Frontier Fiji Environmental Research Series

REPORT 1

Initial Assessment of the fringing reefs of Western Gau

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Frontier Fiji Environmental Research

Report 1

Initial Assessment of the Fringing Reefs of Gau

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International Ocean Institute – Pacific Islands

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Frontier-Fiji

The Society for Environmental Exploration and International Ocean Institute – Pacific Islands have been conducting collaborative research into environmental issues since 2006 under the title of Frontier-Fiji. Frontier-Fiji conducts research into biological diversity and resource utilisation of both marine and coastal terrestrial environments.

Fiji, located in the Pacific Islands is renowned for its biological and ecological diversity. The majority of this country is dependent in some way on its marine resources for protein. They have traditionally used management techniques to maintain these resources but are coming under increasing pressure from unsustainable exploitation. As a result, conservation and development work is of paramount importance in order to better protect and conserve those areas coming under increasing pressure. Frontier-Fiji conducts baseline survey work on the western island of Gau, Fiji's fifth largest island in an effort to provide biological and resource utilisation data for the preparation of sustainable management initiatives for the region.

International Ocean Institute – Pacific Islands (IOI-PI)

IOI operates out of 25 countries where it produces research and policy-related publications dealing ocean governance and ocean science. IOI works to ensure the sustainability of the ocean as "the source of life", and to uphold and expand the principle of the common heritage as enshrined in the United Nations Convention on the Law of the Sea.

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The Society is a non-profit making company limited by guarantee and was formed in 1989. The Society's objectives are to advance field research into environmental issues and implement practical projects contributing to the conservation of natural resources. Projects organised by The Society are joint initiatives developed in collaboration with national research agencies in co-operating countries.

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1. EXECUTIVE SUMMARY

Frontier-Fiji was invited by the communities of Gau and their partner organisations to conduct research on the island's marine resources. This research is intended to provide a scientific basis to the management of the resources and give an indication of the health of the island's marine ecosystems. During the first 9 months of study, Frontier-Fiji conducted underwater visual surveys within 11 of the island's 18 coastal regions. An intensive baseline survey method was utilised in order to study the health of the fringing reefs and highlight practices that are having a detrimental impact on the reefs.

Poor land management practices, such as slash and burn, are causing high levels of sedimentation in regions such as Nawaikama and Nukuloa, resulting in lower hard coral levels and impacting the local reef fish assemblages. The use of unsuitable slopes for farming in addition to the use of slash and burn is causing sedimentation from runoff. USP and IOI-PI have implemented mangrove planting projects and promoted the use of seawalls which will no doubt be aiding in the reduction of sedimentation, however improvement is needed in land management to reduce this sedimentation noticeably.

There is evidence of eutrophication in some regions, however this may well be a localised effect near certain villages. There is little use of fertilizers on Gau, but influx of nutrients is evident from the growth of fleshy macroalgae. The removal of some of the island's pigs from the seashore may be acting to reduce eutrophication. However proliferation of flush toilets with no treatment of sewage may cause problems in future to reefs near settlements.

There is little large-scale commercial fishing on Gau, therefore over-fishing is largely localised and likely due to methods used as opposed to the volume of fish taken. Fishing is often non-selective with few fish thrown back and undersized fish are regularly caught. Methods utilised often result in damage to the reefs such as trampling, trawling of small nets and occasionally poison fishing.

Overall Gau's reefs are relatively healthy. The implementation of the small marine reserves has involved the communities in the direct management of their marine resources. Frontier-Fiji's research has been designed to aid Gau's communities and partner organisations in the design and implementation of projects to protect and reduce pressures currently placed on the island's reefs.

2. INTRODUCTION

2.1 Status of reefs world wide

Coral reefs are incredibly diverse ecosystems that are second only to tropical rainforests in terms of productivity and complexity (Coral Reef Alliance 2007). Coral reefs 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 (Coral Reef Alliance 2007). These are particularly delicate ecosystems with a low tolerance to change; becoming stressed incredibly easily (Souter & Linden 2000). However with encroaching human populations and cyclical events such as El Nino, there are a great many pressures on coral reefs (Lindahl *et al* 2001). The most recent Status of the Coral Reefs of the World (Wilkinson 2004) stated that up to 20% of the world's coral reefs have been effectively destroyed in the last 20 years. These reefs show no immediate prospects of recovery. The World Resources Institute (WRI, 1998) suggested that as much as 60% of the world's reefs are threatened by human activity.

Coral reefs are found entirely within the tropics with many developing countries reliant upon the reefs for income and protein (Gomez 1997). In many coastal areas of developing countries, virtually all animal protein consumed comes from reef fisheries. Many of the countries reliant on coral reefs for food are expected to double in population within the next 30 to 50 years (McManus 1997), therefore placing even greater pressure on these reefs.

Coral reefs can provide additional economic input to nations through tourism (Souter & Linden 2000). The influx of the tourist dollar has caused more protective measures to be brought in as tourist activities can significantly contribute to national economies (Gomez 1997).

With increasing development of poorer nations within the tropics there is greater pressure placed on reefs (Russ & Alcala 1999). Pressures including increased coastal development and collecting fish and invertebrates for trade with developed countries are some of the major areas causing concern for reef conservationists (Dulvy *et al* 2004, Jennings *et al* 1999, Gomez 1997). These impacts are explained further in the following sections.

2.2 Coral bleaching

Scleratinian corals (reef forming corals) have a narrow tolerance range for water temperatures. Within the range of 25 - 29 °C corals are able to grow and reproduce (Brown & Ogden 1993), above this narrow range the coral becomes stressed and can result in bleaching (Hill *et al* 2005). Prolonged increases in water temperatures can result in permanent death of large areas of reef. The 1997/1998 El Nino Southern Oscillation was the most severe on record and affected coral reefs worldwide (Garpe *et al* 2006). The El Nino event of 1998 was estimated to have destroyed 16% of the world's reefs in 9 months (Wilkinson 2000).

The National Oceanic and Atmospheric Agency (NOAA) monitors sea surface temperatures, as research has shown strong links between sea temperatures and bleaching events. Their website serves to predict bleaching 'hotspots' where sea surface temperatures are sufficiently high that bleaching may occur. Hotspots, areas of elevated sea temperatures, are becoming more common with bleaching events expected to occur more frequently in future years (Hoegh-Guldberg 1999).

Fiji suffered a bleaching event in March-April 2000 with up to 80% of reefs effected, only those reefs in the far north were unaffected. There was also variable bleaching in 2001 and 2002. However, in 2002 these reefs were reported to be making a strong recovery with increasing densities of *Acropora* recruits at sites around Suva (Sulu *et al* 2003). The NOAA site monitored in Fiji is located in Beqa lagoon on the south coast of Viti Levu. During April 2006 temperatures were sufficiently high for Fiji to be placed on Level 1 alert (the second highest of alert levels).

2.3 Eutrophication

Corals require oligotrophic conditions (nutrient poor) with clear blue water to allow sufficient sunlight for the algae (zooxanthellae) within the tissues to produce sugars to fuel coral growth (McLaughlin, C. J. *et al* 2003). Influx of nutrients from agricultural run-off, pollution or untreated sewage can destroy reefs by upsetting the balanced relationship coral has with algae. This 'phase-shift' results in coral being outgrown by algae that competes with the coral for space and light (McManus & Polsenberg 2004). This shift can happen dramatically quickly and result in a sudden drop in productivity in the form of fish and invertebrate populations and result in failing fisheries. Fishery failure can have dramatic impacts on local human populations dependent on the reef for income and protein for consumption (Koop *et al* 2001). Areas downstream of well-defined point sources of nutrient influx are characterised by low coral diversity, low coral recruitment, high rates of partial mortality, reduced skeletal density, reduced depth distribution and high rates of bioerosion (Fabricus *et al* 2005). These effects can lead to hard coral dominated areas becoming dominated by non-reef building organisms, especially turfing and fleshy macroalgae.

Nutrient levels at several sites along the Coral Coast of Viti Levu, Fiji, have exceeded levels considered to be harmful to coral reef ecosystems (Mosley & Aalbersberg 2003). These elevated nutrient levels accompanied by over fishing of herbivore species have contributed to the recent widespread growth of macro-algae species along this coast, resulting in a shift of the coral-algal balance. Nutrient levels were highest at sites near hotels and other populated sites (Mosley & Aalbersberg 2003). At sites not significantly impacted by human activities levels of nutrients were comparable to that of non-polluted sites elsewhere in Fiji.

2.4 Sedimentation

In waters with very low sedimentation, coral is capable of growing at depths of up to 100m. Water clarity is directly linked to coral growth (Yentsch *et al* 2002). Sedimentation caused by coastal development, agricultural runoff and coastal erosion can damage reef health in a number of ways. Sedimentation swamps corals causing suffocation, reduces light levels in addition to preventing recruitment of new corals by smothering the rocky surfaces needed for settlement (McLaughlin *et al* 2003).

Only 16% of Fiji's land is suitable for agriculture with much of the land either water logged mangroves or too steep for agriculture (ESCAP 2007). Additionally, traditional farming methods utilise slash and burn resulting in high levels of sedimentation near population centres (Zann 1994). Increased coastal development along the coastline near Suva has led to one of the world's highest levels of Tributylyin (TBT) contamination (Naidu & Morrison 1994). Suva harbour has expanded dramatically in the last 20 years and as a result of poor waste disposal in addition to industrial development and port activity is heavily polluted with sediment and pollution (Naidu and Morrison 1994).

2.5 Destructive Fishing

Fishing methods such as blast fishing, poison fishing, reef pounding and reef trampling can have profound effects on coral reefs from over harvesting. Destruction and modification of the reef structure from these fishing methods can cause shifts in the reef fish assemblies. This shift can result in poor reef health, reduced hard coral and reef complexity plus reduced catches and diversity (McManus 1997).

Blast fishers hunt specifically for schooling reef fish so that only a few bombs will assure a relatively large catch (Pet-Soede, *et al* 1999). Generally clumps of corals are targeted, with mortality suffered within a 1-2m radius. Difficulties in locating dead fish among coral rubble can also lead to substantial waste (McManus 1997). Blast fishing is considered one of the most harmful anthropogenic threats to coral reefs. In addition to target species blast fishing removes commercially unattractive and inedible species of all sizes. This reduces the overall fish abundance and in addition the damage of the reef structure causes a coral-algal phase shift (Pet-Soede *et al* 1999).

Widespread use of cyanide as a method of fish capture has been prevalent in the Philippines and Indonesia. This use has caused concern as it is causing widespread reef degradation (Mous *et al* 2000). Laboratory experiments have shown that exposure to cyanide results in coral bleaching or death of the polyps (Jones & Steven 1997). Zann (1994), states that natural poisons such as *Derris* are commonly used in Fiji.

2.6 Over fishing

Over fishing or overexploitation of the reef resources can have a myriad of effects dependent on the animals targeted. Top down fishing of the large predatory fish from a reef fish community has a cascade effect resulting in a reduction of hard coral cover and colonisation by benthic algae (Dulvy *et al* 2004). Removal of key herbivores, such as urchins, can result in overgrowth of macroalgae due to the reduced herbivory. This shift in coral-algal abundance will in turn result in reduction of diversity and biomass of reef fish assemblages (McManus 1997).

