Frontier Fiji Marine Environmental Research

TECHNICAL REPORT 4

A study investigating the effect of Marine Protected Areas on reef health and fisheries in small island communities

FRONTIER-FIJI

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Gillis, L. G., Steer, M. D., Belle, E. M. S. and
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Abstract

The island of Gau in the south of the Fiji archipelago, has suffered from decreasing fish stocks over the last decade. To try and preserve essential marine resources, Marine protected areas (MPAs) were introduced in front of all coastal villages. This study investigates important aspects of coral reef health over a one year period. Each monitored variable was chosen in order to assess the overall health of the coral reef ecosystem. Three sites were chosen and were monitored every three months over a one year period. The MPAs for each village were introduced over several years, it was therefore expected that sites which held older protected areas would have greater hard coral coverage and diversity, as well as a higher abundance of fish species. We found no evidence that fish biomass and coral health were higher in areas with longer serving MPAs, however, a general increase in reef health was observed at all sites. We suggest that the difference in reef health between sites can be attributed to different levels of human activity. Further research is required to develop more effective marine management. The successful implementation of marine protected areas for coastal management is indeed very important for islands like Fiji where people rely on the marine resources for their livelihood.

Key words: Coral reefs, Marine Protected Area, fish biodiversity, fish biomass, coral growth, and coral diversity

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1. Introduction

1.1 Environmental and Anthropogenic Stressors of Coral Reefs

Coral reefs are diverse ecosystems that are second only to tropical rainforests in terms of productivity and complexity (Carr *et al*. 2001). They amount to less than one percent of the world's marine ecosystems and yet are estimated to provide food and shelter for up to 25% of all marine life (Carr *et al*. 2001). They are particularly delicate ecosystems which survive within a narrow range of temperatures and salinities, with a low tolerance to change (Souter & Linden 2000). With encroaching human populations and cyclical events such as El Nino, there are a great many pressures on coral reefs (Lindahl *et al.* 2001). Many developing countries rely upon reefs for income, coastal defense and as a food source (Gomez 1997). A vital part of some economies is also bought in by tourism from the marine environment (Souter & Linden 2000), which has allowed a greater level of protective measures for coral reefs to be introduced (Gomez 1997).

Scleratinian corals (hard corals) in particular have a narrow range of water temperatures for optimum growth, being able to grow and reproduce between 25 and 29°C (Brown & Ogden 1993). Temperatures above this range can cause the coral to become stressed and can result in bleaching, where the coral expels it is associated zooxanthellae (Jones *et al.* 2000). Fiji suffered a bleaching event in March-April 2000 with 80% of reefs being affected (Vieux *et al*. 2004). Other notable episodes of bleaching occurred in 2001 and 2002, however, these events were not as sever (Vieux *et al*. 2004).

Corals also require clear water to allow sufficient sunlight for the algae (zooxanthellae) within the tissues to generate necessary nutrients to support coral growth (McLaughlin *et al.* 2003). Influx of substances from agricultural run-off, pollution or untreated sewage can cause additional damage to the reefs. Sedimentation reduces light levels in addition to preventing recruitment of new corals by smothering the rocky surfaces required for settlement (McLaughlin *et al.* 2003). A phase shift may occur where coral is outgrown by algae, which compete with coral for space and light (McManus & Polsenberg 2004). This change can occur quickly and result in a sudden drop in fish and invertebrates (McManus & Polsenberg 2004). Changes in fisheries can have dramatic impacts on local human populations dependent on the reef for good income (Koop *et al.* 2001).

Furthermore, the overexploitation of the reef resources can modify the whole equilibrium of the ecosystem. For instance, fishing of large predatory fish from a reef community can have a cascade effect resulting in colonization by benthic algae and a reduction in hard coral cover. This can result in an increased number of herbivore fish which feed on the algae and are normally kept in low numbers by the predatory fish species (Dulvy *et al* 2004). By contrast, removal of key herbivores, such as parrot fish, can result in overgrowth of macroalgae (McManus & Polsenberg 2004).

1.2 Marine Management

Marine protected areas have nave been implemented in many coastal areas to protect threatened species and habitats, ensuring they are not degraded by human influences (Botsford *et al.* 2003). They are used as a management tool to protect areas of high biodiversity value and to support the structure and functioning of the wider marine ecosystem (Sala *et al.* 1993). Marine protected areas which have involved the community from inception have been shown to be particularly successful (Russ & Alcala 1999).

The Locally Managed Marine Area network Fiji (LMMA-Fiji) has taken management back to the community with the creation of a network of reserves that are administered by the local community. These reserves were established with the help of partner research organizations to provide research expertise and knowledge in the form of training and workshops on adaptive management.

In Fiji, the foundation of the Customary Marine Tenure Act is the traditional *Qoliqoli* method of marine management whereby all the waters from the mean high tide line out to the reef wall edge are under the authority of the regions chief (Veitayaki *et al.* 1995). This traditional method of management, when supported by the Fijian government has been proven successful in protecting local fish stocks and improving the reef health (Veitayaki *et al.* 2003).

2. Area Description

Gau Island is part of the Lomai'Viti chain of islands and is situated 90 km east of Fiji's capital Suva, on the island of Viti Levu. This island is composed of a variety of terrestrial and coastal ecosystems such as rainforests, grasslands, mangroves and coral reefs (Veitayaki *et al.* 1995). The island of Gau has little coastal development (Veitayaki *et al.* 1995). On the western side of Gau, a barrier reef extends northwards from the southern tip, approximately two thirds of the way north of the island (Figure 1). There is a deep lagoon between the barrier reef and the land, with fringing reefs also extending up the western coastline. The island's remoteness means that there is little tourism with a currently unoccupied resort at Nukuyaweni representing the only development on the island.

