Frontier Fiji Marine Environmental Research

REPORT 3

A Study Investigating The Effect Of Marine Protected Areas On Reef Health And Fisheries In Small Island Communities

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Gillis, L. G., Steer, M. D. and Fanning E. (eds.)

International Ocean Institute

Society for Environmental Exploration UK

Gau Island

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Tel: +44 (0)20 7613 3061
Fax: +44 (0)20 7613 2992
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For more information:

Frontier -Fiji
International Ocean Institute – Pacific Islands,
University of the South Pacific,
Lower Campus,
Laucala Bay Road,
Suva,
Fiji
Tel: +679 323 2960
E-mail: Veitayaki_J@usp.ac.fj

Society for Environmental Exploration

50-52 Rivington Street,
London, EC2A 3QP. U.K.
Tel: +44 (0) 20 7613 3061
Fax: +44 (0) 20 7613 2992
E-mail: research@frontier.ac.uk
Internet: www.frontier.ac.uk

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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. Marine protected areas (MPA’s) were introduced in front of all coastal villages to try and preserve essential marine resources. The study investigated important aspects of coral reef health over a one year period. Each specific monitored variable was chosen so that conclusions could be drawn regarding the overall health of the ecosystem. Three regions were chosen, each site was monitored every three months over a one year period. The MPA's for each village were not introduced in one year but over several, therefore it was expected that sites which held older protected areas would have greater hard coral coverage and diversity as well as a larger abundance of fish species. It was also predicted that all sites would show a general increase in entire ecosystem health over the year period. There was no evidence that fish biomass and coral health were higher in areas with longer serving MPA’s. However, the second hypothesis was supported by the data; a general increase in reef health was observed. These overall results were unexpected, further analysis of the data and conditions of the sites suggests that there was a bias caused by independent factors such as human activity. These are the preliminary results; further research is required in Gau for the improvements of fisheries are to develop effective marine management. The use of marine protected areas for coastal management is important for regions like Fiji where many islands 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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.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 and 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 bought in by tourism from the marine environment (Souter & Linden 2000). This has allowed a greater level of protective measures for coral reefs to be introduced (Gomez 1997).

Scleratinian corals (hard corals) have a narrow range of water temperatures for optimum growth, within 25 - 29 °C corals are able to grow and reproduce (Brown & Ogden 1993). Temperatures above this range can cause the coral to become stressed and can result in bleaching, where the coral will expel the zooxanthellae (Jones *et al* 2000). Fiji suffered a bleaching event in March-April 2000; 80% of reefs were effected (Vieux et al 2004).

Corals require clear water to allow sufficient sunlight for the algae (zooxanthellae) within the tissues to generate necessary nutrients to support coral growth (McLaughlin, C. J. *et* *al* 2003). Influx of substances from agricultural run-off, pollution or untreated sewage can damage reefs. A phase shift may occur where coral is outgrown by algae; which competes with the coral for space and light (McManus & Polsenberg 2004). This change can occur quickly and result in a sudden drop in productivity in the form of fish and invertebrate populations (McManus & Polsenberg 2004). Changes in fisheries can have impacts on local human populations dependent on the reef for income (Koop *et al* 2001).

Other negative impacts on coral reefs include sedimentation, which reduces light levels in addition to preventing recruitment of new corals by smothering the rocky surfaces required for settlement (McLaughlin *et al* 2003). Furthermore, over-fishing or overexploitation of the reef resources can cause problems within trophic levels which have strong implications for the entire ecosystem. Top down fishing of large predatory fish from a reef community has a cascade effect resulting in colonization by benthic algae and consequently a reduction in hard coral cover. This can result in an increased number of herbivore fish which feed on the algae and normally are kept in check by the predatory fish species (Dulvy *et al* 2004). Removal of key herbivores, such as parrot fish, can result in overgrowth of macroalgae due to the reduced herbivores herbivorysMcManus & Polsenberg 2004).

1.2 Marine Management

Marine protected areas have nave been implemented in many coastal areas to protect regions of threatened species and habitats; ensuring they are not degraded by human influences (Botsford *et al* 2003). They are also used as a management tool to protect areas of high biodiversity and 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 very successful (Russ & Alcala 1999). Fiji has embraced the concept of marine protected areas and has developed various methods to implement them.

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

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 proved successful in protecting the fishing stocks and improving local fish stocks and reef health (Veitayaki *et al* 2003).

2. Area Description

Gau 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. Figure 1 shows a map of Gau, which is composed of a variety of terrestrial and coastal ecosystems for example 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. Between the barrier reef and the land there is a deep lagoon, with fringing reefs also extending up the western coastline. The islands 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

2.1 Integrated Coastal Management of Gau

All the lagoonal waters on Gau come under the jurisdiction of the High Chief and the *mataqali*. 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 to allow recovery of local reefs through seeding. Frontier-Fiji was requested to join the various agencies 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 Rationale of the Program

For this paper we wanted to investigate the potential success of marine protected areas on Gau. It was decided to choose three regions which had MPA's for different periods of time. We then took data from phases 064(2006) and 074(2007) which would give us an indication of changes in each ecosystem health over a period of one year, each monitoring period was completed at the same time; October to November. None of the specific transects that we analyzed data from were in the MPA's for each region, however it was felt that 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 protected areas of seven, three and two years respectively. Three full transects were chosen from each site per monitoring phase to compare changes. A transect covers a distance of 45 m running along the contours of the reef at a constant depth. Depth ranges covered are 10-12m (reef bottom) and 6-8m (reef slope).