Overexploitation of important predators can act to destabilise other populations of reef fish and therefore the reef community overall (Carr *et al* 2001). There is growing concern that artisanal fishing poses a threat to coral reef systems (Hawkins & Roberts 2004). Jennings & Polunin (1996) stated that removing 5% of fish biomass could significantly alter the structure of fish communities. This is because larger predatory species are preferentially targeted which keep community structures in check. In a study of artisanal fishing in Fiji (Jennings & Polunin 1997) the biomass of piscivorous fish differed significantly between *Qoliqoli* (fishing grounds). This was significantly correlated with fishing intensity. Artisanal fishing in the South Pacific is incredibly hard to monitor as it is comparatively non-target specific, carried out part-time and involves a multitude of landing points (Adams & Dalzell 1994). Zann (1994) in a study of Fiji's reefs found those reefs closest to major villages, towns and areas subject to commercial fishing are subject to heavy fishing pressure.

2.7 Live Fish Trade

Reef fish are collected live for both the aquarium trade and for the live fish food market in Asia. The US is the largest importer of coral reef fish species for food, jewellery and aquariums, with global trade increasing annually by 10-30% (Bruckner 2000). Up to 95% of exploited fish are directly collected from the coral environment with certain species, which are often rare with vulnerable life histories, reaching high prices. A number of methods are used such as hook and line, dynamite and cyanide fishing in order to collect prized species (Polunin & Graham 2006). Juveniles are increasingly targeted with spawning aggregations regularly targeted. This collection of wild fish has large mortality rates and has a negative impact on local reef fish communities reducing fish abundance and diversity.

The aquarium trade also involves the collection of 'live rocks', soft and hard coral (Bazilchuk 2006). The live rock trade has been expanding in Fiji for the last 10 years and it has since become one of the main producers of live rock in the world. Live-rocks are dead hard coral rubble with coralline algae and other attached marine life. Live rocks are prized by aquarium enthusiasts as they aid in maintaining the clarity of the water and improve the aesthetics. In 2001 Fiji exported about 800,000 kg of live rock. Live rock collection in some regions of Fiji has resulted in a degradation of the local reef communities, undermining of reef structure and underwater erosion (Keith-Reid 2006). Large amounts of rock is rejected by buyers and left on beaches as accumulating piles of waste. The Coral Coast is the main area of Fiji where this practise is carried out. A recent initiative within one of the coastal communities of the Coral Coast is however, reducing the collection of live rocks through cultivation of planted pumice stones (Bazilchuk 2006). These rocks are left to become populated by coralline algae and are used as a replacement for live rocks with no resultant destructive collection.

2.8 Coastal Management

Research into reef health has highlighted a number of areas that are causing a great deal of pressure to be placed on reefs that require monitoring and further research. A great deal of this research is being carried out in the South Pacific in countries such as Fiji (Zann 1994, Jennings & Polunin 1996, Graham *et al* 2005, Adams 1998). The South Pacific is generating a great deal of interest for coral reef conservationists due to the prevalence of the use of locally run management schemes often utilising traditional management methods (Zann 1999). Marine protected areas have been traditionally utilised to protect areas of threatened species and habitats (Botsford *et al* 2003), to protect areas of representative species and habitats (Hastings and Botsford 2003) to ensure they are not degraded by human activities, and to provide areas of relatively unaffected areas of high biodiversity and value to support the structure and functioning of the wider marine ecosystem DEFRA (2007).

The use of marine protected areas or no-take fishing zones has increased in popularity over the last three decades immensely although not every marine protected area has been a success. Unwillingness of local communities to comply with seeming ‘unfair’ legislation handed down by government has led in places such as the Philippines to a breakdown of the protected area. Those areas that involve the community from inception; involve the community in decisions and where education is provided have been shown to be far more successful (Russ & Alcala 1999).

Fiji is becoming a focus for conservationists looking at management methods that involve the community. The Locally Managed Marine Area network (LMMA) has taken management back to the community entirely with the setup of a network of reserves that are managed by the local community. These reserves are established with the help of partner research organisations to provide research expertise and knowledge in the form of training and workshops in the manner of adaptive management (LMMA).

Fiji is unusual in terms of marine resource management in that there are few legislated marine protected areas within Fiji. To date there are two legislated marine reserves in Fiji, the Great Astrolabe reserve of Kadavu and Shark Reef of Beqa lagoon. The Customary Marine Tenure Act, which was put before government prior to the 2006 military coup has largely negated the need for government legislated marine reserves. This act is based around 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 jurisdiction of the regions chief and the *mataqali*, a landowning group (Veitayaki *et al* 1995). This traditional method of management when supported by the Fijian government has been very successful in protecting the fishing stocks and even improving local fish stocks and reef health. The Makogai *Qoliqoli* with the support of the Minister responsible for fisheries refused to provide fishing permits for the region. This is not ratified by legislation but rather by traditional agreement and has been said by some to be Fiji's most effective marine conservation area (Adams & Dalzell 1994).

There is at present only one legislated marine reserve in the Beqa lagoon of Viti Levu. Shark Reef, established in 2004, is owned by the local communities Wainiyabia and Galoa who have relinquished their traditional fishing rights in return for a fee for every tourist visiting the marine reserve (Fiji-Sharks). Although very successful, this marine reserve has worked mainly due to the income generated by local dive operations, which takes tourists diving each day with the reefs large population of bull and reef sharks. Without an incentive such as the tourist dollar schemes such as this one are unlikely to work therefore other approaches are being tested in regions such as Gau's locally managed marine areas network (Veitayaki personal communication)

2.9 Integrated Coastal Management of Gau

Gau Island is situated 90km east of Fiji's capital Suva, and all the lagoonal waters come under the jurisdiction of the High Chief and the *mataqali*. As a result any fishing within the lagoon is illegal without a licence approved by the local ruling landowners and chief. Gau's chief allows no commercial fishing within its waters for non-residents of Gau (Paramount Chief personal communication). However there were concerns within the community and partner organisations such as the University of the South Pacific (USP), the International Ocean Institute – Pacific Islands (IOI-PI) and WWF-Fiji for the islands fish stocks and coral reef health (Veitayaki personal communication). These concerns are very much focused on the islands marine resources and their sustainability in terms of the fish and invertebrate stock.

Gau, with the support of partner organisations such as IOI-PI, USP and WWF-Fiji has become part of the Locally Managed Marine Area Network (LMMA) in Fiji (Veitayaki *et al* 1995). This initiative links a rich tradition of village management of ocean resources with modern methods of monitoring with the members of the community designing and implementing the management regime (LMMA). The success of this program in the Philippines led to the expansion across South-East Asia and the South Pacific.

Gau's island communities have embraced the LMMA with all of the islands 18 communities declaring at least one no-take zone (from interviews with regional leaders). Additionally an island council of elders and community members, the Lomani'Gau, was setup with the sole purpose of ensuring the protection of the islands marine resources. Despite this support there is concern amongst the islands partner organisations as there has been increasing pressure from those areas that have had the protected areas for over 2 years to reopen these areas to fishing (Veitayaki *pers comm*). The major concern for IOI-PI is that other than small-scale surveying carried out in 2 of the islands 18 regions, no research has been conducted on the health of the islands marine resources and the impacts current practices are having on these ecosystems is unknown. Additionally knowledge of marine ecosystems is largely based on anecdotal evidence with little or no knowledge of marine ecology and biology for management decisions to be based on.

Frontier-Fiji were requested to join these agencies to provide research the state of the coral reefs of Gau in order to provide the scientific basis to the management of the islands resources. The LMMA network is reliant on the help of outside organisations such as Frontier-Fiji to provide support, guidance, project design, monitoring, analysis and communication to communities in the adaptive management of their marine resources. A number of organisations are involved with the communities of Gau providing teaching in the form of workshops, resources for alternative sustainability projects. Examples of the type of projects these partner organisations have undertaken are shown in table 1.

Sustainability Projects	Source of funding	Community Improvement Projects	Source of training
Cattle farm in Malawai (money provided by the French to buy cattle).	France	Mangrove planting. *Rhizophora* seedlings planted near villages.	USP/IOI
Bee hive project in Navukailagi. Money and materials provided to create honey making business.	Fiji	Pigs removed from digging seagrass beds, mudflats and mangroves and placed in pens along the seafront.	USP/IOI
Giant clam reseeding and farming. Juvenile giant clams transported from Makogai & placed in cages on reef flats.	Fiji	Drains within villages cleared of rubbish & many paved to prevent clogging. Burial pits & burn pits created in many villages to prevent rubbish discarded into sea.	USP
Five fish aggregating devices constructed from local materials placed off a number of settlements (although not all have been utilised).	Japan	Seawalls constructed in some regions to prevent erosion & sedimentation. Some have used reclaimed rock from reefs however.	USP

Table 1: Summary of sustainability projects currently implemented by the Japanese International Cooperation Agency (JICA) and the University of South Pacific (USP).

This initial report is a result of the first 9 months of study of the islands reef resources in terms of health and impacts. This is in no way a comprehensive report of the island and as yet there are no full answers as the direction the islands communities should take in terms of management but is intended as a means of communication of the initial results and to highlight areas of future research which will help Frontier-Fiji and the communities of Gau to attain those goals.

3. METHODOLOGY

The baseline methodology used has been developed by Frontier-Tanzania and Frontier-Madagascar over 18 years of marine research. This survey was further adapted by Frontier-Fiji to survey the reefs of Gau (Frontier 2007).

Surveys were carried out within 11 of the 18 regions of the island. Survey locations were spaced at least 500m apart along the coastline with each location surveyed at four depths; 10-12m, 6-8m, reef crest and reef flat in order to obtain information on the full aspect of the reef slope. At each depth two consecutive 20m transects are completed. Each survey location is marked with a GPS in order for replications to be carried out at later dates. Every survey is conducted with the reef on the right to maintain consistency.

Surveys carried out at 10-12m and 6-8m use SCUBA whilst those carried out on the reef crest and flat are carried out using snorkel gear. For safety of divers from abrasion, snorkel surveys are only carried out from mid-rising to high tide.

Each transect requires 5 survey personnel trained within their specific area to a high standard. Survey teams are matched according to their air consumption rates to reduce the need to abort surveys. Average time to complete one transect is approximately 20 minutes however in complex areas with high levels of fish and hard coral coverage a single transect can take up to 45 minutes to complete.

3.1 Survey team members

Boat marshal: The first role of this surveyor is to act as a safety marshal for the team of surveyors. They keep track of the surveyors location using the surface marker buoys carried by the divers. Using dive flags they warn any passing boat traffic of the diver's presence. Time submerged for divers is kept to a maximum of 45 minutes which is monitored by the boat marshal, any overstay of this time will result in an alert being raised and rescue divers put on standby.

In addition to their role as safety marshal this surveyor is required to collect surface data. Information collected is surface water temperature, wind strength, wind direction, cloud cover, surface impacts and boat traffic.

Surface water temperature is measured in °C and collected using a recreational dive computer. Wind strength is on an arbitrary scale of 1-5. Wind direction is recorded as the direction the wind is coming from. Surface impacts recorded include any biological debris and litter floating on the surface near the survey location.

Physical diver: This diver controls the safety underwater in addition to the pace of the survey. They have overall responsibility of ensuring safe diving practices are adhered to making regular checks of diver's air, depth, dive-time and buddy pair locations. The physical diver carries a 50m fibreglass tape measure and a 6m length of ball bearing chain to record rugosity (English *et al* 1997). The second transect is also 20m long. At the end of the second transect the surveyor waits for the other three surveyors to finish unless dive time is low whereby the second transect is abandoned in order for divers to return within the 45 minute maximum dive time.