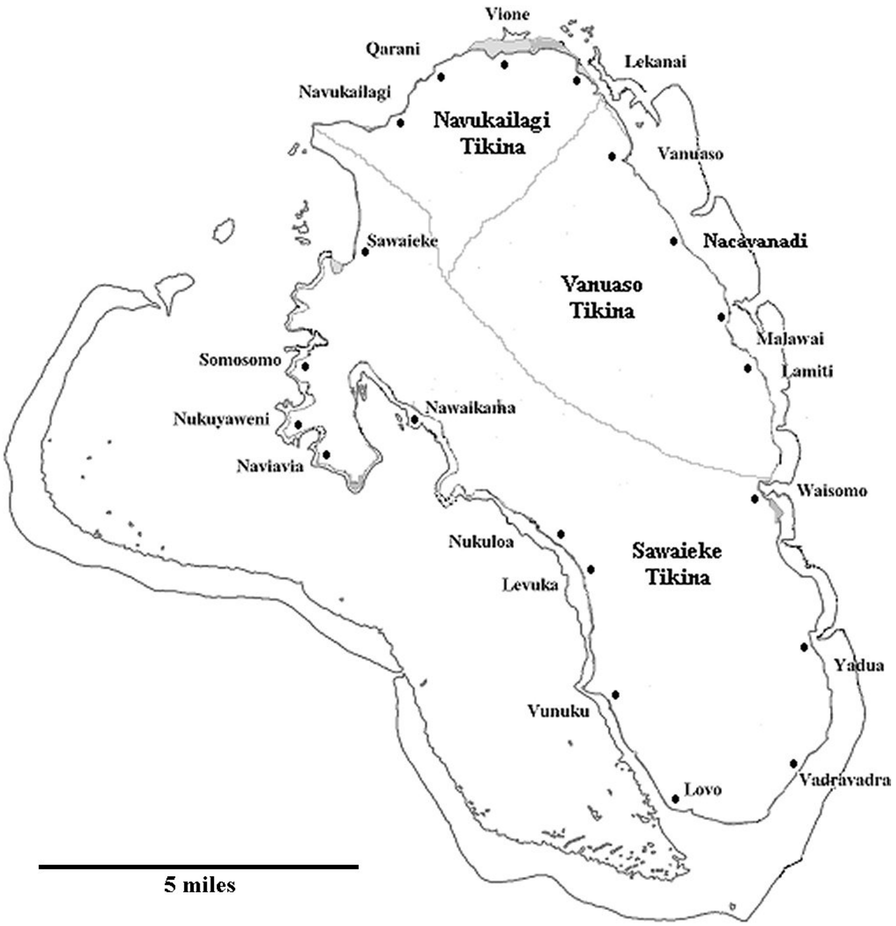

Figure 1. Map of Gau Island showing the different districts.

2.1 Integrated Coastal Management of Gau

All the lagoonal waters on Gau come under the jurisdiction of the High Chief and the *mataqali*. At present, Gau's chief allows no commercial fishing within its waters for non-residents of Gau. However, there were concerns within the community for the islands fish stocks and coral reef health (Veitayaki *personal communication*). With the assistance of partner organizations such as the International Ocean Institute – Pacific Islands (IOI-PI) and World Wildlife Fund (WWF) Fiji, Gau has become part of the Locally-Managed Marine Area (LMMA) network in Fiji (Veitayaki *et al.* 1995). Gau's communities have adopted the LMMA, with all of the islands coastal communities declaring at least one no-take zone. These protected areas were established with the intention of improving fish stocks by providing a refuge and allowing the recovery of local reefs through seeding. Frontier-Fiji was invited to join the project to provide research on the state of the coral reefs of Gau in order to develop the management of the island's resources.

2.2 Objectives of the study

The main purpose of this study was to observe coral reef health with regard to the effect of the marine protected area. Previous studies have shown that MPAs can positively influence adjacent ecosystems (Walters *et al.* 1999). Prior to this study it was expected that regions which have had protected areas for the longer periods would have improved reef ecosystems including an increased biomass and biodiversity in fisheries, larger numbers of invertebrates, greater percentage hard coral cover and lower algae cover.

Three regions were chosen which had MPAs in place for different periods of time, and the evolution of each ecosystem health was assessed. Each monitoring period included three transect sites and was completed between October and November. None of the specific transects studied were situated within the MPA; however, if effective, the protected areas should contribute to the overall health of the ecosystem in each area. The regions of Nawaikama, Somosomo and Nukuyaweni where chosen, each of these have had protected areas set up seven, three and two years ago, respectively.

3. Material and Methods

3.1 Biodiversity Surveys

All data was collected using the Baseline Survey Protocol (BSP) which provides information on benthic coverage, fish data, invertebrate species and environmental conditions of the site. This method allows many aspects of the marine environment to be documented to determine whether there is any correlation with these environmental variables. Three transects were carried out at each site for each time period (October to March 2006 and 2007); each transect covered a distance of 45m, running along the contours of the reef and were conducted at two separate depths (6-8m and 10-12m). Monitoring was completed using a diving survey team of 4 surveyors.

The physical surveyor recorded the physical and environmental factors. This surveyor took a compass bearing and placed a tape measure transect along a given depth contour, parallel to the shore. Environmental factors recorded included depth, temperature and visibility at 0m, 20m, 25m, and 45m.

The fish surveyor monitored the size and frequency of fish encountered along the transect in a hypothetical $5m^3$ box extending 2.5 m either side of the tape measure and 5 m above it. The size of any fish entering this space was also estimated to the nearest 5cm. Fish surveyed were limited to 18 families, belonging to six trophic groups.

The benthic surveyor noted the benthic substratum found directly underneath the 1 transect and recorded the length against the tape measure (in cms) of each new substrate or coral genera. Additionally, the surveyor identified hard coral and soft coral to genus level.

The algae and invertebrate surveyor looked for invertebrates within a 5m wide corridor above the transect line. Any invertebrate was recorded to genus or family level, with some notable indicators of over fishing or low reef health being recorded to species level.

3.2 Data Analysis

Fish abundances were converted to biomass (kg) using published length weight relationships from FishBase (Froese and Pauly 2004) using the following equation:

$$W = bL^{b}$$

Where W is fish biomass (kg), L is the length of fish and b a published allometric scaling value specific to each species (Froese and Pauly 2004).

The Shanon-Weiner diversity index (H') was used to calculate fish diversity for each transect using the following equation:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Where the abundance of the ith species, $p_i = n_i/N$, *with* N being the total number of fish caught and n_i the number of individuals in species i. S is the total number of species caught.