Each variable which was chosen to be monitored was important in understanding the health of the ecosystem. The coral percentage cover and diversity were recorded; this is the most important aspect of estimating health of the reef areas. Hard corals are the architecture of the ecosystem; they support huge levels of biomass of fish species as well as large numbers of invertebrates. Combining hard coral coverage with algae coverage from each region allows the investigation of changes in phase shifts from coral to algae which have severe effects on biodiversity thus fisheries. The main reason for developing MPA's in each region was to improve fish stocks for the adjacent villages. To analyse this we used data collected on invertebrate number, fish biomass, biodiversity and trophic group. These are all vital components of monitoring fish stocks hence if the marine protected areas are providing protection for important species.

3. Objectives for investigating the impact of marine protected areas on ecosystem health

The main purpose of this study was to observe coral reef health in regard to the effect of the marine protected area. Previous studies have shown MPA´s can positively influence adjacent ecosystems (Walters *et al* 1999).

Prior to the study it was expected that regions should show a significant difference in fisheries as well as better overall reef health over a period of one year. Regions which have had protected areas for the longer periods would be expected to have improved reef ecosystems which would include components such as increased biomass and biodiversity in fisheries, larger numbers of invertebrates, greater percentage hard coral cover and lower algae cover. As such it was expected to see Nawaikama to have the most recovered ecosystems with greatest fish biomass and biodiversity, Somosomo should show the second greatest reef health. Lastly Nukuyaweni which has held a marine protected area for 2 years would show the lowest levels of hard coral cover and fishery health.

3.1 Methodology

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. It allows many aspects of the marine environment to be documented and used to determine whether there is any relationship within this environment. These relationships can provide potential explanations for reef health status. Three transects were monitored from each site per phase; each transect was surveyed at two separate depths 6-8m and 10-12m. It was found to be difficult to monitor specific transects per phase due to the nature of the monitoring completed in the past.

Therefore on occasions transects were chosen in close proximity to each other. Monitoring was completed using a four man diving baseline survey team; each person held a specific role in surveying the reef. To fully survey one transect, a team completed a survey within 1-2 hours using 1 tank.

3.2 Materials

The four surveyors monitored different aspects such as physical, fish, substrate, algae and invertebrates. The Physical surveyor recorded the physical and environmental factors. This surveyor took a campus bearing and placed a tape measure transect along a given depth contour, parallel to the shore. Environmental factors were recorded including depth, temperature and visibility at 0 m, 20 m, 25 m, and 45 m. The fish surveyor monitored the size and frequency of fish encountered along the transect in a hypothetical 5 m^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 estimated to the nearest 5 cm. Fish surveyed were limited to 18 families, belonging to six trophic groups. The Benthic surveyor noted the benthic substratum which is 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 was trained to identify hard coral and soft coral to genus level so that a measure of biodiversity at sites could be taken. The algae and invertebrate surveyor investigated invertebrates within a 5 m wide corridor above the transect.

Any invertebrate was recorded to genus or family level, with some notable indicators as exceptions being recorded to species level. Such as those which are protected and particular organisms which are indicators of over fishing or low reef health.

3.3 Data Analysis

All data analysis was carried out using Microsoft Excel 2003 and Past version 1.91 (2009). 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 each transects. The following equation was used with biomass of each species encountered on each transect.

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

Where p_i (the proportional abundance of the *i*th species) = n_i/N; 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 significant difference analysis of variance was used with replication (ANOVA) using phase and region as factors. This is a suitable statistical test when there are more than two independent ways of assigning the observations into groups and there is more than one observation per factor combination. In specific sections ANOVA one factor was used. Because of the form of the invertebrate data it was decided to use a Kruskal Wallis statistical test this is a non parametric version of a one-way ANOVA. Due to multiple testing we applied a Bonfessoni correction for all statistical tests; this decreased the significant value to 0.025.

4. Results

4.1 Hard Coral Cover

Hard coral cover for each transect was converted to percentage cover of the 20 m transect. All sites showed a increase in hard coral cover growth from the previous year (figure 2). The lowest coral cover found was in Nukuyaweni and the highest in Somosomo.