The physical surveyor collects data on temperature, depth, rugosity and visibility. Temperature is measured in °C using a dive computer as is depth. Rugosity is measured as the degree of complexity of the reef. A 6m ball bearing chain is laid along the tape measure, where due to its weight it follows the substrate completely. The point where the ball bearing chain stops on the tape measure is recorded. Rugosity is measured as distance covered by chain where the shorter the length, the more complex the reef substrate. Finally visibility is measured in metres on the horizontal scale. Table 2 shows at what point on the two transects the data is collected.

	Transect 1 Start	Transect 1 end	Transect 2 start	Transect 2 end
Depth	✓	✓	✓	✓
Temperature	✓		✓	
Visibility	✓		✓	
Rugosity		✓		✓

Table 2: Points on the transect where the physical diver collects data.

Fish surveyor: This surveyor acts as a buddy for the physical diver in addition to recording fish encountered in the transect area. The surveyor records all fish that enter into the transect area. The transect measures 20m in length reaching 5m wide and 5m high, with the total area surveyed measuring 100m^2. The species, abundance and size of each fish entering the transect area are recorded. Fish identified to species level are restricted to the following families; *Pomacentridae, Sphyraenidae, Chaetodontidae, Pomacanthidae, Lethrinidae, Caesonidae, Mullidae, Serranidae, Scombridae, Scaridae, Siganidae, Lutjanidae, Acanthuridae, Haemulidae, Carangidae, Balistidae, Labridae,* and from the subclass *Elasmobranchii*. Fish from other families and subclasses are ignored as they are either not typical reef dwellers (pelagic visitors), cryptic, nocturnal or have no commercial importance (Stewart & Beuchars 2000). The full species list of fish surveyed is shown in Appendix 1.

All fish surveyors are required to pass size estimation exercises to a high level of accuracy in order to collect this data (Harvey *et al* 2004). Fish surveyors are also tested regularly in order to maintain 90% identification accuracy.

In order to carry out a fish survey, 5m of visibility is required therefore if visibility drops below 5m the entire survey is aborted.

Substrate surveyor: This surveyor uses the Line Intercept Transect (LIT) method (English *et al* 1997). This involves recording the transitional change of substrate under the tape measure. The point where the substrate changes under the tape (the intercept) is recorded, to an accuracy of 1cm, plus the change in type of substrate. Benthic categories used are hard coral, soft coral, recently killed coral (RKC), rock, rubble, silt, sand, sponge, seagrass, algae and anemone. Hard corals are further identified to genus level with their growth form recorded as either: laminar, columnar, corymbose, branching, digitate, encrusting, massive, submassive, solitary or foliose (English *et al* 1997). Hard coral genera identified on Gau are listed in Appendix 2.

All surveyors are required to pass tests to identify both substrate type and hard coral genus to a minimum of 90% accuracy.

Algae & Invertebrate Surveyor: This surveyor acts as a buddy for the substrate surveyor. The transect area for this surveyor covers 2.5m to either side of the tape measure, a total area of $100m^2$. The surveyor traverses the transect in a zigzag fashion in order to record invertebrate abundance and algal cover (Solandt *et al* 2002). The surveyor looks in all crevices and overhangs in an attempt to record all invertebrates on each transect.

Invertebrate numbers per transect are recorded. Invertebrates recorded are; *Diadema* sp., *Tripneustes gratilla, Heterocentrotus* sp. *Acanthastar planci, Echinidae*, *Tridacna* sp., *Charonia tritonis*, anemones, Holothurians, *Stichopus chloronotus,* Crustacea, *Stenopus hispidus.*

Algal coverage is recorded on an arbitrary scale with guidance given as shown in table 3.

Scale	**Algal species cover**
1	One or two small patches of algae.
5	Larger patches found regularly in transect.
10	Almost entire transect carpeted by algae.

Table 3: Scale used to record algal coverage of transect.

A selection of species of algae is taught to surveyors with the remaining species encountered classified according to their form and colour. All macroalgae can be classified by one of three colours (red, brown and green) and by one of three forms (coralline, fleshy and filamentous). Algae identified to genus level are; *Halimeda* sp., T*urbinaria* sp., *Dictyosphaeria* sp. S*argassum* sp and seagrass.

3.2 Data Analysis

All data analysis was carried out using Excel and Minitab 15.

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

$$W = a.L^{b}$$

Where W = weight at the intercept, L = length of fish and b a published value specific to each species (Fishbase 2004).

Fish diversity for each of the transects was calculated using the Shanon-Weiner diversity index. The following equation was used with biomass of each species encountered on each transect for *pi*.

$$H' = -Sp_i \ln p_i$$

Where *pi* (the proportional abundance of the *i*th species) = $\frac{ni}{N}$

One-way ANOVA was used to test for differences between samples. A Tukey's pairwise comparison between each region was used to give a comparison between each individual region and every other region, thereby providing the significances for every site against the others.

Pearsons correlation analysis was used to test for relationships between two variables and if a significant relationship was found a regression analysis was then carried out to observe the strength and direction of relationship.

3.3 Survey location

The island has been divided into regions for purposes of data analysis and site description a map of which is shown in figure 1 and table 4 details each regions characteristics. Each populated region is presided over by a ruling chief in addition to land owning groups therefore decisions regarding land use and protection of marine resources is reliant on informed decisions made by these groups.

Figure 1: Map of Gau showing the fringing, barrier and patch reef systems (S 18 00' 86.4" E 179 10' 52.3" – base camp location)

Region	No. of transects completed	No. of MPAs	Period of time protected	Habitat types present	Impacts	Fishing methods used	Fishing
Vione (VIO) S 17º56 E 179º17 to E 179º18	6	1	3 years	Fringing reef Extensive mangroves Extensive seagrass beds	Wind and wave exposure	Handlines Spearfishing	Low
Qarani (QAR) S 17º56 E 179º17 to 16	10	1	6 months	Fringing reef Mud flats Seagrass beds	Sedimentation Agricultural runoff Heavy boat traffic	Handlines Spearfishing	Low
Sawaieke (SWK) S 17º575 to 17º595 E 179º145 to 179º16	8	1	2 years	Fringing reef Barrier reef Patch reef Mangroves Seagrass beds Mud flats	Sedimentation Agricultural runoff Boat traffic	Handlines Spearfishing	Medium
Somosomo (SOM) S 17º595 - 18º00 E179º16 to 179º14	26	1	2 years	Fringin g reef Barrier reef Mangroves Seagrass beds	Agricultural runoff Free roaming pigs Boat traffic	Handlines Gillnets	High
Nukuyaweni (NYK) S 18º00 to 18º02 E 179º16 to 179º14	46	1	1 year	Fringing reef Barrier reef Small seagrass beds	Some agricultural runoff	Handlines Spearfishing Gillnets	Low
Naviavia (NVV) S 18º02 to 18º025 E 179º14 to 179º15	58	0	N/a	Fringing reef Small mangrove Seagrass beds	Wind and wave exposure Sedimentation	Handlines Spearfishing	Low
Nawaikama (NWK) S 18º025 to 18º03 E 179º15 to 179º16	18	2	6 years and 2 years	Fringing reef Barrier reef Mangrove Seagrass beds Mud flats	Heavy sedimentation Agricultural runoff Free roaming pigs Gravel extraction Large boat traffic	Gleaning Seine nets Spearfishing Handlines	High
Nukuloa (NUK) S 18º03 to 18º03 E 179º16 to 179º18	6	1	6 months	Fringing reef Barrier reef Mud flats	High wind and wave exposure Heavy sedimentation Agricultural runoff	Handlines Spearfishing	Low
Lovu (LOV) S 18º06 E 179º19 to 179º205	13	2	3 years and 2 years	Fringing reef Barrier reef Extensive seagrass beds	Heavy sedimentation High wind and wave exposure	Spearfishing Handlines Gleaning	Medium
Vadravadra (VVD) S 18º06 to 18º055 E 179º205 to 179º22	10	1	1 year	Fringing reef Seagrass beds	Wind and wave exposure	Spearfishing Handlines	Low
Yadua (YAD) S 18º055 to 18º035 E 179º22 to 179º21	6	1	1 year	Fringing reef Seagrass beds	Wind and wave exposure	Spearfishing	Low

Table 4: Survey areas described region by region in order of longitude.

4. RESULTS

4.2 Fish Abundance

Fish abundance on surveys was calculated by converting species abundances into biomass (kg). Figure 2 shows the mean biomass of fish surveyed per transect over the four depths surveyed. Yadua had the highest biomass per transect in total and in range.

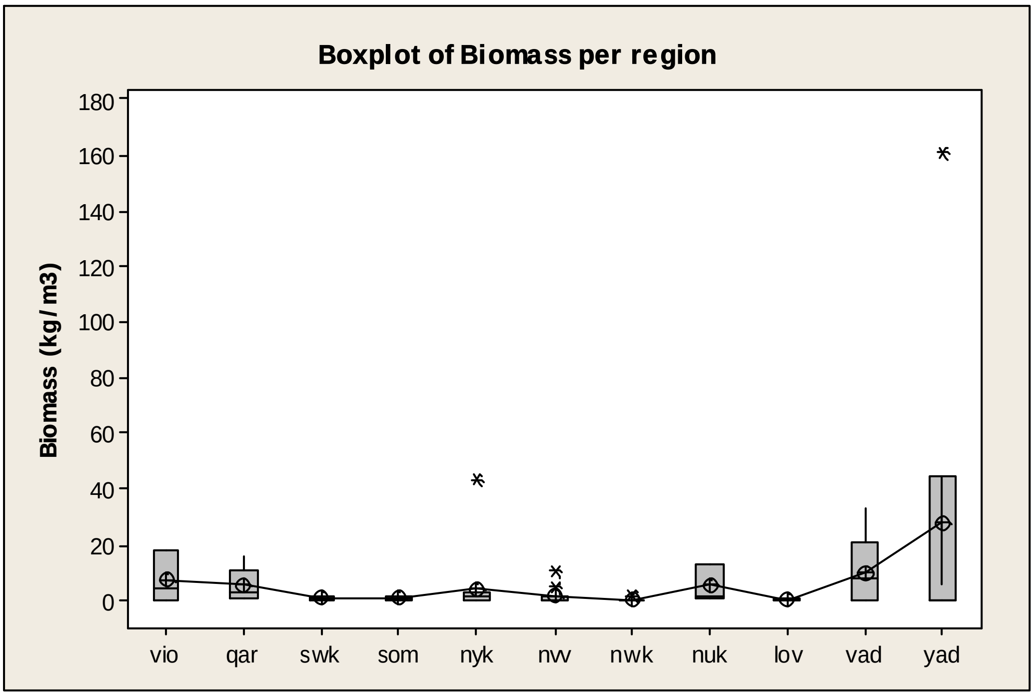

Figure 2: Boxplot of biomass of surveyed fish per transect for each region in kg/m^3

There was a significant difference between sites of biomass of fish ($p<0.001$). Further post-hoc analysis using pairwise comparisons for each region (table 5) shows Vione and Qarani to be significantly different to 4 other regions. A Pearsons correlation analysis showed there to be a significant relationship between biomass and depth ($p=0.03$) and a further regression analysis showed this to be a positive relationship whereby biomass increased with depth.