To determine whether there was a significant difference between sites, analysis of variance (ANOVA) were performed using phase and region as factors.

4. Results

4.1 Hard Coral Cover

All sites appeared to show an increase in hard coral cover compared to the previous year (Figure 2). The lowest coral cover was found in Nukuyaweni and the highest in Somosomo. However, a two-way ANOVA indicated no significant difference between regions (F=1.301, p=0.287) or between time periods (F=0.236, p=0.236).

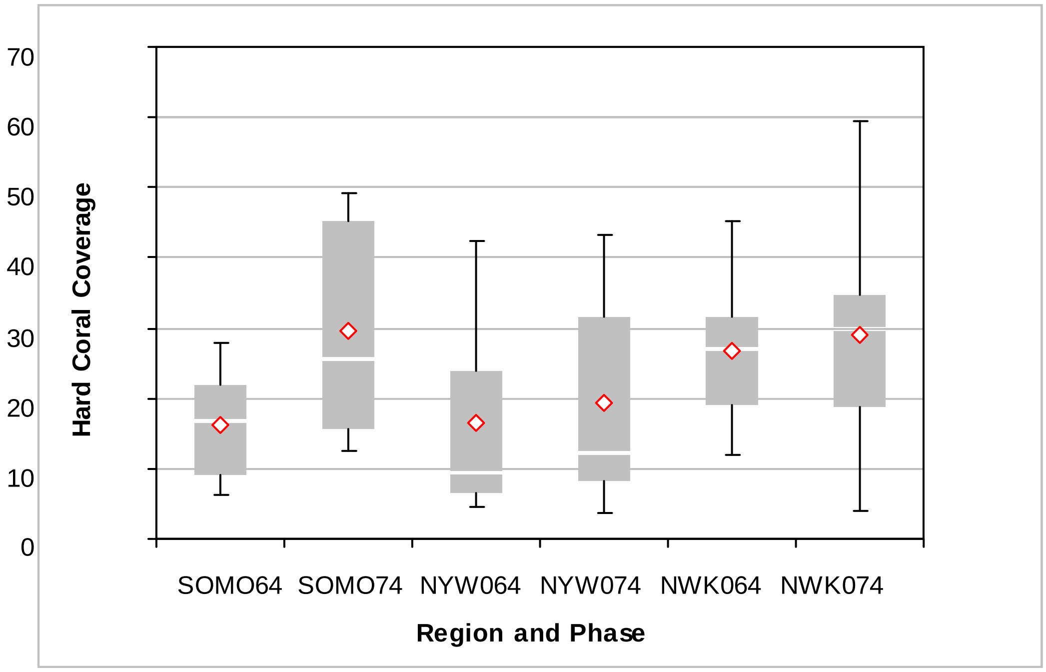

Figure 2. Box plot showing percentage hard coral cover in each region and phase. 064 refers to the last quarter of the year 2006 and 074 to the last quarter of the year 2007. SOM: Somosomo; NYW: Nukuyaweni; NWK: Nawaikama.

4.2 Hard Coral Diversity

Hard coral diversity was calculated as the number of hard coral genera found per transect. Genus richness ranged from 3 genus per transect to 23 genera per transect (Figure 3). Somosomo and Nawaikama showed a general increase in genus richness during the year monitoring period. By contrast, the majority of Nukuyaweni transects indicated a decrease of genus richness, only one section showed a greater number of species. An ANOVA analysis showed that there was a significant difference in genus richness per region (F=9.259, p<0.0001) but no significant difference between time period (F=4, p=0.054).

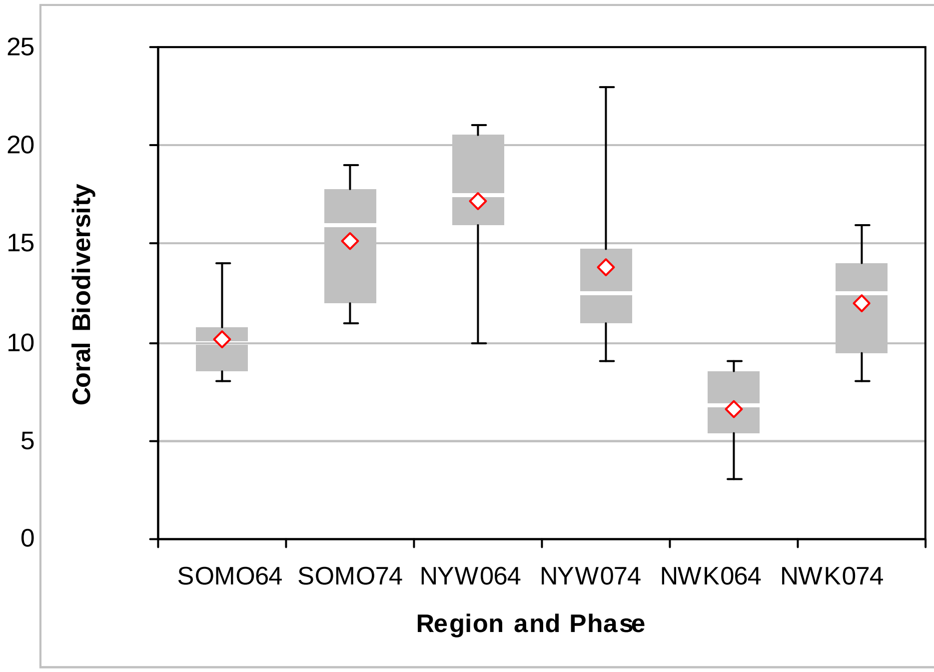

Figure 3. Box plot showing coral diversity, measured as genus per transect, in each region and phase.

4.3 Fish Abundance

Fish abundance was calculated by converting species abundance and size into biomass (kg). Somosomo had the highest biomass increase over one year, whereas Nukuyaweni and Nawaikama showed no clear variation (Figure 4). An ANOVA analysis showed no significant difference between regions (F=2.6, p=0.0908) or time periods (F=0.687, p=0.413).