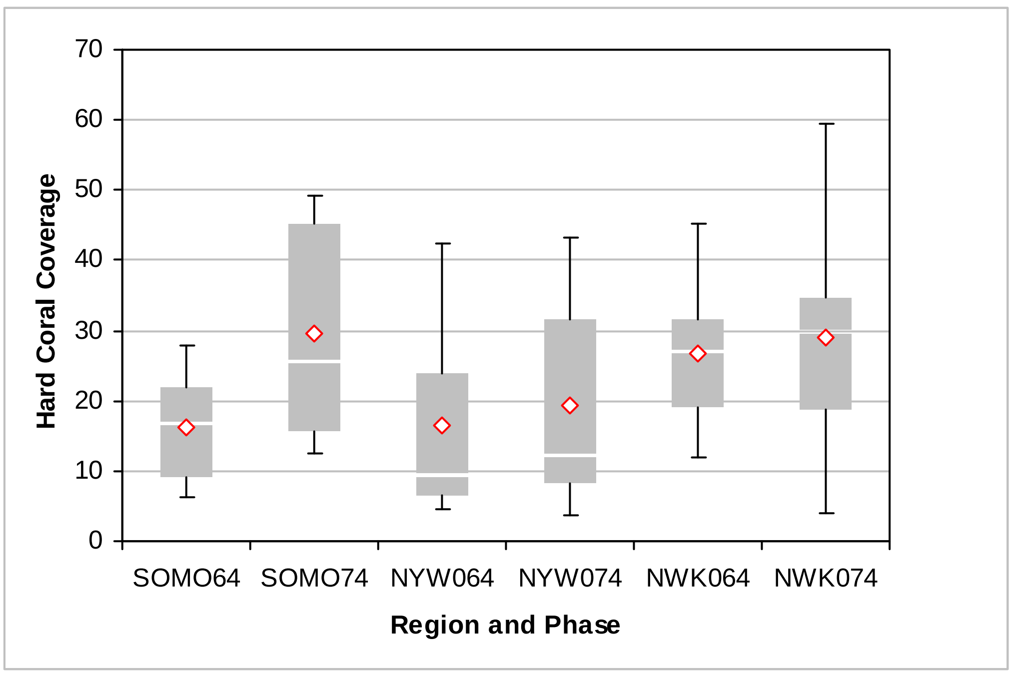

Figure 2: Box plot showing percentage hard coral cover in each region and phase.

An ANOVA 2 factor with replication analysis gave probability values which indicated no significant difference between regions (F_2=1.301, p=0.287 where p<0.025), however a difference was found between phases (F_1=0.236, p=0.236 where p<0.025).

4.2 Hard Coral Diversity

Hard coral diversity was counted simply as the number of hard coral genera found per transect. Genus richness ranged from 3 genus per transect to 23 genera per transect.

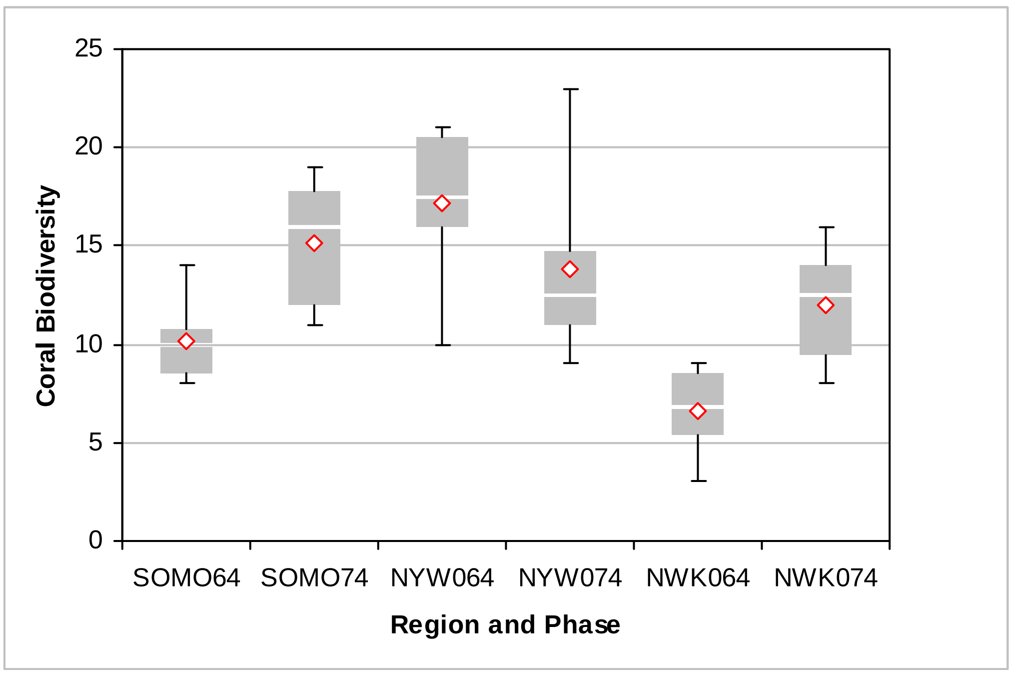

Figure 3: Box plot showing coral diversity, measured as genus per transact, in each region and phase.

All three regions showed a general increase in genus richness during the year monitoring period (figure 3). However the majority of Nukuyaweni transects indicated a decrease of genus richness, only one section showed a greater number of species. An ANOVA 2 way factor with replication test showed there to be a difference in genus richness per region (F_2=9.259, p=0.000738 where p<0.025). However this analysis did not show there to be a difference per phase (F_1=4, p=0.054 where p<0.025).

4.3 Fish Abundance

Fish abundance on surveys was calculated by converting species abundance into biomass (kg).