	VIO	QAR	SWK	SOM	NYK	NVV	NWK	NUK	LOV	VAD	YAD
VIO	-	NS	NS	0.035	NS	0.009	0.043	NS	0.048	NS	NS
QAR	-	-	NS	0.036	NS	0.017	0.034	NS	0.04	NS	NS
SWK	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS
SOM	-	-	-	-	NS	NS	NS	0.046	NS	0.05	NS

NYK	-	-	-	-	-	NS	NS	NS	NS	NS	NS
NVV	-	-	-	-	-	-	NS	0.037	NS	0.006	0.049
NWK	-	-	-	-	-	-	-	0.044	NS	NS	NS
NUK	-	-	-	-	-	-	-	-	NS	NS	NS
LOV	-	-	-	-	-	-	-	-	-	NS	NS
VAD	-	-	-	-	-	-	-	-	-	-	NS
YAD	-	-	-	-	-	-	-	-	-	-	-

Table 5: Post hoc analysis matrix of fish biomass per region

4.2 Fish biodiversity

Biodiversity of fish was calculated using the Shanon-Weiner (H') formula. A natural population would be expected to fall between 1.5-3.5 H'. Figure 3 shows a boxplot of fish biodiversity per region. Biodiversity ranged from 0.43 H' to 2.75 H' so there are some sites with very low biodiversity.

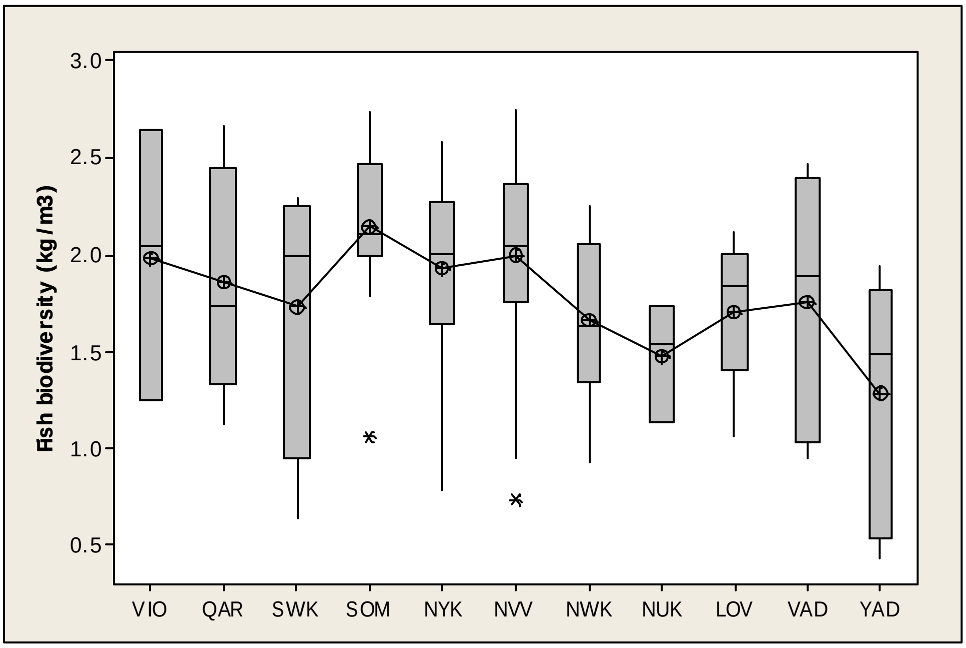

Figure 3: Boxplot of fish biodiversity per region in order of longitude.

An ANOVA of biodiversity between sites showed a significant difference (p<0.01). Further post-hoc analysis of the regions using pair-wise comparisons (table 6) showed Somosomo to be the most distinct on the island for fish biodiversity per transect. There was no significant relationship between fish biodiversity and depth (Pearsons correlation analysis, p>0.05).

	Vione	Qarani	Sawaieke	Somosomo	Nukuyaweni	Naviavia	Nawaikama	Nukuloa	Lovu	Vadravadra	Yadua
Vione	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Qarani	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sawaieke	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS
Somosomo	-	-	-	-	NS	NS	0.016	0.022	0.033	NS	0.002
Nukuyaweni	-	-	-	-	-	NS	NS	NS	NS	NS	0.008
Naviavia	-	-	-	-	-	-	0.048	0.05	NS	NS	0.002
Nawaikama	-	-	-	-	-	-	-	NS	NS	NS	NS
Nukuloa	-	-	-	-	-	-	-	-	NS	NS	NS
Lovu	-	-	-	-	-	-	-	-	-	NS	NS
Vadravadra	-	-	-	-	-	-	-	-	-	-	NS
Yadua	-	-	-	-	-	-	-	-	-	-	-

Table 6: Pair-wise comparisons of regions biodiversity (H')

4.3 Trophic group abundance

All fish species surveyed were assigned to one of six trophic groups; planktivore, piscivores, invertivore, herbivore, detritivore, corallivore. This was done using FishBase (2004) using published food items and assigned trophic levels. Figure 4 shows the total biomass of each trophic group as a percentage of the total biomass of fish surveyed. Herbivorous fish feature heavily in Vione, Nawaikama and Lovu. Coralivores such as butterfly fish can be used as indicator species of high levels of hard coral. Whilst coralivores did not form a large composite of most of the regions areas such as Somosomo and Naviavia had larger percentages of coralivores than regions such as Yadua and Nukuloa. Piscivores are generally apex animals and therefore fewer in number but larger in size. Regions such as Vione, Qarani,Vadravadra and Yadua have large biomass of piscivores generally from sightings of small numbers of large piscivores. On one transect only 3 piscivores were sighted out of a total 45 but these fish were over 2m in length therefore contributing largely in percentage of biomass.

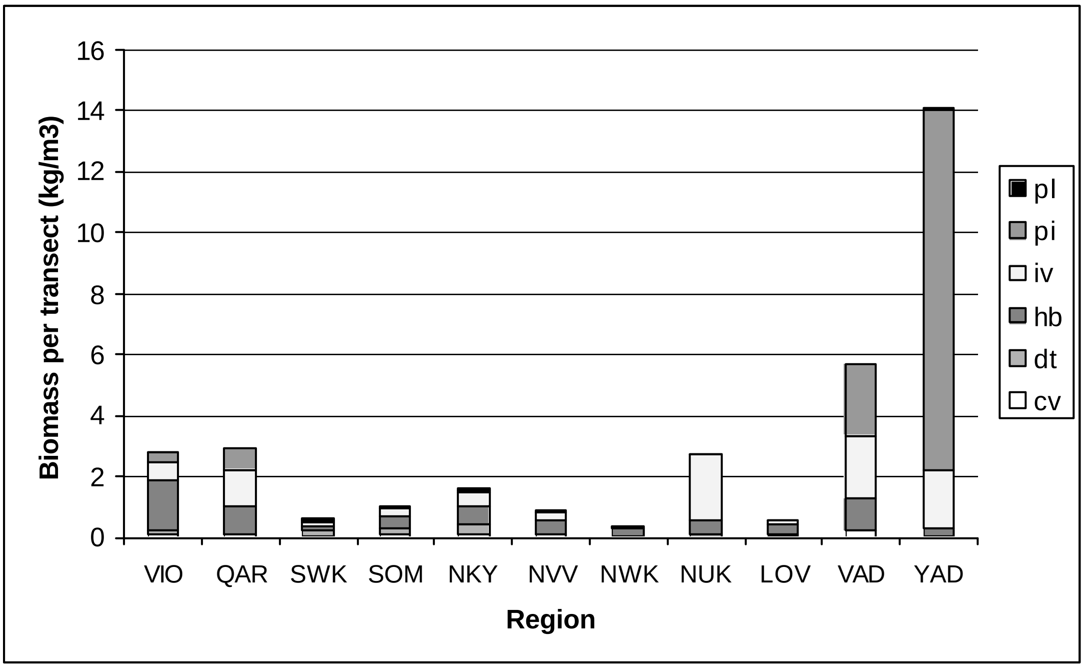

Figure 4: Stacked column of biomass for each trophic group (pl - planktivore, pi - piscivore, iv - invertivore, hb - herbivore, dt - detritivore, cv - corallivore).

4.4 Substrate cover

The results of the LIT transects were converted to percentage cover for each substrate type surveyed; hard coral, soft coral, algae, anemone, rock, rubble, sand, silt, recently killed coral (RKC). Figure 5 shows per region the mean substrate cover for each type.

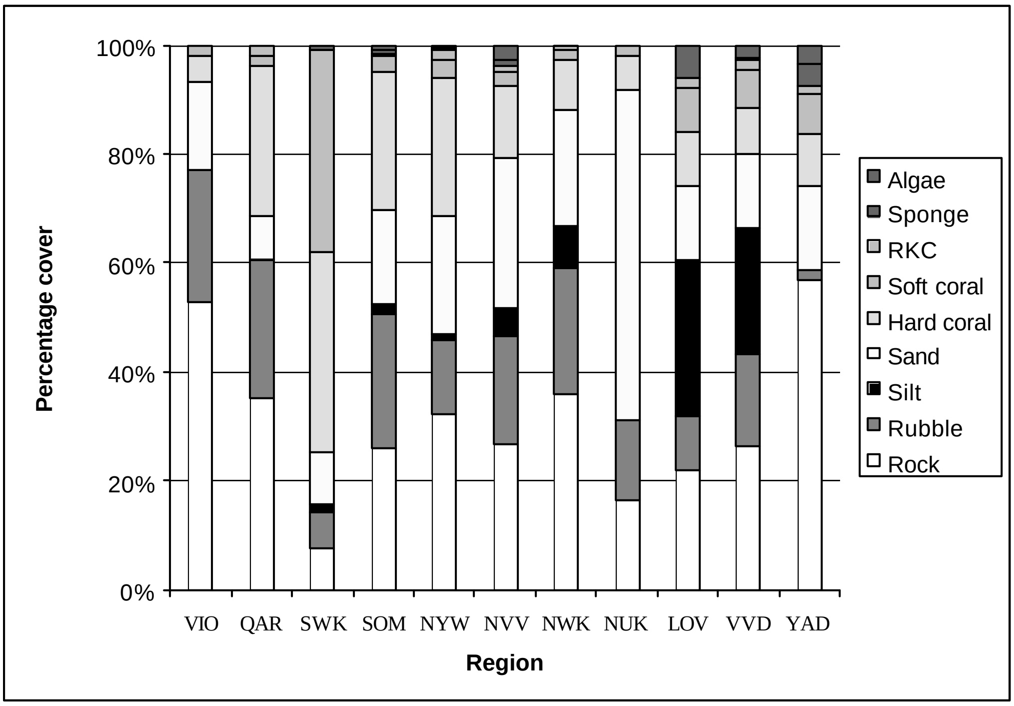

Figure 5: Stacked column of mean substrate cover per region.

4.5 Hard coral cover

Hard coral cover for each transect was converted to percentage cover of the 20m transect. Figure 6 shows the mean hard coral percentage cover for each region. Hard coral cover was higher in the mid regions of the island with the lowest found in Vione.