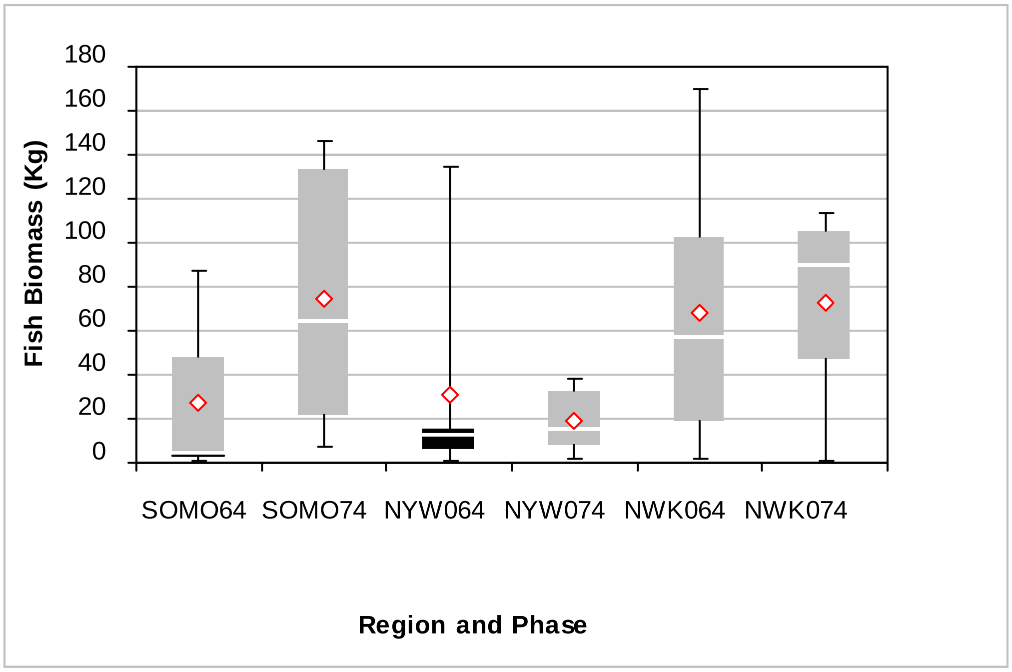

Figure 4. Box plot of biomass for surveyed fish for each region and time period in kg/m³ in order of longitude

4.4 Fish biodiversity

Biodiversity of fish was calculated using the Shannon-Weiner (*H'*) formula. According to Carr *et al.* (2001), a natural population would be expected to fall between 1.5-3.5 *H'*. Here indices of fish biodiversity ranged from 0.0788 to 5.193, with the majority of sites exhibiting relatively low levels of biodiversity (Figure 5). There was no significant difference between the three regions (ANOVA, F=5.087, p=0.0125), or time period (ANOVA, F=0.589, p=0.448).

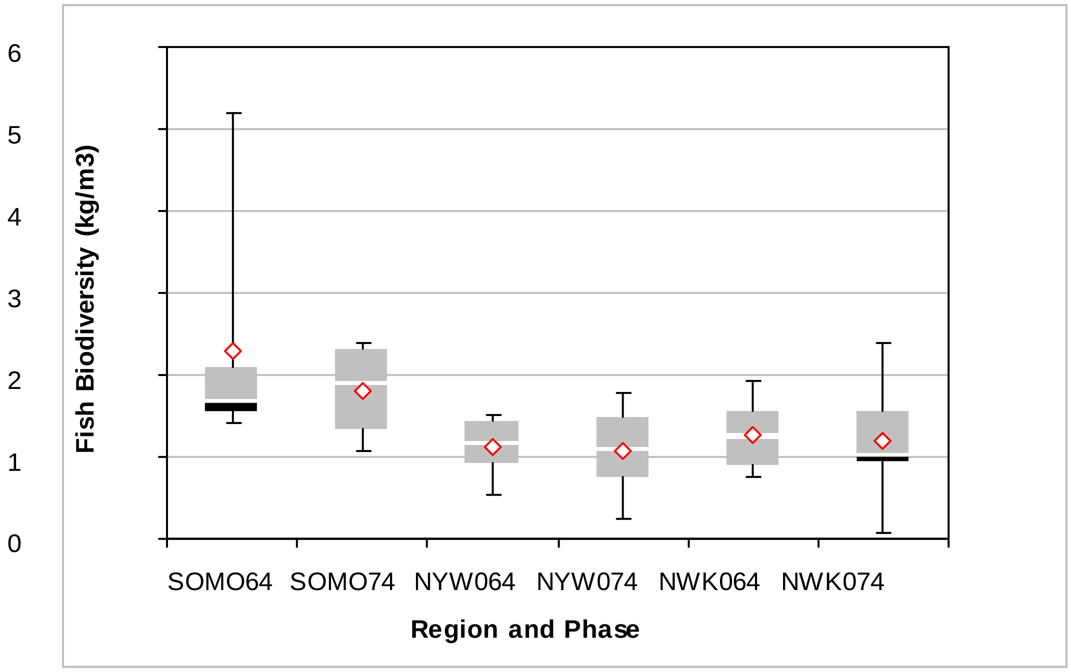

Figure 5. Box plot of fish biodiversity per region and phase.

4.5 Trophic Group Abundance

All fish species surveyed were assigned to one of the following six trophic groups: planktivore, piscivore, invertivore, herbivore, detritivore, corallivore. This was completed with FishBase using published food items and assigned trophic levels (Froese and Pauly 2004).