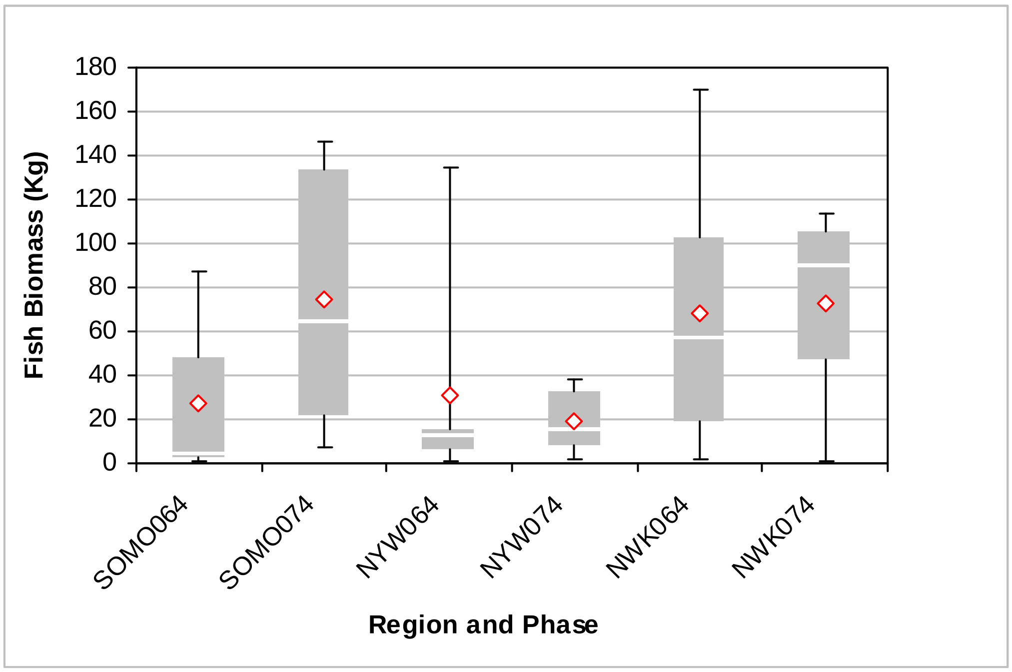

Figure 4: Box plot of biomass for surveyed fish for each region and phase in kg/m³ in order of longitude

Somosomo had the highest biomass over one year; Nukuyaweni and Nawaikama showed less biomass than the previous year (figure 4). However the majority of transects in Nukuyaweni and Nawaikama indicated an increase in biomass from the previous year.

An ANOVA 2 factor with replication analysis gave high probability values which indicated no significant difference between regions (F_2=2.6, p=0.0908 where p<0.025) and phases (F_1=0.687, p=0.413 where p<0.025).

4.4 Fish biodiversity

Biodiversity of fish was calculated using the Shannon-Weiner (*H'*) formula. A natural population would be expected to fall between 1.5-3.5 *H'* (Carr et al 2001). Indices ranged from 0.0788 to 5.193, with the majority of sites exhibiting relatively low levels of biodiversity (figure 5). All sites showed an increase in biodiversity over the monitoring period.

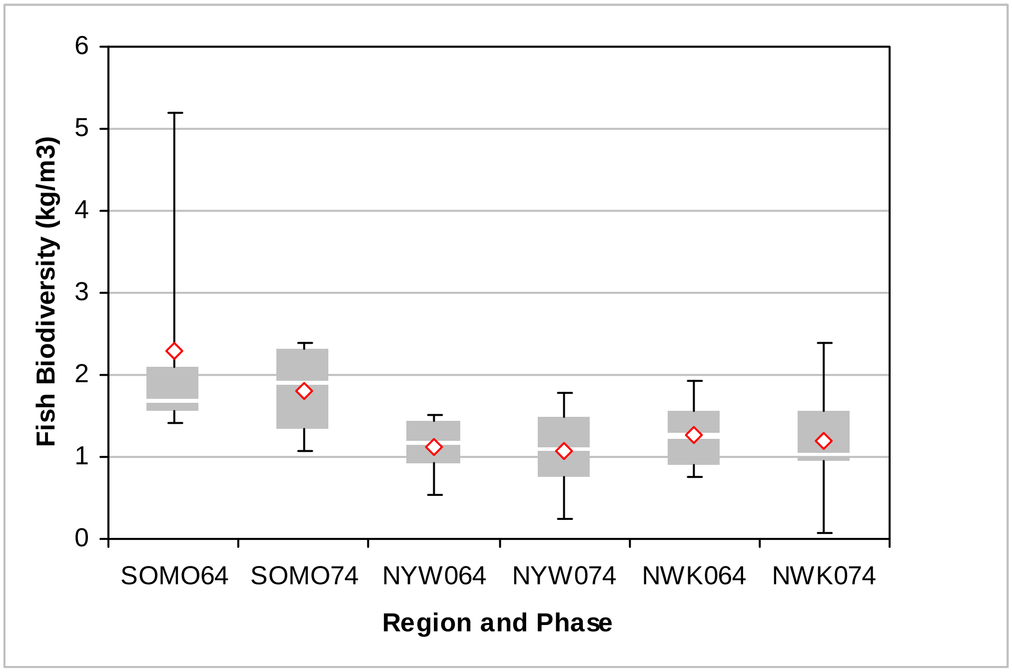

Figure 5: Box plot of fish biodiversity per region and phase.

A difference was found using ANOVA 2 way factor with replication between the three regions (F_2=5.087, p=0.0125 where p<0.025), no difference was found between the phases (F_1=0.589, p=0.448 where p<0.025).