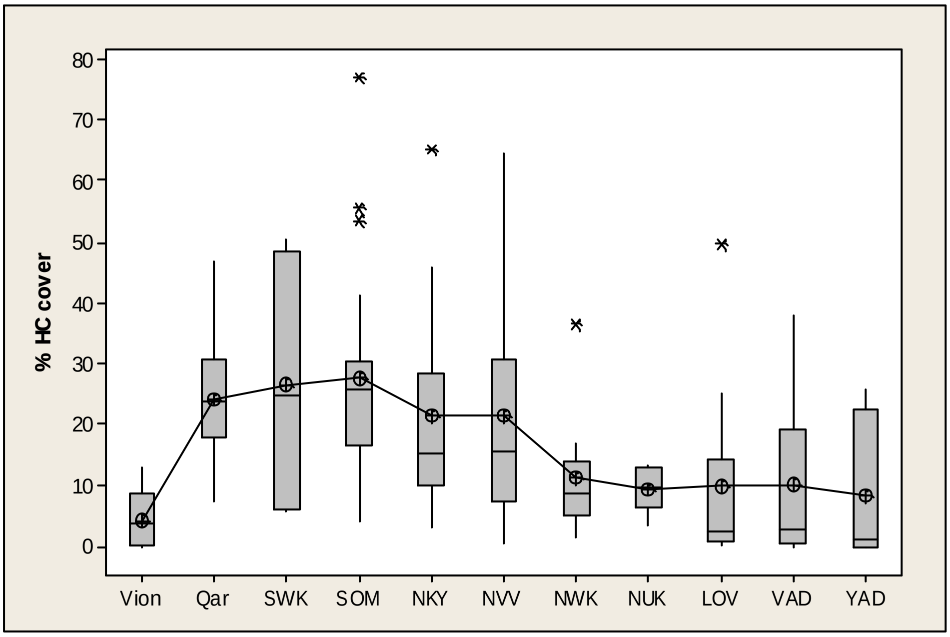

Figure 6: Boxplot of hard coral percentage cover per region in order of longitude.

An ANOVA showed there to be a significant difference between regions ($p<0.01$). Further post-hoc analysis was carried out using pair-wise comparisons. Table 7 shows a matrix with the results of the pair-wise comparisons. Vione, Qarani, Somosomo, Lovu and Yadua are each significantly different to four or more other regions.

	Vione	Qarani	Sawaieke	Somosomo	Nukuyaweni	Naviavia	Nawaikama	Nukuloa	Lovu	Vadravadra	Yadua
Vione	-	0.003	0.07	0.007	0.022	0.038	NS	NS	NS	NS	NS
Qarani	-	-	NS	NS	NS	NS	0.013	0.009	0.009	0.019	0.007
Sawaieke	-	-	-	NS	NS	NS	NS	NS	NS	NS	NS
Somosomo	-	-	-	-	NS	NS	0.01	0.018	0.002	0.011	0.005
Nukuyaweni	-	-	-	-	-	NS	NS	NS	0.024	NS	0.029
Naviavia	-	-	-	-	-	-	NS	NS	0.027	NS	0.041
Nawaikama	-	-	-	-	-	-	-	NS	NS	NS	NS
Nukuloa	-	-	-	-	-	-	-	-	NS	NS	NS
Lovu	-	-	-	-	-	-	-	-	-	NS	NS
Vadravadra	-	-	-	-	-	-	-	-	-	-	NS
Yadua	-	-	-	-	-	-	-	-	-	-	-

Table 7: Pair-wise comparisons of regions according to their hard coral coverage in a matrix.

Hard coral diversity was counted simply as the number of hard coral genera found per transect. Shanon-Weiner biodiversity was impossible to calculate for hard coral due to the lack of species identification. There are over 4000 species of coral and often differences involved microscopic. Due to the use of semi-skilled volunteers, identification was kept to genus level. Genus richness ranged from 1 genus per transect to 13 genera per transect in Nawaikama.

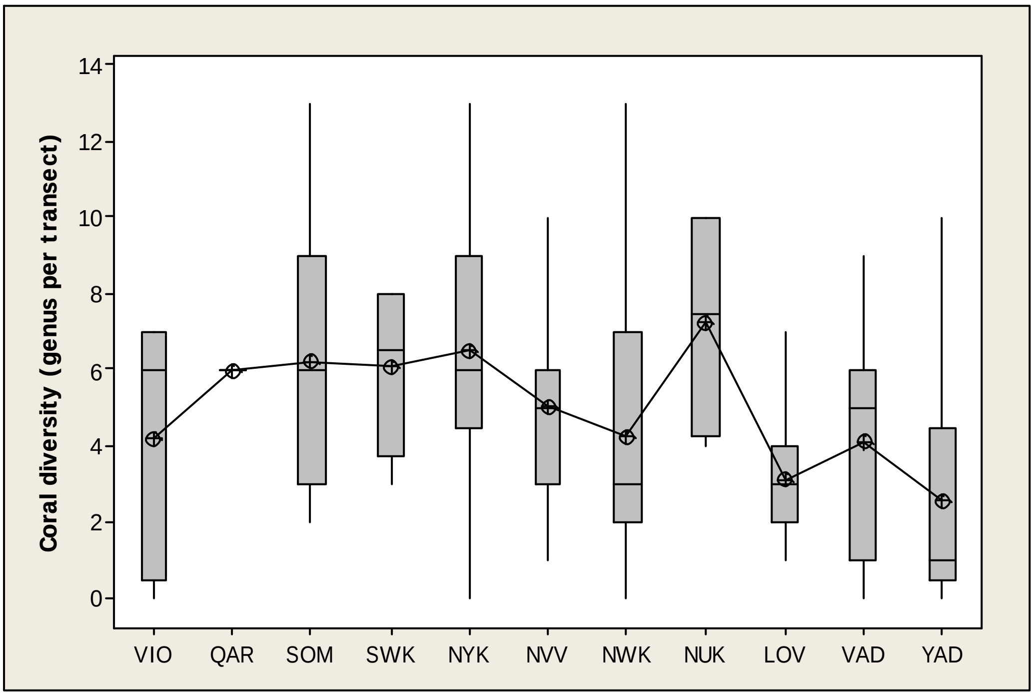

Figure 7: Boxplot of coral diversity per region.

An ANOVA showed there to be significant difference in genus richness per region ($p<0.01$). Further post-hoc analysis of coral diversity in the form of pairwise comparisons is shown in table 8. Lovu was significantly different to 4 other regions as was Yadua.

	Vione	Qarani	Sawaieke	Somosomo	Nukuyaweni	Naviavia	Nawaikama	Nukuloa	Lovu	Vadravadra	Yadua
Vione	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Qarani	-	-	NS	NS	NS	NS	NS	NS	0.058	NS	NS
Sawaieke	-	-	-	NS	NS	NS	NS	NS	0.001	NS	0.015
Somosomo	-	-	-	-	NS	NS	NS	NS	0.00	0.051	0.001
Nukuyaweni	-	-	-	-	-	NS	NS	NS	0.00	0.023	0.00
Naviavia	-	-	-	-	-	-	NS	NS	0.003	NS	0.005
Nawaikama	-	-	-	-	-	-	-	NS	NS	NS	NS
Nukuloa	-	-	-	-	-	-	-	-	0.004	NS	0.043
Lovu	-	-	-	-	-	-	-	-	-	NS	NS
Vadravadra	-	-	-	-	-	-	-	-	-	-	NS
Yadua	-	-	-	-	-	-	-	-	-	-	-

Table 8: Matrix of pair-wise comparisons as per coral diversity per region.

The number of colonies of hard coral was counted in order to view coral abundance as opposed to coverage. Number of colonies per transect ranged from 1 to 53. Figure 8 shows a boxplot of coral abundance over the 11 regions from north to south.

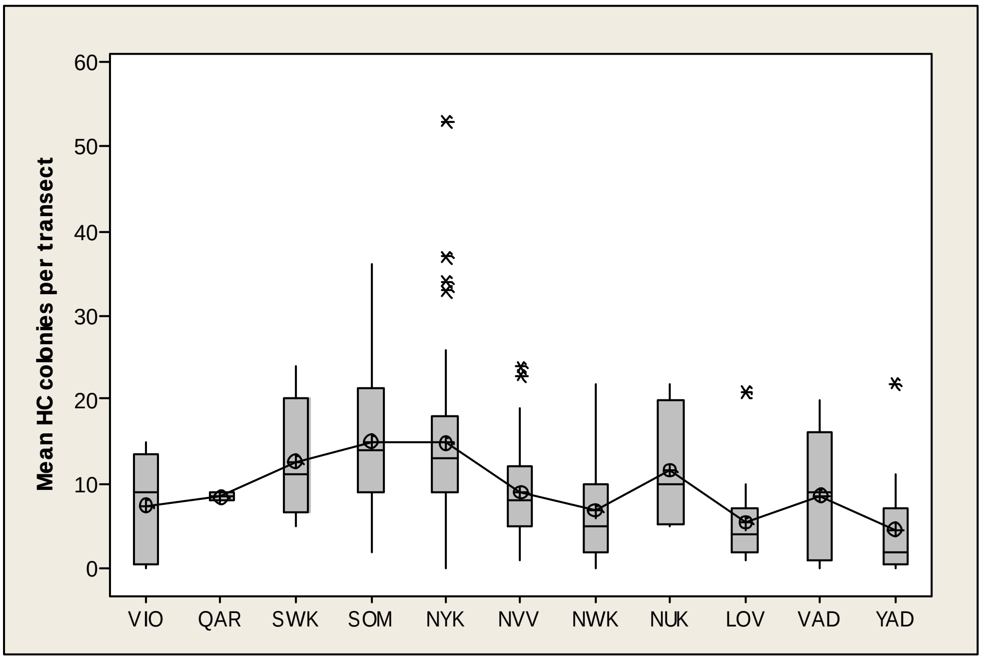

Figure 8: Boxplot of hard coral colonies per region in order of longitude.

An ANOVA showed there to be significant difference in number of colonies per transect between regions ($p<0.01$). Figure 8 shows a boxplot of the hard coral colonies per transect for each region.

4.6 Algal abundance

Algal cover was calculated using an arbitrary scale by trained observers. A scale of 1 to 10 was used to indicate abundance of algal growth across the transect area covering $100m^2$. Figure 9 shows in summary average algal cover per region of the areas surveyed.

