutjanus biguttatus</i>	<i>Naso annulatus</i>
<i>Katsuwonus pelamis</i>	<i>Lutjanus fulviflamma</i>	<i>Naso brachycentron</i> *
<i>Rastrelliger kanagurta</i>	<i>Lutjanus fulvus</i>	<i>Naso brevirostris</i>
<i>Scomberomorus commerson</i>	<i>Lutjanus kasmira</i>	<i>Naso caesi</i>
<i>Scomberomorus</i> sp.*	<i>Lutjanus monostigma</i>	<i>Naso hexacanthus</i>
	<i>Lutjanus rivulatus</i>	<i>Naso lituratus</i>
Serranidae	<i>Lutjanus semicinctus</i>	<i>Naso minor</i>
<i>Cephalopholis argus</i>	<i>Lutjanus</i> sp.*	<i>Naso</i> sp.
<i>Cephalopholis cyanostigma</i>	<i>Macolor</i> spp.	<i>Naso thynnoides</i>
<i>Cephalopholis microprion</i>	<i>Pinjalo pinjalo</i>	<i>Naso unicornis</i>
<i>Cephalopholis urodeta</i>		<i>Naso vlamingii</i>
<i>Epinephelus fasciatus</i> *		<i>Zebrasoma scopas</i>
<i>Epinephelus fuscoguttatus</i> *		<i>Zebrasoma veliferum</i>
<i>Epinephelus hexagonatus</i>		
<i>Epinephelus howlandi</i> *		Scaridae
<i>Epinephelus maculatus</i>		<i>Cetoscarus bicolor</i>
<i>Epinephelus malabaricus</i> *		<i>Chlorurus bleekeri</i>
<i>Epinephelus melanostigma</i> *		<i>Chlorurus microrhinos</i>
<i>Epinephelus merra</i>		<i>Chlorurus sordidus</i>

Grade A	Grade B	Grade C
<i>Epinephelus polyphekadion</i>		<i>Hipposcarus longiceps</i>
<i>Epinephelus</i> sp.		<i>Scarus chameleon</i>
<i>Epinephelus spilotoceps</i>		<i>Scarus flavipectoralis</i> *
<i>Epinephelus tauvina</i>		<i>Scarus forsteni</i>
<i>Gracila albomarginata</i>		<i>Scarus frenatus</i>
<i>Plectropomus areolatus</i>		<i>Scarus ghobban</i>
<i>Plectropomus laevis</i>		<i>Scarus oviceps</i>
<i>Plectropomus maculatus</i> *		<i>Scarus prasiognathos</i>
<i>Plectropomus</i> sp.		<i>Scarus rubroviolaceus</i>
<i>Variola</i> spp.		<i>Scarus schlegeli</i>
		<i>Scarus</i> sp.
		<i>Scarus spinus</i>
Siganidae		Mullidae
<i>Siganus argenteus</i>		<i>Parupeneus barberinoides</i>
<i>Siganus doliatus</i>		<i>Parupeneus barberinus</i>
<i>Siganus puellus</i>		<i>Parupeneus crassilabris</i>
<i>Siganus punctatissimus</i>		<i>Parupeneus cyclostomus</i>
<i>Siganus punctatus</i>		<i>Parupeneus multifasciatus</i>
<i>Siganus</i> sp.		
		Labridae
		<i>Cheilinus chlorourus</i>
		<i>Cheilinus fasciatus</i>
		<i>Cheilinus trilobatus</i>
		<i>Epibulus insidiator</i>
		Sphyraenidae
		<i>Sphyraena barracuda</i> *
		<i>Sphyraena genie</i> *

Abbreviations list

CAP Canonical analysis of principal coordinates

PCO Principal coordination analysis (ordination)

FLMMA Fiji Locally Managed Marine Area

MaxN The maximum number of species in the field of view at one time over the complete sampling period using stereo-BRUV when conducting fish assemblage surveys

No-take marine reserve: Area protected from all extractive practices, including fishing

PERMANOVA Permutational analysis of variance

SCUBA Self Contained Underwater Breathing Apparatus

Stereo BRUV Baited remote underwater stereo-video

UVC Underwater visual census

Definitions

Definitions taken from (Fauth *et al.* 1996)

Community: groups of organisms that are spatially connected regardless of phylogeny or guild

Assemblage: group of individuals from various species spatially connected

Population: group of conspecifics within an assemblage

Targeted: Those fish species targeted by fisherman