4.5 Trophic Group Abundance

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

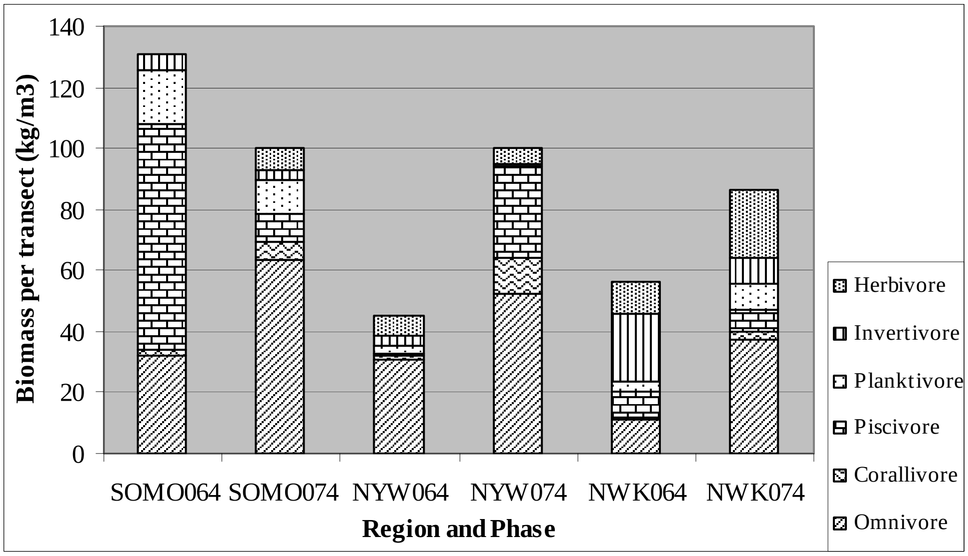

Figure 6: Biomass for each trophic group in each region and phase.

Herbivorous fish feature in all regions although they only showed an increase in Somosomo and Nawaikama (figure 6). Piscivores are fish which are at the top of the food web; they tend to be fewer in number but larger in size. In all the regions these were recorded however only in Nukuyaweni was an increase in piscivore biomass documented. Invertivores showed a decrease in abundance from 2006-2007 across all areas; in Nukuyaweni no recordings were shown for the second phase of monitoring.

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.

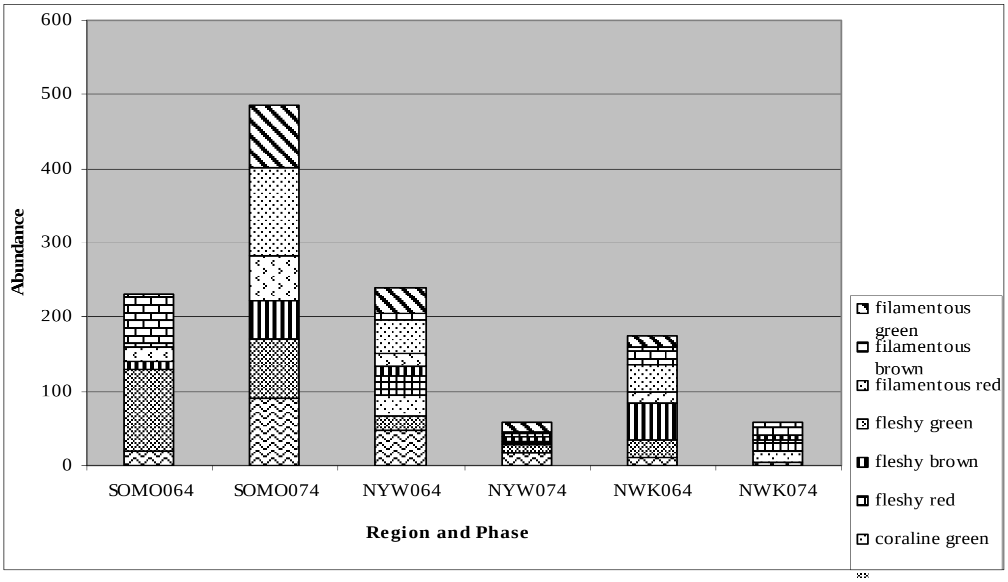

Figure 7: Algae abundance across the regions and phase.

Nawaikama and Nukuyaweni showed a decrease in algae abundance from 064 to 074; Nukuyaweni dropped by approximately 75% and Nawaikama approximately by 60%. However Somosomo doubled the abundance of coverage from the initial monitoring (figure 7). Using ANOVA 2 factor with replication analysis showed there to be no difference between regions (F_2=0.624 p=0.542 where p<0.025) or the two phases (F_1=0.294 p=0.591 where p<0.025).

4.7 Invertebrate Abundance

Key invertebrate abundance was measured by the number of individuals encountered on a 100 m² transects.