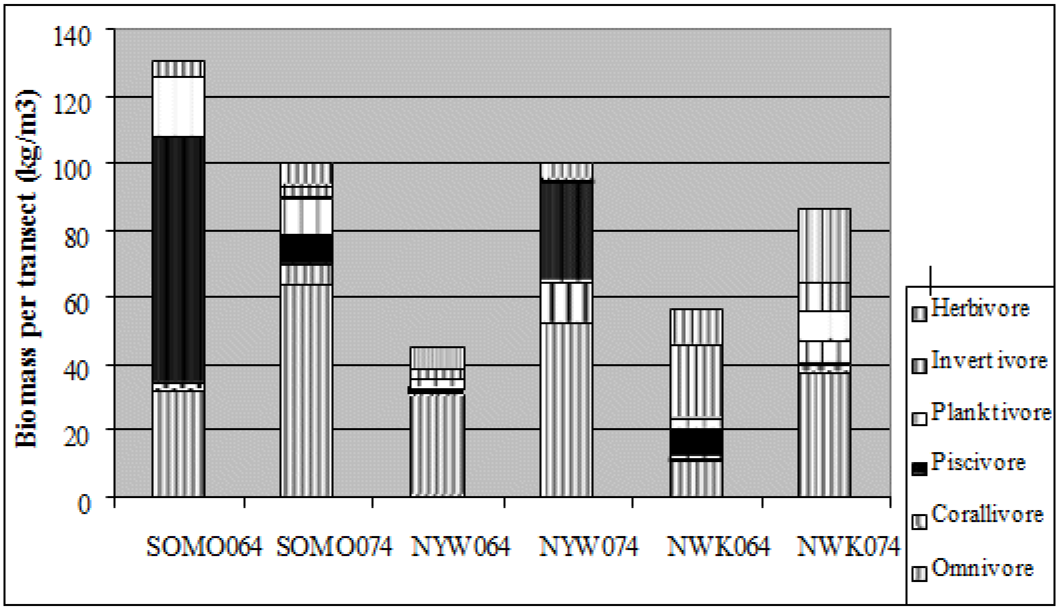

Figure 6: Biomass for each trophic group in each region and phase.

In Somosomo and Nawaikama the amount of herbivorous fish increased between 2006 and 2007 (Figure 6). In particular, piscivores are at the top of the food web, they tend to be fewer in number but larger in size. They were recorded in all regions; however, only in Nukuyaweni was there a notable increase in piscivore biomass. By contrast, invertivores showed a decrease in abundance from 2006 to 2007 across all areas.

4.6 Algal abundance

Algal cover was calculated using an arbitrary scale by trained observers. A range of 1 to 10 was used to indicate abundance of algal growth across the transect area covering 100m².

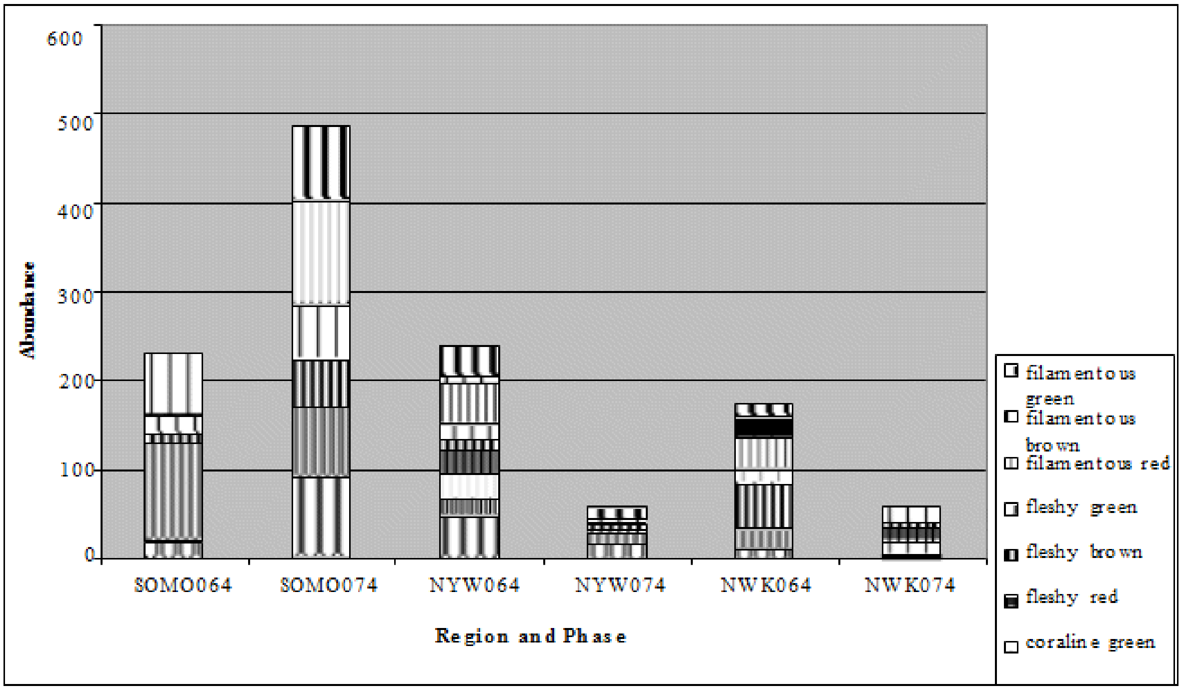

Figure 7: Algae abundance across the regions and phase.

Nawaikama and Nukuyaweni showed a decrease in algae abundance from 2006 to 2007. By contrast, Somosomo doubled the total abundance of algae coverage from the initial monitoring (Figure 7). However, there was no significant difference between regions (F=0.624, p=0.542) or time periods (F=0.294, p=0.591).

4.7 Invertebrate Abundance

The abundance of key invertebrates was measured as the number of individuals encountered on 100m² transects. All regions showed an increase in invertebrate abundance between 2006 and 2007 (Figure 8). However, ANOVA did not reveal a significant difference between regions (F=1.928, p=0.187). Nudibranchs were only recorded during winter 2007 but no significant difference was found between regions (ANOVA, F=2.153, p=0.197).