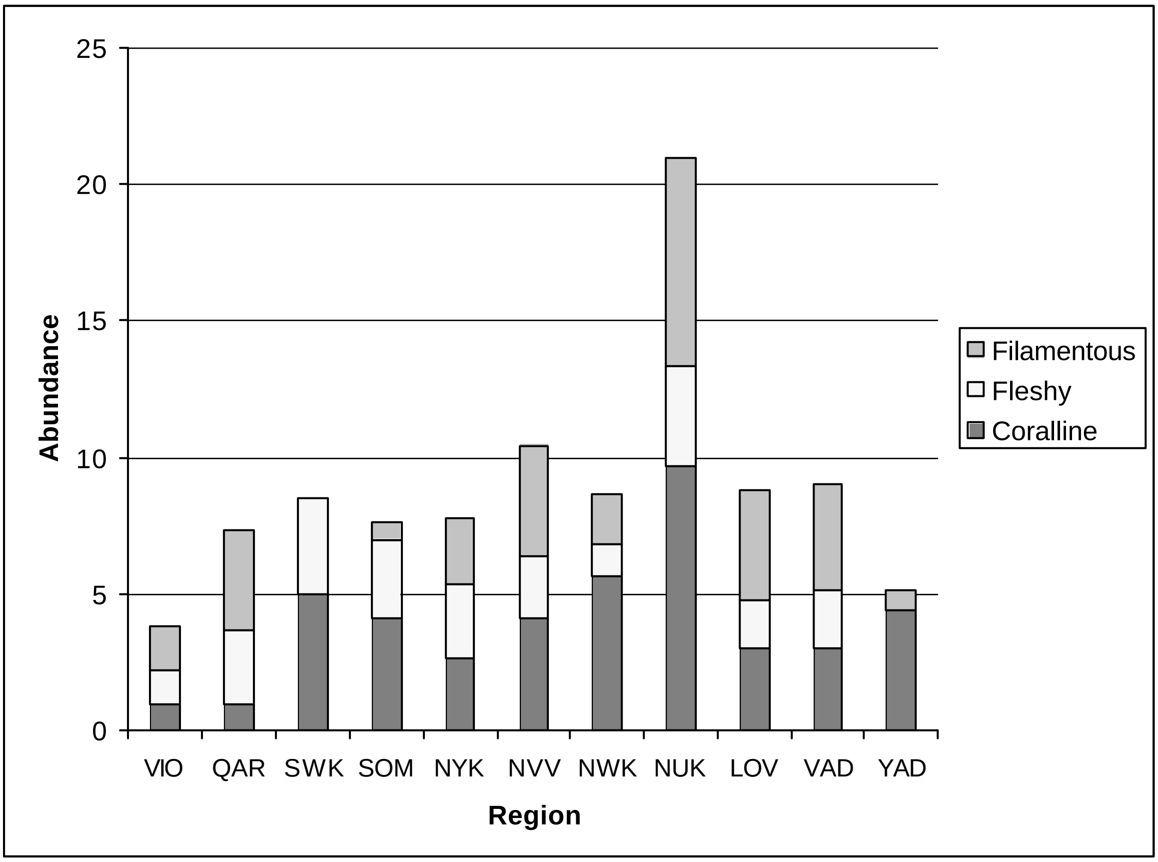

Figure 9: Stacked column graph of algal abundance across the regions in order of longitude.

An unstacked ANOVA was used to test for differences of algal abundance between regions for coralline, filamentous and fleshy. There was no significant difference in coralline or filamentous algae between regions (p>0.05) although there was a significant difference in abundances of fleshy algae between the regions (p=0.023). Further post-hoc analysis of abundances of fleshy algae used pairwise comparison. The results are shown in table 9.

	Qarani	Sawaieke	Somosomo	Nukuyaweni	Naviavia	Nawaikama	Nukuloa	Lovu	Vadravadra
Qarani	-	NS	0.05	NS	NS	NS	NS	NS	NS
Sawaieke	-	-	NS	NS	NS	NS	0.05	NS	0.05
Somosomo	-	-	-	NS	0.015	NS	0.001	0.002	0.04
Nukuyaweni	-	-	-	-	NS	NS	0.028	NS	NS
Naviavia	-	-	-	-	-	NS	NS	NS	NS
Nawaikama	-	-	-	-	-	-	0.027	NS	NS
Nukuloa	-	-	-	-	-	-	-	NS	NS
Lovu	-	-	-	-	-	-	-	-	NS
Vadravadra	-	-	-	-	-	-	-	-	-

Table 9: Post-hoc analysis of pair-wise comparisons of fleshy algae abundance between regions.

The potential that increased turbidity indicated increased nutrient influx to the water was investigated by testing for a relationship between visibility and fleshy algal coverage. A correlation analysis between fleshy algal abundance and visibility was carried out. There was no significant relationship (p>0.05).

4.7 Invertebrate Abundance

Key invertebrate abundances were measured by number of individuals encountered on a 100m^2 transect. Figure 10 shows in graphical form the average number encountered per region.

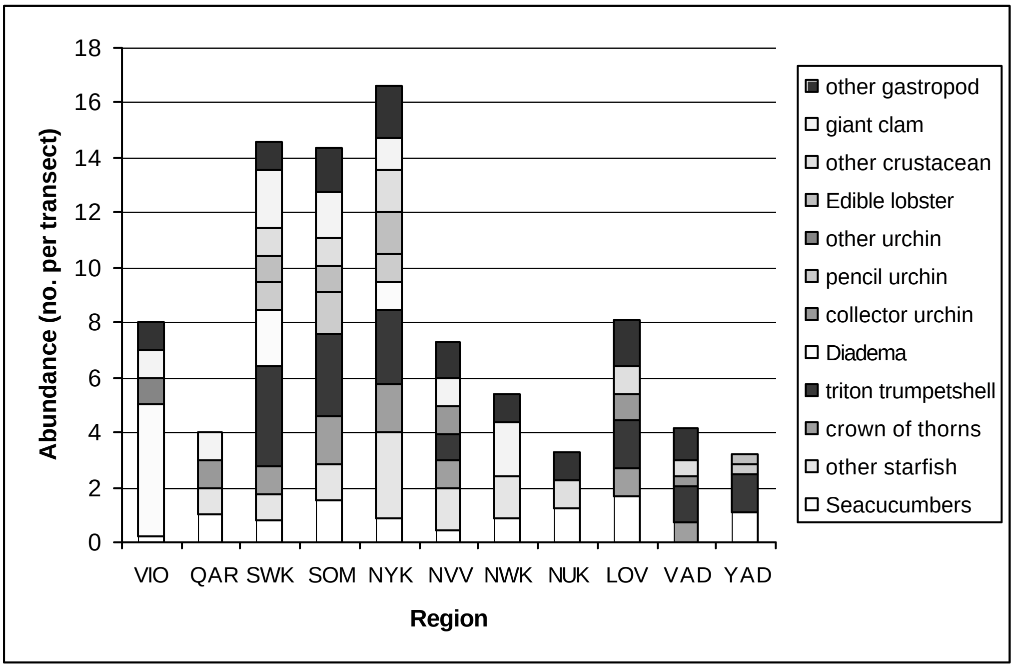

Figure 10: Key invertebrates surveyed shown in stacked columns.

Sea cucumbers were the only invertebrates encountered in every one of the regions surveyed. The southern and northern regions showed the least abundance for invertebrates, although it must be taken into consideration that these are the regions that have been surveyed least.

An unstacked ANOVA for each invertebrate group surveyed was carried out. Significant differences were found for number of diadema per region (p<0.00), number of collector urchin per region (p=0.001) and number of giant clams per region (p=0.028). Further post-hoc analysis used pairwise comparisons for Diadema abundance found Vione to be significantly different to Sawaieke (p=0.041), Nukuyaweni (p=0.005) and Naviavia (p<0.00), Qarani to be significantly different to Somosomo (p=0.031), Nukuyaweni (p=0.002) and

Naviavia ($p<0.00$). Post-hoc analysis for urchin abundance found Qarani to be significantly different to Nukuyaweni ($p=0.044$) and Naviavia ($p=0.007$).

4.8 Sedimentation

A Pearsons correlation analysis was carried out to test for a relationship between percentage hard coral cover and the level of sedimentation recorded as visibility. There was a significant relationship between visibility and percentage hard coral cover ($p=0.024$). A further regression analysis of this relationship showed this to be an inverted relationship ($HC=20.9 + 0.072\ xVis$, $p<0.01$) with areas with lower levels of visibility (higher sedimentation) having lower hard coral coverage.

A Pearsons correlation analysis was carried out to test for a relationship between rugosity and hard coral coverage. There was no significant relationship ($p>0.05$) between reef complexity and hard coral. Additionally there was no significant relationship between biodiversity of fish and rugosity ($p>0.05$).

4.9 Principal Component Analysis

As the data was continuous and normally distributed Principal Component Analysis was used to explore the degree to which the following variables explained the variance between site locations. 25% of the variance was explained by the location, 19.8% explained by the region, rugosity 15.1%, visibility 13.1% of the variation, hard coral 11.8%, fish biomass 8.7% and biodiversity 6.5% of the variation.

5. DISCUSSION

Principal component analysis showed after individual location the variance seen per transect was explained largely by the region. This variance between regions has been shown additionally through the significant differences between regions for fish biomass, fish diversity, coral coverage, coral diversity, algal diversity and invertebrate abundance. Each region surveyed is managed by a different community group. Each region often has very different physical characteristics and as such subject to differing levels of anthropogenic impacts. Therefore the analysis of the data collected by region is vindicated and each region shall be considered separate throughout.

Hard coral coverage was lowest in the most northern region, Vione, with the southerly regions also showing low hard coral coverage however these showed more variance between transects and locations. Those central regions of the island, Sawaieke to Naviavia showed the highest hard coral coverage and, with the exception of Naviavia, the highest coral diversity. Nukuloa has relatively low hard coral coverage although it has some of the highest levels of coral diversity for the island. Many surveyors reported seeing large numbers of small juvenile corals in this region. Nukuloa often has poor visibility and is very exposed to wind and wave action. There is little rocky substrate with large silt and sand patches that are unsuitable for coral settlement and recruitment. However the high number of juvenile corals and coral diversity suggests this area could be ripe for regeneration if further protection was afforded and sedimentation reduced.

The presence of the barrier reef and the resultant absorption of energy appears to be offering an amount of protection to the central regions from Sawaieke south to Naviavia as these areas had the highest levels of hard coral coverage, hard coral diversity, fish biodiversity and fish biomass (with the exception of Yadua). South of the peninsula from Nawaikama the regions are still surrounded by the barrier reef but have much lower hard coral coverage and fish biomass. The lagoon here is much larger, with the distance from the barrier greater with more exposure to large waves originating from the Lovu region. To reduce erosion from immediately in front of the villages both Nawaikama and Nukuloa have constructed concrete seawalls and therefore reduced coastal erosion from human traffic. Levuka, directly south of Nukuloa has started to build a seawall to prevent erosion & sedimentation. Unfortunately the rocks used to build this seawall have come from the reef and therefore may have caused more damaged than good in the construction.

The majority of human movement around Gau occurs by sea and therefore the seafront of villages, such as Levuka, suffer considerably from erosion caused by human traffic. The construction of seawalls such as those encouraged by IOI-PI will aid in reducing this erosion though the sources of these construction materials should be monitored.

5.1 Sedimentation

Hard coral coverage was directly linked to visibility levels and therefore sedimentation rates. Areas of poor visibility had lower levels of hard coral. A number of surveys were abandoned in regions such as Nawaikama and Nukuloa due to visibility levels dropping below the required 5m. In fact the northern section of the Nawaikama bay region has not been surveyed at all due to high sedimentation levels. 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 funnelling currents into the bay. The communities of Nawaikama, Nukuloa and Levuka are all situated at the foot of steep hills and are predominantly farming villages. Small subsistence farms are located on the steep hillsides above the villages. Traditional methods of farming on Gau include crop rotation and slash and burn. Whilst this is the traditional method for farming the area burnt often far exceeds that needed for planting. The burns are often uncontrolled and once started are left to run their course. At one point the hillside behind Frontier-Fiji's research station was subject to slash-and-burn, with an area over 1km^2 being burnt. The area subsequently planted only covered approximately 200m^2 (personal observation). Often the areas used for farming are unsuitable for farming due to poor soil, aspect and slope but due to problems of landownership often it is the only option available to farmers. Thus in some areas erosion of topsoil is evident with resultant habitats consisting of grass species with little or no forest cover.

Dredging of the Nawaikama reef flats by the Public Works Depot is having an additional impact on this area in terms of sedimentation. This dredging is to collect gravel to fill potholes on the islands singular road. There are few mangroves near the dredging site and the seagrass beds are small with low density (from Frontier-Fiji seagrass watch surveys). Little sediment can be trapped by these ecosystems to combat the effects of this dredging.