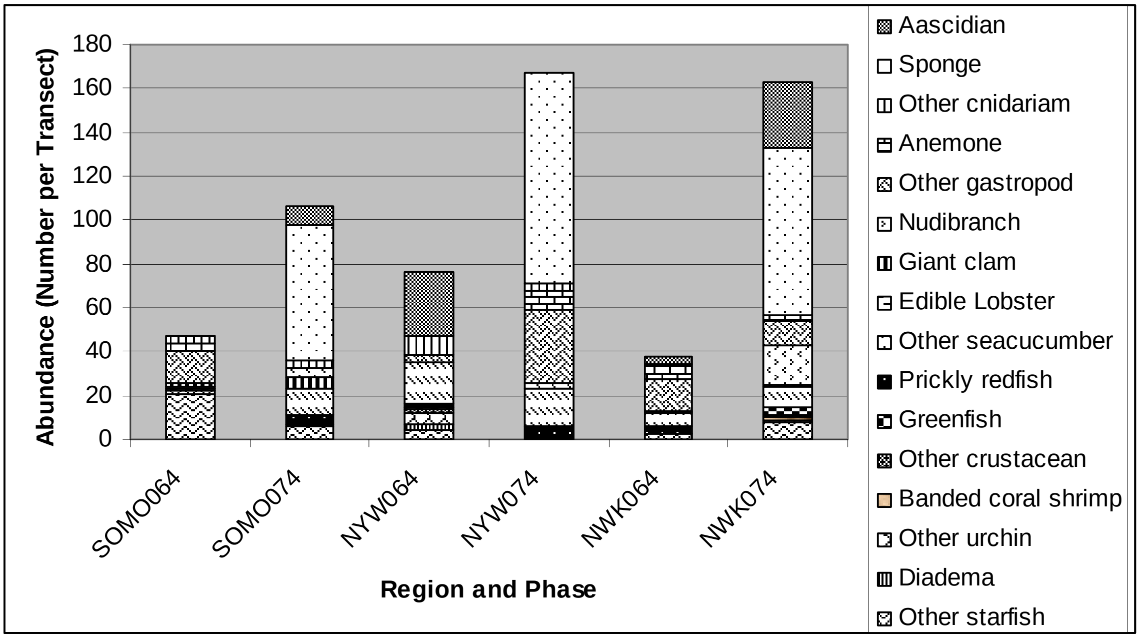

Figure 8: Abundance of key invertebrates in each region and phase.

All regions demonstrated increased invertebrate abundance from phases 064 to 074 (figure 8). Sponges showed one of the greatest increases from no sightings to substantial abundances, Nudibranchs showed numbers only during the monitoring phase of 074.

Statistical analysis was used on each individual invertebrate species which had been spotted in both monitoring phases as well as number of invertebrates found over all.

The only a difference was found between phases for Ascidians in Nawaikama (F_2=0.005075 p=0.003948 when p<0.025). In Somosomo the a difference was found between phases overall numbers of invertebrates (F_2= 0.01307, p=0.01041 where p<0.025). Further analysis found there to be no difference between regions over the phases where 064 phase (F_2=0.2506, p=0.308, p<0.025) and 074 phase (F_2= 0.298, p=0.2095, p<0.025).

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 as such 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. The loss of hard coral cover can have consequences for biodiversity, fisheries and shoreline protection.

Hard coral coverage was lowest in Nukuyaweni (figure 2). The region with the highest hard coral coverage was Somosomo (figure 2). Further analyses (ANOVA) of the data indicated that there was a difference over the year monitoring period.

An increase in coral diversity was shown across all areas, where Somosomo and Nawaikama showed the greatest increase of biodiversity (figure 3). However Nukuyaweni held the largest coral biodiversity for all regions. ANOVA testing supported the data that there was a difference between areas. However it was thought that villages with longer serving MPA's would show greater levels of coral species and higher coral coverage. Our data disagreed with this hypothesis.

The presence of the barrier reef and the resulting absorption of wave energy appear to be offering an amount of protection to the central regions of Somosomo and Nukuyaweni as they held the highest coverage and biodiversity respectively. Nukuyaweni has little or no agricultural run-off which the data supports as this site had the highest level of hard coral diversity although at the slowest growth rates. The slower rate of coral growth for this region is believed to be due to the construction of the hotel via elevated land run-off causing sedimentation in the water column. This may slow down coral growth as light availability is severely reduced thus affected calcification rates (Roger, 1990). Somosomo also experiences agriculture runoff although on a much smaller scale comparable to Nawaikama, as well as a small level of boat traffic which indicates its higher overall hard coral coverage, growth rate and biodiversity

It is possible that the lower levels of hard coral coverage in Nawaikama are due to the distance from the barrier which allows for more exposure to large waves originating from the Lovu region.

Nawaikama acts as a sink for all sediment runoff from the southern regions due to prevailing winds, aspect of the bay and the Naviavia peninsula funneling currents into the bay. 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. Often the areas used for farming are unsuitable for farming due to poor soil, aspect and slope. Nawaikama had the greatest impact from anthropogenic influences than other sites which would have influenced the regions low coral diversity, high algae and low invertebrate numbers (figure 7 and 8).

5.2 Fisheries

Fish abundance, diversity, trophic abundances, key invertebrate abundance and algal dominance can be used as indicators of over-fishing. Low fish biodiversity and abundances are indicative of an overexploited reef population (Cooke *et al* 2000). Food webs are an important aspect of coral reef ecosystems; consequently studying the changes in trophic groups can provide us with an indication of stress and over fishing. There are three 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 these are species which 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 macro algae levels by cropping; if they are over fished it may lead to a phase shift from coral to algae. These species are generally targeted after Piscivores become non-viable (Banse 2007). Invertivores are an important indicator of overall biodiversity of the reef systems as this trophic group feeds on important invertebrates (Banse 2007).