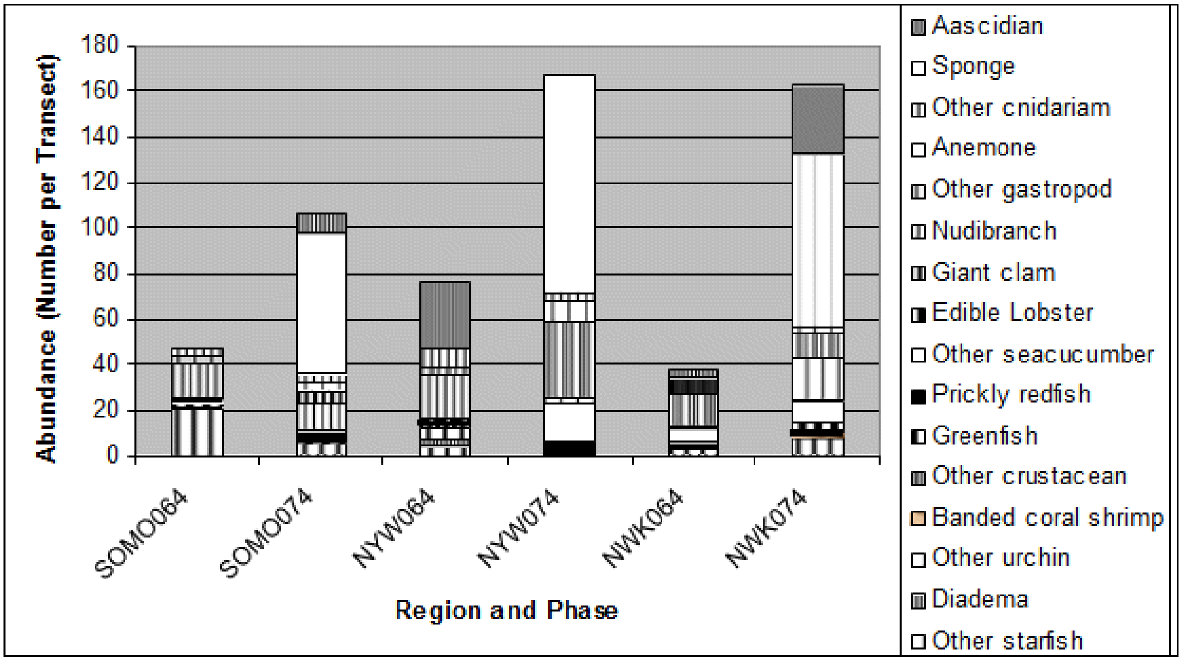

Figure 8: Abundance of key invertebrates in each region and phase.

5. Discussion

5.1 Coral Abundance and Diversity

Hard coral is the building block of the reef ecosystem. These corals grow in large colonies and are the architect of this environment. They control levels of macroalgae which can have a negative impact on ecosystems by competing with the coral for space and nutrients (McManus & Polsenberg 2004). The loss of hard coral cover can then have multiple negative consequences for biodiversity, fisheries and shoreline protection.

Hard coral coverage was lowest in Nukuyaweni and highest in Somosomo (Figure 2), although no significant difference was found between sites or monitoring period. Therefore, this result does not support our hypothesis that villages with longer serving MPAs show greater levels of coral diversity and abundance.

The high coral cover and biodiversity found, respectively, at Somosomo and Nukuyaweni could be explained by the presence of the barrier reef and the resulting absorption of wave energy offering some protection to the central regions. In addition, Nukuyaweni has so far little or no agricultural run-off. However, the relstively slow rate of coral growth at this site could be due in part, to the construction of an hotel, which could have led to elevated land run-off causing sedimentation, known to slow down coral growth by reducing light availability (Roager 1990). Somosomo also experiences agriculture runoff although on a much smaller scale, comparable to Nawaikama, as well as a small level of boat traffic.

The slightly low levels of hard coral diversity in Nawaikama could be due to the distance from the barrier which allows for more exposure to large waves originating from the Lovu region. Nawaikama also acts as a sink for all sediment runoff from the southern regions due to prevailing winds, the orientation of the bay and the presence of the Naviavia peninsula. The community of Nawaikama is situated at the foot of steep hills and comprises predominantly farming villages. Small subsistence farms are located on the steep hillsides above the villages. However, the areas used for farming are often unsuitable for farming due to poor soil, aspect and slope which often leads to increased agricultural run off. Nawaikama is therefore more affected by anthropogenic influences than other sites.

5.2 Fish Biodiversity

Low fish biodiversity and abundances are obvious indicators of an overexploited reef population (Cooke *et al.* 2000). In addition, the study of trophic abundance can provide important indication of stress and over fishing. There are three main groups which can be used as an indicator of overfishing: invertivores, piscivores and herbivores (Banse 2007). Piscivores are predatory fish such as snappers and groupers and are usually heavily fished due to their large size. They are frequently the first to suffer from over exploitation as they are generally targeted species (Banse 2007). Herbivores are grazers which maintain low macroalgae levels; their over-exploitation can therefore lead to a phase shift from coral to algae. These species are generally targeted after piscivores become non-viable (Banse 2007). Finally, invertivores are an important indicator of overall biodiversity of the reef systems as they feed on important invertebrates (Banse 2007).

Over a year period we would expect to already see an increase in overall biomass of all trophic levels for commercially important species which would be protected within the protected area. Therefore, we would expect areas which held established marine protected areas for longer periods to have a greater level of biodiversity.

In terms of total fish biomass, ANOVA analyses found no significant difference between regions or time periods. However, this measure does not provide any information about the types of fish found on the reef. By contrast, trophic level analyses revealed noticeable difference between regions and time periods.

Piscivores were recorded in all regions. However, only in Nukuyaweni did biomass significantly increase for this trophic group, with no piscivore recorded during the first time period. However, due to the size of each of these individual groups, it is possible that a few large individuals caused a bias. Conversely, this may also account for Somosomo's decrease in biomass for this group. Another factor may the barrier reef which could be discouraging roaming predatory fish such as sharks.

Herbivorous fish featured in all regions although they only showed a significant increase in Somosomo and Nawaikama. This may be linked to the decrease in piscivores which are predators of this trophic group. By contrast, Nukuyaweni showed a decrease in herbivores which can be accounted for by the increase in predatory fish species. However, higher levels of herbivorous fish could also suggest an increase in the algal abundance of the region and a possible phase shift. Somosomo, which showed an increase in herbivorous fish species, did experience an important increase in algae cover during the second monitoring period (Figure 7).

The abundance of invertivore fish is directly linked to invertebrate numbers and consequently is an excellent indication of the biodiversity of the ecosystem. Their abundance declined at all sites between 2006 and 2007. Surprisingly, the abundance of invertebrates showed a sharp increase during the same time period, especially sponges which constitute an important food for invertivore fish. This increase in food sources has therefore not yet contributed to an increase in the abundance of intrivores. It is expected that the next monitoring phase will see a significant increase in invertivores. However, the sudden increase in Somosomo's algae abundance might also cause a decrease in invertebrate biodiversity and abundance and thus no increase in invertivore numbers.