An initiative started by USP that has had moderate success on the west coast has involved planting mangrove seedlings. A series of workshops were delivered centred around the importance of mangroves and methods of increasing areas of mangrove through planting *Rhizophora* seedlings. These stands, first planted in 2003, are maturing, require no maintenance and are acting to help trap sediment.

A second initiative of USP and IOI-PI has been to try to reduce the damage caused by pigs to the shoreline especially the mudflats and mangroves to reduce sedimentation and loss of diversity. Previously pigs were left to roam free whereas following workshops detailing the damage these pigs can do, the local smallholders were encouraged to keep their pigs in pens. This has had varying success. The pens constructed are generally very small with poor workmanship therefore many pigs have broken free. Additionally some pigs have been released as the burden of feeding and keeping the animals has proven too much for the owner.

During the study period volcanic activity in Tonga resulted in large rafts of pumice stones across Fiji. These pumice stones were deposited throughout Gau's coastline covering the beaches. Initially the stones were relatively large floating on top of the water and therefore at times greatly reducing light levels below. Over a period of 3 months these stones were broken down further to smaller pebbles with some seen lower in the water column. It is possible these pumice stones could have had an impact on the hard coral cover from reduced light levels and increased sedimentation when the rocks break down further. The pumice stone rafts occurred near the end of this study period therefore impacts from this have not been seen in the results so far discussed. Secondly this is not a localised event so impacts would be hard to detect without extensive resurveying within regions.

5.2 Eutrophication

Algal growth and abundance was used as an indication of nutrient influx (eutrophication). Fleshy and filamentous algae when found in abundance are indicators of an unhealthy region. Fleshy and filamentous 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. Nukuloa showed far higher levels of algal abundance than any other region. Fleshy algae growth was significantly different between regions with Somosomo and Nukuloa the most distinct for algal growth. There was no correlation between visibility (and therefore sedimentation) and algal abundance. This suggests nutrient influx may not be directly linked to agricultural processes and coastal erosion. This is probably due to the limited use of fertilisers on Gau. Fertilisers are expensive and therefore often impractical for the small-scale largely sustainable farmers of Gau.

The island has no sewage treatment facilities. The traditional island toilet is a pit toilet that is covered over when full and left to decompose. With development and the construction of more modern homes there are an increasing number of flush toilets on Gau. The waste from these toilets is carried directly out to sea through waste pipes. It is not clear yet whether there are many outlet pipes or one pipe for all toilets per village but this influx of nutrients could well prove to increase nutrients near population centres. Highly populated regions with more flush toilets per head may experience higher algal abundances especially regions such as Nawaikama where currents tend to accumulate all run off in a small area.

5.3 Fishing Impacts

There is no large-scale commercial fishing permitted within Gau's lagoon waters which under the rules of *Qoliqoli* are ruled by the paramount chief and land owning group the *Mataqali.* Ships from Suva fish the outer reef slopes of the barrier reef at night. Whilst this is perfectly legal, local feeling is antagonistic towards this practise as they feel these large ships are stealing the fish. There are a small number of small-scale commercial fisheries operating within Gau's coastal waters that are owned and operated entirely by residents of Gau with the paramount chief's blessing. There are a couple of sea cucumber fisheries where the catch is dried in the sun and sold to a Chinese businessman from Suva. Sea cucumber catches generally attain $25 (Fiji) per kg (dry weight). Few fish caught are sold off the island in this manner as there are no facilities to keep catches on ice and transport links between Suva are unreliable and slow. Therefore most catches are sold between villages. Spear fishing occurs predominantly in the south with some use of SCUBA, although the equipment is often unsafe, as it has not been tested for many years. There is a peak in fishing activities on Saturdays in order to prepare for Sundays which are strictly observed as a day of rest on Gau, a predominantly Methodist island.

Fish abundance, diversity, trophic abundances, key invertebrate abundance and algal dominance can be used as indicators of reef fish over fishing. .

Low fish biodiversity and abundances are indicative of an overexploited reef population (Cooke *et al* 2000). The region of Somosomo showed strong biodiversity levels although biomass levels were lower, conversely Yadua showed the lowest levels of biodiversity of those surveyed with the highest levels of biomass and piscivores were predominant. This form of data should therefore not be completely relied on to predict areas of over fishing.

The abundance of trophic groups such as invertivores, piscivores and herbivores can be used as an additional indicator of over fishing. High levels of piscivores are indicative of predatory fish levels, which in targeted fisheries, such as artisanal fisheries, are the first to suffer from overexploitation. Piscivore abundance was high in Yadua, Vadravadra, Vione and Qarani suggesting high levels of predatory fish within the reef fish assemblages. However, not all these regions are enclosed by the barrier reef which may be acting to discourage roaming predatory fish such as sharks.

High levels of herbivorous fish suggest a shift in the algal abundance of a region and can indicate high levels of fishing. This is an indication that a shift has occurred in the balance between hard coral and macroalgal and suggests a proliferation in macroalgae. Herbivore levels were highest in Vione, Qarani and Vadravadra with very low levels in Yadua and Sawaieke suggesting over fishing in Vione, Qarani and Vadravadra.

A further indication of over fishing is a proliferation of macroalgae as a result of top down fishing, removing the predatory fish followed by the smaller commercially less important herbivorous fish which maintain macroalgae levels through grazing. Increased macroalgae can cause a quick shift in the hard coral cover of a region and in turn the structure of the reef fish assemblage such as reducing invertivores. Fleshy macroalgae was prolific in Nukuloa, Nawaikama, Sawaieke and Yadua although in regions such as Nukuloa and Nawaikama this is likely due to high levels of topsoil erosion and therefore eutrophication.

Invertebrate abundance and proliferation of indicatory invertebrates can additionally be used as indicators of over fishing. Low numbers of diadema urchins are indicative of over fishing. They are important grazers and a decline of these has led to a shift in many reef communities from stony coral abundance to macroalgal abundance. Diadema numbers were low in all regions except Vione, Sawaieke and Nukuyaweni.

Gleaning is common on Gau and is generally carried out by women and children on the reef flats. Spearfishermen often collect large invertebrates at depth with some invertebrates more prized than others. Giant clams are prized in Fiji for eating and their shells often used as decoration. Giant clam numbers were high Sawaieke and Nukuyaweni. Edible lobsters are highly prized trophies for spearfishermen however in islands such as Gau where exporting catches is difficult these are consumed entirely locally. Edible lobster populations are highest in Sawaieke, Somosomo, Nukuyaweni and Yadua. Crustaceans, other than the edible lobster, were high in numbers in Sawaieke, Somosomo, Nukuyawni and Lovu. Overall invertebrate numbers were highest in Sawaieke, Somosomo and Nukuyaweni suggesting low gleaning pressure in these regions.

Using fish biomass, biodiversity, algal cover, trophic group abundance and invertebrate abundance only Nukuloa and Nawaikama are areas that are of concern. These may be additionally impacted by poor land management practices causing low fish diversity and biomass levels. Overall invertebrate abundance was surprisingly low in some areas suggesting gleaning pressure is high. There is little or no commercial fishing on Gau and due to cost of fuel, therefore little fishing occurs from motor powered boats. Some regions such as Somosomo and Sawaieke use punts and traditional bamboo rafts '*billibilli*' to fish further than the village reefs. Some regions like Nawaikama fish mainly on foot on the reef flats near the village using seine nets and handlines.

Fish aggregation devices constructed out of natural materials such as palm fronds have been installed with the aid of JICA funding and IOI-PI. These have been a real success in regions such as Somosomo where catches at these devices have been reportedly large. In some regions though they have been largely ignored and as a result removed. At present this is still a pilot study with regular visits by the sponsor Professor Murai in order to collect information on catches.

Fishing is having an impact in some regions although this may well be restricted to small locales. Destructive fishing practices such as cyanide and dynamite fishing are not used although there are rumours of natural poisons made from tree bark, that are supposedly utilised when weather has been too poor to allow fishing. Generally fishing is indiscriminate with undersize or inedible fish rarely thrown back as these are either eaten or used for bait. Protected species such as turtles are regularly caught and in some regions are actively targeted. There is also evidence of nursery areas for slow breeding species such as reef sharks being targeted.

5.4 Management and use of MPAs

All of the islands communities have at least one MPA of varying size, period of protection and degree of protection given. The MPA's extend from the mean high tide line to the reef crest. Fishing is supposedly forbidden; although fishing was observed within MPA's at both Yadua and Vadravadra. Some regions have clearly marked the MPA's with buoys, some regions such as Somosomo, the distinction is less clear. Often conflicting answers were given to the location of the MPA, its size and length of time the areas had been protected. Often the MPA's are very small and of very poor quality in terms of the reef diversity.

The MPA's were established with the intention of improving fish stocks by providing a refuge and to allow recovery of local reefs through seeding of the protected area. Badly damaged areas with low diversity and abundance of hard coral may take more time to significantly improve fish stocks than those areas that are of good health that can provide refuge and food for larger numbers of fish. MPA location, size and degree of protection are an area for future research for Frontier-Fiji.

5.5 Natural Predators

Crown of thorns starfish are natural predators of hard coral and in small numbers are part of the natural cycle of coral death and growth on the reef. Blooms of crown of thorns have caused widespread damage on reefs such as the Great Barrier Reef. Six of the regions surveyed recorded crown of thorns in low numbers. Surveyors noted these were generally no larger than 10cm radius. There is no evidence of a crown of thorns bloom on Gau's reefs. The gastropod triton trumpet shells were recorded in all the regions where crown of thorns were recorded (except Qarani). . These are natural predators of crown of thorns and aid in keeping numbers down. High numbers of tritons can indicate presence of crown of thorns but numbers of tritons were similarly low. Unfortunately triton trumpet shells are regularly fished firstly as they are consumed and secondly as the shells are culturally significant in Fijian culture. The shells when hollowed out are used as calling horns to summon community members to events. Therefore on Gau's reefs these are probably poor indicators of high numbers of Crown of Thorns. Direct observations of crown of thorns were low or non existent in all regions surveyed.

5.6 Coral Bleaching

Fiji was warned of a coral bleaching hotspot by NOAA in April 2006 when water temperatures in Beqa lagoon were recorded above 30ºC; however, results of benthic surveys recorded little bleaching in this period. Recently killed coral was recorded in Qarani, Somosomo, Nukuyaweni, Naviavia, Lovu, Vadravadra and Yadua. In Qarani, Lovu, Vadravadra and Yadua this bleaching was recorded only on the shallow reef flats and generally on *Acropora* species.

During April and May bleaching was evident on the shallow reef flats with mainly *Acropora* species affected (personal observation). It is possible that either too few surveys were conducted during this period to reflect this bleaching or as the bleaching was only observed in the shallows the effect was diluted. The benthic surveys carried out were not in fixed locations. Surveyors returned to sites using a hand-held GPS accurate to 6m therefore when sites were resurveyed surveyors were unlikely to position the transect in exactly the same spot as previous surveys. Therefore small-scale recovery of corals from bleaching was impossible to measure. Frontier-Fiji have therefore setup permanent quadrat transects in order to track bleaching and recovery. *Acropora* species are the most vulnerable to coral bleaching and therefore these permanent quadrats have been situated in *Acropora* rich areas. Initial feelings are that there appears to have been good recovery from this bleaching with little long-term damage (personal observation).