Over a year period we would expect to see an increase in overall biomass for all trophic levels. Especially for commercially important species such snapper and groupers which would have better protection from the no-take zones. Areas which held established marine protected areas for longer periods should show a slower rate in biomass values as these regions would have been given a longer time period to recover fish stocks; however we would expect to see these areas experience greater biodiversity.

The regions of Nukuyaweni and Nawaikama showed an increase in both biodiversity and biomass, thus healthier reef systems (figure 4 and 5). Somosomo showed a decrease in these variables (figures 4 and 5). ANOVA analyses found no difference between regions and phases in terms of biomass; however a significant difference was indicated between regions for biodiversity but not between phases. However this form of measurement does not tell us anything about the types of fish which are being recorded on the reef. Therefore this type of data should not be completely relied on to predict areas of overfishing, to fully comprehend the changes in ecosystems trophic levels are considered as well.

Piscivore abundance were recorded in all regions, however only in Nukuyaweni did biomass increase for this trophic group (figure 6). In all the other regions they were shown as decreasing in abundance. During the first phase of monitoring, Nukuyaweni recorded no sightings of piscivores however there was a significant biomass the following year (figure 6).

Due to the size of each of these individual groups it may be that not many fish were actually seen only a few larger individuals which caused a bias. Conversely this may also account for Somosomo's significant decrease in biomass for this group from the first monitoring year to the next. Another factor may be due to the barrier reef which may be acting to discourage roaming predatory fish such as sharks.

Herbivorous fish featured in all regions although they only showed an increase in Somosomo and Nawaikama (figure 6). This may be linked to the decrease in piscivores which are predators of this trophic group. Conversely Nukuyaweni showed a decrease in herbivores which can be accounted for by the increase in predatory fish species (figure 6). However higher levels of herbivorous fish are more likely to suggest a shift in the algal abundance of a region. This is an indication that a shift has occurred in the equilibrium between hard coral and macroalgae and suggests a proliferation in these invasive plants. Increased macroalgae can cause a sudden shift in the hard coral cover of a region and in turn the structure of the reef fish assemblage such as reducing invertivores. Somosomo has showed an increase in herbivorous fish species, from our data this region did experience greater abundance of algae during the second phase of monitoring (figure 7). This may equate to a phase shift in this area.

Invertivore fish can be linked to invertebrate numbers. Consequently they are an excellent indication of the biodiversity of the ecosystem. All sites showed no increase in this trophic group numbers;

Nawaikama and Nukuyaweni showed a decrease in abundance (figure 6). The invertebrate data showed a significant increase in number from 2006 to 2007, especially in important food sources for invertivore fish such as sponges (figure 8). This increase in food sources has not contributed yet to the abundance of trophic levels. It is expected that the next monitoring phase should observe an increase in invertivores to correspond to the change in invertebrates. However the sudden change in Somosomo's algae abundance may cause a decrease in biodiversity of invertebrates and thus no change for this trophic group.

5.3 Eutrophication

Although 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 thus cause fundamental 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 in 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 one Somosomo showed a significant increase in abundance (figure 7).

Both Nukuyaweni and Nawaikama were found to have reduction in levels of algae. Further analyses (ANOVA) showed a difference between regions and phases.

The lowest coverage of algae was shown by Nawaikama which was an unexpected result. It was thought that a highly populated area like this would have a larger coverage of algae as this region has more flush toilets per head which we thought to equate to increased sewage in the water column; especially in this area where currents tend to accumulate all run off in a small lagoon. Generally villagers do not have extended pipe lines from flush toilets thus sewage is piped directly onto adjacent reefs. The reduction in algae cover at

Nawaikama could be due to the lengthening of their sewage pipe so that it transports sewage beyond the lagoon area. The increase in abundance of herbivores will also have maintained algae coverage to a minimum.

The recent increase of algae in Somosomo was felt to be related to their introduction of a 'public' flushing toilet. The physical geography within this region is similar to Nawaikama where sewage is prevented from moving out of the lagoon area. Observations suggested the waste pipe did not stretch beyond the lagoon area. The toilets have not been positioned for a lengthy period. However the data indicates a large increase in algae coverage. Phase shifts between coral to algae dominated ecosystems can occur very quickly. Our information indicates that the sewage from this area is already causing eutrophication in the water column.

It was unexpected for Nukuyaweni to have such high coverage of algae in the first monitoring year as it is in an unpopulated area. It was felt that this was caused by the construction of the resort. This can lead to coral mortality consequently allowing algae to gain a foot hold in ecosystems (Rogers, 1990). Our data would support this hypothesis, during the phase 064 hard coral coverage decreased and algae levels increased which was the time period of the majority 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 during the phase 064 which could be correlated to high algae levels.

5.4 Invertebrate Abundance

Biodiversity is a key component of healthy coral reefs. Invertebrates especially are an important part of reef ecosystems as they form a vital role in food webs. All regions showed an increase in invertebrate numbers. Nawaikama showed the most increase in numbers of invertebrates whilst Nukuyaweni demonstrated the greatest abundance of invertebrates overall (figure 8).

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 anything left on the shoreline is collected.

As such invertebrate abundance and proliferation of indicatory invertebrates can additionally be used as guides for over fishing. Low numbers of *Diadema* urchins are indicative of over fishing; all sites showed low numbers of *Diadema* urchins only Nawaikama showed an increase of other urchins (figure 8). They are important grazers and a decline of these has led to a shift in many reef communities from stony coral abundance to macroalgae abundance.