5.3 Eutrophication

Although coral reefs have one of the highest rates of primary productivity per unit biomass, they cannot withstand increased nutrient enrichment (Naim 1993). This nutrient influx is known as eutrophication and causes increased algal abundance and growth. Species of algae can inhabit coral growth and cause phase shifts in community structure (Bythall et al. 2000). Fleshy, coralline and filamentous algae when found in abundance are indicators of an unhealthy region (Gattuso 1996). These types of algae are capable of out-competing hard coral for space and light, but under normal circumstances are kept in check by a lack of nutrients and predation by herbivores (Gattuso 1996). Although all regions had recordings of these three types of algae, only Somosomo showed their abundance double in a year time. By contrast, both Nukuyaweni and Nawaikama showed a reduction in algae levels.

The coverage of algae was surprisingly low at Nawaikama, which is a highly populated area. We would have expected sewage in the water column to cause increased amounts of algae, especially as currents tend to accumulate all the run-off of sediments from other areas. The reduction in algae cover at Nawaikama could be due to the lengthening of the sewage pipe, which now transports sewage beyond the lagoon area. The recent increase in abundance of herbivores could have also maintained algae coverage to a minimum.

The recent increase of algae in Somosomo could be related to the introduction of a ‘public’ flushing toilet. The physical geography of this region is similar to Nawaikama, where sewage is prevented from moving out of the lagoon area. Phase shifts between coral to algae dominated ecosystems can occur very quickly. Our information therefore indicates that the sewage from this area is already causing eutrophication in the water column.

It was also unexpected for Nukuyaweni to have a high coverage of algae in the first monitoring year, as it is situated in an unpopulated area. This high level of algae could have been caused by the ongoing construction of a resort. This can lead to coral mortality consequently allowing algae to gain a foot hold in the ecosystem (Rogers 1990). Our data would support this hypothesis, with hard coral coverage decreasing and algae levels increasing during the period of the construction. When the majority of the building work had been completed, hard coral coverage increased whilst algae levels decreased. The biomass of herbivore fish also increased, which is likely to be correlated with high algae levels.

5.4 Invertebrate Abundance

Invertebrates are an important part of reef ecosystems as they form a vital role in food webs. All regions showed a sharp increase in invertebrate numbers, whilst Nawaikama and Nukuyaweni demonstrated the greatest abundance of invertebrates overall.

Gleaning is common on Gau and is generally carried out by women and children on the reef flats (personal observation). This is a traditional practice where during low tide any edible or of common value left on the shoreline is collected. As such records of invertebrate abundance can be used as guides for over fishing. All sites showed low numbers of *Diadema* urchins which is indicative of over fishing, only Nawaikama showed an increase of other, non edible, urchins. Sea urchins are important grazers and a decline of these could contribute to a shift from a coral ecosystem to one dominated by macroalgae.

Key invertebrate species such as giant clams showed an increase in the regions of Somosomo. Giant clams are prized in Fiji for consumption and their shells are often sold as decoration. Only Somosomo showed a sighting of edible lobsters, which actually decreased the following year; all other regions showed no recordings which is an indication of over fishing for these slow growing species. Overall, invertebrate numbers were highest in Nawaikama and Nukuyaweni suggesting low gleaning pressure in these regions.

Importantly, sea cucumbers showed a general increase in most regions. There are two main sea cucumber fisheries in Gau; sea cucumbers are not consumed by the locals, instead, the catch is dried in the sun and exported to China. Sea cucumber catches generally attain $25 (Fiji) per kg (dry weight). General fishing on the island is not highly sought after as there is no storage capacity to stock fish. Therefore the methodologies and prices paid for sea cucumbers make these valuable resources and as such their numbers should be monitored closely.

6. Conclusion and recommendations

The purpose of this study was to comprehend if the marine protected areas which have been implemented around the island of Gau have been effective in protecting the reef ecosystems, and consequently the associated fisheries. Each of the three regions had established MPAs at different time periods.

Although Nawaikama's marine protected area was created 7 years ago, the data does not show that this region has the healthiest reefs. This could be due to human pressures on the environment which could have countered the beneficial impact of the MPA. Indeed, Nawaikama has the highest human population with greatest levels of infrastructure. Although the coral coverage and diversity was relatively low, fisheries were deemed healthy in Nawaikama. It showed healthy levels of fish biomass, biodiversity, trophic balance and invertebrates, which could be indirectly linked to the fact that it is the longest serving MPA, with villagers being more aware of location of the protected area.

Somosomo, which has implemented a MPA for three years, showed the greatest increase in many indicators of the reef health such as fish biomass, hard coral coverage and diversity. However, the region also showed abundant algae growth which has enhanced the numbers of herbivores. This may be due to eutrophication caused by the construction of new public toilets. Changes in trophic levels could also be due to over-fishing.

The implementation of the MPA in Nukuyaweni two years ago should have amounted to improved fisheries. Being geographically isolated, Nukuyaweni had the least human pressures. Although the region showed the highest levels of hard coral diversity and showed considerable coral coverage, it did not show a significant increase from one year to the next. This could be due to the fact that the MPA has only been in existence for two years. Nukuyaweni also showed the lowest levels of fish biomass and biodiversity. One reason could be that MPAs are not properly marked and localized fishing may still occur in these areas. Nukuyaweni has the least human pressures due to the isolation of the region, which means that it may also be more difficult for other villagers to be aware of the location of the marine protected area. This would make this particular MPA extremely difficult to enforce.

Due to the intricate relationship between villages and their reefs, it is difficult to compare each site directly without accounting for all possible contributing factors. Indeed, several additional ecological, physical and geological differences between regions also need to be taken into account before conclusions can be drawn regarding the effectiveness of the marine protected areas.