Key invertebrate species for example giant clams showed an increase in the regions of Somosomo (figure 8). Giant clams are prized in Fiji for eating and their shells are often used as decoration. Only Somosomo showed a sighting of edible lobsters which actually decreased for the following monitoring year, all other regions showed no recordings which is an indication of over fishing for these slow growing species (figure 8). Overall invertebrate numbers were highest in Somosomo and Nukuyaweni suggesting low gleaning pressure in these regions.

Importantly sea cucumbers showed a general increase in all regions only in Nukuyaweni did they show a slight decline although indicator species such as Prickly redfish showed an increase in this region (figure 8). There are two sea cucumber fisheries in Gau; the catch is dried in the sun and sold to Chinese businessman from Suva. Sea cucumber catches generally attain $25 (Fiji) per kg (dry weight).

General fishing on the island is not highly sought after as there is not storage capacity to stock fish. Therefore the methodologies and prices paid for sea cucumbers make these valuable resources and as such there numbers should be monitored closely.

6. Management and Marine Protected Areas

The purpose of this study was to comprehend if the marine protected areas which have been implemented around the island of Gau, Fiji have been effective in protecting the reef ecosystems and consequently the fisheries associated with these environments. Each of the three regions had established MPA’s at different time periods; it was interesting to note how these affected various aspects of the reef. Although our transects did not fall within the actual marine protected areas, it was thought that a corresponding change should occur in adjacent areas.

Although Nawaikama has two marine protected areas; 7 years and 3 years old, the data does not support that this region has the healthiest reef areas. However it was felt that the

reason for this was the human pressures on the environment than the impact of the MPA. Nawaikama has the highest human population with greatest levels of infrastructure which in turn have increasing influences on the surrounding ecosystems. Although the coral coverage and diversity was low, fisheries were deemed healthy in Nawaikama. It showed significant numbers for fish biomass, biodiversity, trophic balance and invertebrates.
It was thought this could directly be linked to the longer serving MPA. As villagers would be more aware of location of the protected area. Somosomo showed that changes in human pressures are causing negative impacts to the reef health. It has implemented a MPA for three years; this region showed the greatest increase from one year in factors such as fish biomass, biodiversity, hard coral coverage and coral diversity. All vital aspects of a healthy coral ecosystem. However, the region showed abundant algae growth which had enhanced the numbers of herbivores. It was felt this may be due to eutrophication from the new public toilets. This demonstrates how sensitive coastal ecosystems can be. Changes in trophic levels where felt to be due to fishing.

The implementation of the MPA should have amounted to improved fisheries. The MPA's are not marked and localized fishing may have occurred in these areas. Nukuyaweni had the least human pressures; being geographically isolated. Although the region showed the highest levels of hard coral diversity and showed considerable coverage of coral it did not show a significant increase from one year to the next this would be due to the fact that the MPA has only be in existence two years, a inference could be formed that a protected area needs to be in place at least two year before they show any significant impact on reef health. Nukuyaweni also showed the lowest levels of fish biomass and biodiversity. Due to the isolation of the region, it may be more difficult for other villagers to be aware of the location of the marine protected area. There are only a handful of people at the resort at any one time and sometimes there is no one. This would make this particular marine protected area extremely difficult to enforce.

For each aspect of reef health that was monitored a ANOVA statistical analysis found a significant difference from the first phase of monitoring to the second phase of monitoring. This supported evidence which rejected the NULL hypothesis that stated that no difference would be found between phases thus our hypothesis was deemed correct. The ANOVA analyses coupled with other data showed a strong indication that the MPA's were having a positive influence on the fisheries, biodiversity and coverage of coral. All sites showed a significant increase in these areas from the previous year.

From analyzing the data it was felt that no firm statements could be made regarding the changes in the regions ecosystems. Due to the intricate relationship between villages and their reefs, difficulties are created in comparing each site directly with each other at the present. There are several ecological, physical and geological differences between regions in Gau which need to be taken into account before conclusions are drawn regarding the effectiveness of the marine protected areas. To control bias which may occur from these discrepancies key recommendations need to be implemented so that vital marine management plans can be cultivated.

6.1 Future Recommendations

To gain a more precise idea of modifications in the ecosystems it would be suitable to investigate changes on a specific section of the reef. To try and subtract some of the bias caused by unreliable GPS units it would be sensible to develop permanent transects

at each region which Frontier monitors, these sites could then be used for a direct comparison every six months preferable at the same time to subtract prejudice caused by changes in weather conditions. Preferable four permanent transects in each region at appropriate depths in the marine protected areas and the non marine protected areas. The GPS points are good for monitoring general health of areas but are not exact enough to be able to complete proper analyses on the data. It would be interesting if a short report was attached to data which noted any changes which had occurred in Gau both terrestrial and marine, these events could then be correlated with the data to see if any effect had been felt on adjacent reef systems.

Lastly data collection and inputting needs to be more standardized if proper analyzing is going to be used on the date produced. During the day to day running of the camp this may prove difficult but if this could be implemented for the permanent transects these would provide both Frontier and the University of the South Pacific with some essential data which they can use for influencing key decision makers on the changes in the coral reef areas.

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