To gain a more precise idea of the evolution of the coral reefs in these regions, it would be important to investigate changes on a specific section of the reef. It would also be beneficial to set up permanent transects for long term monitoring. These sites could then be used for direct comparison every six months, preferably at the same time of the year, to account for seasonal variations. We suggest the set up of four permanent transects in each region at appropriate depths, both within the marine protected areas and outside the protected areas. In addition, it would be interesting to correlate any changes between terrestrial and marine environments, and implement appropriate measures to protect the reef ecosystems. Data collection and input should also be more standardized to provide both Frontier and the University of the South Pacific with some comparable data which can be used for influencing key decision makers and demonstrating the need for more effective protection of coral reefs.

7. References

Banse, K. (2007) Do we live in a largely top-down regulated world. *Journal of Bioscience* 32:791-796.

Brown, B. E. and Ogden, J. E. (1993) Coral Bleaching. *Scientific American* **268** (1): 64-70.

Bythall, J.C., Hills-Starr, M.L and Rogers, S.C. (2000) Local variability but landscape stability in coral reef communities following repeated hurricane impacts. *Marine Ecology Progress Series* 204:93-10.

Carr, M.H., Anderson, T.W. and Hixon, M.A. (2001). Biodiversity, population regulation, and the stability of coral reef fish communities. Proceedings National Academy of Sciences USA 99:11241-11245.

Dulvy, N. K., Freckleton, R. P. and Polunin, N. V. C. (2004) Coral reef cascades, and the indirect effects of predator removal by exploitation. *Ecology Letters* **7**:410-416.

Froese, R. and Pauly, D. (eds) (2004) FishBase. World Wide Web electronic publication http://www.fishbase.org, version 16 February 2004.

Garpe, K. C., Yahya, S.A.S., Lindahl, U. & Ohman, M. C. (2006) Longterm effects of the 1998 coral bleaching event on reef fish assemblages. *Marine Ecology Progress Series* **315**:237-247.

Gattuso, P.J., Pichon.M. Delesalle.B., Canon.C. and Frankignoulle. (1996) Carbon fluxes in coral reefs L.Lagrangian measurement of community metabolism resulting air-sea CO2 disequilibrium. *Marine Ecology Progress Series* 145:109-121.

Gomez, E. D. (1997) Reef management in developing countries: a case study in the Philippines.

Coral Reefs **16**:S3-S8.

Hastings, A. and Botsford, L. W. (2003) Comparing Designs of Marine Reserves for Fisheries and Biodiversity. *Ecological Applications* **13**:S65-S70.

Jones,J.R., Ward,S., Affendi Yang Amri.Yang,A. and Ove Hoegh-Guldberg. (2000) Changes in quantum efficiency of Photosystem II of symbiotic dinoflagellates of corals after heat stress, and of bleached corals sampled after the 1998 Great Barrier Reef mass bleaching event. Mar.Freshwater.Res. 50:63-71.

Koop, K., Booth, D., Broadbent, A., Brodie, J., Bucher, D., Capone, D., Coll, J., Dennision, W., Erdman, M., Harrison, P., Hoegh-Guldberg, O., Hutchings, P., Jones, G. B., Larkum, A. W. D., O'Neil, J., Steven, A., Tentori, E., Ward, S., Williamson, J. and Yellowlees, D. (2001) ENCORE: The Effect of Nutrient Enrichment on Coral Reefs. Synthesis of Results and Conclusions. *Marine Pollution Bulletin* **42**:91-120.

McLaughlin, C. J., Smith, C. A., Buddemeier, R. W., Bartley, J. D. and Maxwell, B. A. (2003) Rivers, runoff and reefs. *Global and Planetary Change* **39**:191-199.

McManus, J. W. (1997) Tropical marine fisheries and the future of coral reefs: a brief review with emphasis on Southeast Asia. *Coral Reefs* **16** suppl: S121-S127.

McManus, J. W. and Polsenberg, J. F. (2004) Coral-algal phase shifts on coral reefs: ecological and environmental aspects. Progress in Oceanography **60**:263-279.

Naim, O. (1993) Seasonal responses of a fringing reef community to eutrophication (Reninium Island, Western Indian Ocean). *Marine Ecology Progress Series* 99:137-151.

Rogers.S.C. (1990) Responses of coral reefs and reef organisms to sedimentation. *Marine Ecology Progress Series* 62:185-202.

Russ, G. R. and Alcala, A. C. (1999) Management histories of Sumilon and Apo Marine eserves, Philippines, and their influence on national marine resource policy.

Sala, E., Aburto-Oropeza, O., Peredes, G., Parra, I., Barrera, C.J. and Dayton, P.K. (1993) A general model for designing networks of marine reserves. *Science* 298:1991-1993.

Souter, D. W. and Linden, O. (2000) The health and future of coral reef systems. *Ocean Coastal Management* **43**:657-688.

Walters, C. Pauly, D. and Christensen, V. (1999) Ecospace: Predication of Mesoscale Spatial Patterns in Trophic Relationships of Exploited Ecosystems with Emphasis on the Impacts of Marine Protected Areas. *Ecosystems* 2:539-554.

Veitayaki, J, Aalberberg, B, Tawake, A., Rupeni, E and Tabunakawai, K. (2003). The Fiji locally managed marine are network and its influence on national policy development. Resource management in Asia Pacific working paper number 42; Resource management in Asian pacific program.

Veitayaki, J, Tawake, A, Bogiva, A, Meo, S, Nacanieli, R., Vave, R, Radikedike, P. and Fong, S. (1995) Partnerships and the Quest for Effective Community-based Resource Management:-the Mositi Vanuoso Project, Gau, Fiji. The University of South Pacific.

Vieux,C., Aubanel,A., Axford,J., Chancerelley,Y., Fisk,D., Holland,P., Juncker,M., Kirata,T., Kronen,M., Osenberg,G., Pasisi,B., Power,M., Salvat,B., Shima,J. and Vavia,V. (2004) Status of Coral Reefs in the Southwest Pacific to 2004: Fiji, Nauru, New Caledonia, Samoa, Solomon Islands, Tuvalu and Vanuatu. Chapter 13 A century of change in coral reef status in southeast and central Pacific: Polynesia Mana Node, Cook Islands, French Polynesia, Kiribati, Niue, Tokelau, Tonga, Wallis and Futuna. Australian Institute of Marine Science