6. SUMMARY

The purpose of this initial period of study was to find and highlight problems for the health of the islands marine resources specifically the fringing reefs of western Gau. Of the impacts faced by coral reefs in Fiji, sedimentation from poor land management is probably having the biggest impact on reef health. Large areas of clearance through slash and burn has caused extensive topsoil erosion in regions such as Nawaikama. There is little evidence of extensive over fishing most likely due to the paramount chief's refusal to allow large-scale commercial fishing. Due to limited use of motor boats for fishing there is likely to be higher levels of degradation near village and settlements. Destructive fishing practices such as dynamite and cyanide fishing are not habitually used on Gau although potentially there is small-scale use of traditional poisons after particularly poor fishing periods.

Eutrophication is evident in some regions such as Nukuloa, although with the increase of untreated sewage entering the water this may become a greater problem in future years with reefs closest to population centres being the most at risk.

Following the bleaching hotspot of April 2006 there was small-scale bleaching in some of the surveyed regions, though this was not as extensive as those bleaching events of 1998 and 2000.

The reefs of Gau are relatively healthy with few of the problems seen elsewhere in Fiji having reached this island. Much of the impacts facing Gau's reefs can be rectified through better land management, differing use of fishing practices and more integrated coastal management by the islands communities. The implementation of marine reserves is encouraging and the interest shown by all members of community means that the future of Gau's reefs are important to all levels of the community. There are many potential areas for future research that will aid in providing information to allow these communities to better protect their marine resources.

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APPENDIX 1

Fish species list

ANGELFISH

	bicolor angel	*Centropyge bicolor*
	blackspot angelfish	*Genicanthus melospilus*
	emperor angel	*pomacanthus imperator*
	lemonpeel angel	*Centropyge flavissimus*
	regal angel	*Pygoplites diacanthus*
	semi circle angelfish	*Pomacanthaus semicirculatus*
	two spined angelfish	*Centropyge bispinosus*

BARRACUDA

	great barracuda	*Sphyraena barracuda*
	yellowtail barracuda	*Sphyraena flavicauda*
	blackfin barracuda	*Sphyraena qenie*

BUTTERFLYFISH

	bennets butterflyfish	*Chaetodon benneti*
	big longnose butterflyfish	*Forcipiger longirostris*
	blackbacked butterflyfish	*Chaetodon melannotus*
	bluespot butterflyfish	*Chaetodon plebius*
	chevroned butterflyfish	*Chaetodon trifascialis*
	dot & dash butterflyfish	*Chaetodon pelewensis*
	dotted butterfly	*Chaetodon semeion*
	eastern triangle	*Chaetodon baronessa*
	humphead banner	*Heniochus varius*
	kleins	*Chaetodon kleinii (missing)*
	latticed	*Chaetodon rafflesi*
	lined	*Chaetodon lineolatus*
	longfin bannerfish	*Heniochus acuminatus*
	longnosed	*Forcipiger flavissimus*
	masked bannerfish	*Heniochus monoceros*
	mertens	*Chaetodon mertensii*
	ovalspot	*Chaetodon speculum*
	pacific dbl saddle	*Chaetodon ulietensis*
	penant bannerfish	*Heniochus chrysostomus*
	pyramid butterflyfish	*Hemitaurichthys polyepis*
	racoon	*Chaetodon lunula*
	Redfin Butterflyfish	*Chaetodon trifasciatus*
	reticulated butterflyfish	*Chaetodon reticulatus*
	saddleback butterflyfish	*Chaetodon falcula*
	saddled	*Chaetodon ephippium*
	singular bannerfish	*Heniochus singularis*
	speckled	*Chaetodon citrinellus*
	teardrop butterflyfish	*Chaetodon unimaculatus*
	threadfin butterflyfish	*Chaetodon auriga (missing)*
	Vagabond Butterflyfish	*Chaetodon vagabundus*

DAMSELFISH

ambon chromis	*Chromis amboinensis*
bengal sergeant	*Abudefduf bengalensis*
bicolor chromis	*Chromis margaritifer*
black axil chromis	*Chromis atripectoralis*
black damsel	*Neoglyphidodon melas*
blue devil	*Chrysiptera cyanea*
blackmargined damsel	*Pomacentrus nigrimarginatus*
bluegreen chromis	*Chromis viridis*
clark's anemonefish	*Amphiprion clarkii*
dusky anemonefish	*Amphiprion melanopus*
dusky gregory	*Stegastes nigricans*
golden damsel	*Amblyglyphidodon aureus*
grey demoiselle	*Chrysiptera glauca*
humbug dascylus	*Dascyllus aruanus*
indopacific sergeant	*Abudefduf vaigiensis*
jewel damsel	*Plectroglyphidodon lacrymatus*
johnston damsel	*Plectroglyphidodon johnstonianus*
onespot demoiselle	*Chrysiptera unimaculata*
pacific 1/2 + 1/2 chromis	*Chromis iomelas*
philipean damsel	*Pomacentrus philippinus*
pink anemonefish	*Amphiprion perideraion*
princess damsel	*Pomacentrus vaiuli*
reticulated dascylus	*Dascyllus reticulatus*
scissor tail sergeant	*Abudeduf sexfasciatus*
south seas devil	*Chrysiptera taupou*
speckled damsel	*Pomacentrus bankanensis*
staghorn damsel	*Amblyglyphidodon curacao*
surge demoiselle	*Chrysiptera leucopoma*
ternate chromis	*Chromis ternatensis*
threespot dascylus	*Dascyllus trimaculatus*
twospot demoiselle	*Chrysiptera biocellata*
webber's chromis	*Chromis weberi*
whiteband damsel	*Plectroglyphidodon leucozonus*
whitebar gregory	*Stegastes albifasciatus*
whitebelly damsel	*Amblyglyphidodon leucogaster*

EMPEROR

big eye emperor	*Monotaxis grandoculis*
blackspot emperor	*Lethrinus harak*
longface emperor	*Lethrinus olivaceus*
pink ear emperor	*Lethrinus lentjan*
spangled emperor	*Lethrinus nebulosus*

FUSILIER

yellowback fusilier	*Caesio teres*
lunar fusilier	*Caesio lunaris*
scissor tailed fusilier	*Caesio caerulaurea*

GOATFISH

	dash-dot goatfish	*Parupeneus barberinus*
	half and half goatfish	*Parupeneus barberinoides*
	indian goatfish	*Parupeneus indicus*
	Multibarred goatfish	*Parupeneus multifasciatus*
	sidespot goatfish	*Parapeneus pleurostigma*
	two-barred goatfish	*Parupeneus bifasciatus*
	whitelined goatfish	*Parupeneus ciliatus*
	yellow saddle goatfish	*Parupeneus cyclostomus*
	yellowfin goatfish	*Mulloidichthys vanicolensis*
	yellowstriped goatfish	*Mulloidichthys flavolineatus*

GROUPER

	flagtail grouper	*Cephalopholis urodeta*
	highfin grouper	*Epinephelus maculatus*
	honeycomb grouper	*Epinephelus merra*
	leopard coral grouper	*Plectropomus leopardus*
	Malabar grouper	*Epinephelus malabaricus*
	marbled grouper	*Epinephelus polyphekadion*
	Peacock Grouper	*Cephalopholis argus*
	saddleback coral grouper	*Plectropomus laevis*
	slender grouper	*Anyperodon leucogrammicus*
	specklefin grouper	*Epinephelus ongus*
	squaretail coral grouper	*Plectropomus areolatus*

MACKEREL

	spanish mackerel (Walu)	*Scomberomorus commerson*
	Striped mackerel	*Rastrelliger kanagurta*

PARROTFISH

	Bicolor Parrotfish	*Cetoscarus bicolor*
	bleekers parrotfish	*Chlorurus bleekeri*
	bridled parrotfish	*Scarus frenatus*
	Bullethead Parrotfish	*Scarus sordidus*
	bumphead parrotfish	*Bolbometopon muricatum*
	chameleon parrotfish	*Scarus chameleon*
	dark-capped parrot	*Scarus oviceps*
	greencap parrotfish	*Scarus spinus*
	pacific longnose parrotfish	*Hipposcarus longiceps*
	pacific steephed parrotfish	*Chlorurus microrhinos*
	schlegel's parrot	*Scarus schlegeli*
	stareye parrotfish	*Calotomus carolinus*
	swarthy parrotfish	*Scarus niger*
	yellowbarred parrotfish	*Scarus dimidiatus*

RABBITFISH

	dusky rabbitfish	*Siganus fuscencens*
	pencil streaked rabbitfish	*Siganus doliatus*

	scribbled rabbitfish	*Siganus spinus*
	stellate rabbitfish	*Siganus stellatus*
	Uspi rabbitfish	*Siganus uspi*
	vermiculate rabbitfish	*Siganus vermiculatus*
SHARKS		
	blacktip reef	*Carcharhinus melanopterus*
	grey reef	*Carcharhinus amblyrhinchus*
	whitetip reef	*Triaenodon obesus*
SNAPPER		
	black and white snapper	*Macolor macularis*
	black snapper	*Macolor niger*
	fivelined snapper	*Lutjanus quinquelineatus*
	flametail snapper	*Lutjanus fulvus*
	green jobfish	*Aprion virescens*
	half bar snapper	*Lutjanus semicinctus*
	onespot snapper	*Lutjanus monostigma*
	paddletail snapper	*Lutjanus gibbus*
	red snapper	*Lutjanus bohar*
	twospot banded snapper	*Lutjanus biguttatus*
SURGEONFISH		
	achilles tang	*Acanthurus achilles*
	blackstreak surgeonfish	*Acanthurus nigricauda*
	Bluespine Unicornfish	*Naso unicornis*
	Brushtail Tang	*Zebrasoma scopas*
	Convict Surgeonfish	*Acanthurus triostegus*
	Sailfin Tang	*Zebrasoma veliferum*
	dusky surgeonfish	*Acanthurus nigrofuscus*
	elongate surgeonfish	*Acanthurus mata*
	humpback unicornfish	*Naso brachycentron*
	mimic surgeonfish	*Acanthurus pyroferus*
	Moorish Idol	*Zanclus cornutus*
	orangeband surgeonfish	*Acanthurus olivaceus*
	orangespine uniconfish	*Naso lituratus*
	spotted unicornfish	*Naso brevirostris*
	striped bristletooth	*Ctenochaetus striatus*
	striped surgeonfish	*Acanthurus lineatus*
	whitespotted surgeonfish	*Acanthurus guttatus*
	yellow tang	*Zebrasoma flavescens*
SWEETLIPS		
	giant sweetlips	*Plectorhinchus albovittatus*
	harlequin sweetlips	*Plectorhinchus chaetodonoides*
	spotted sweetlips	*Plectorhinchus picus*
TREVALLY		
	bigeye trevally	*Caranx sexfasciatus*

bluefin trevally	*Caranx melampygus*
coachwhip trevally	*Carangoides oblongus*
Golden trevally	*Gnathanodon speciosus*

TRIGGERFISH

halfmoon triggerfish	*Sufflamen chrysopterus*
MoustacheTriggerfish	*Balistoides viridescens*
orangestriped triggerfish	*Balistapus undulatus*
Picasso Triggerfish	*Rhinecanthus aculeatus*
scythe triggerfish	*Sufflamen albicaudatus*
redtooth triggerfish	*Odonus niger*
pinktail triggerfish	*Melichthys vidua*
wedge picassofish	*Rhinecanthus rectangulus*
yellow margin triggerfish	*Pseudobalistes flavimarginatus*

WRASSE

axilspot hogfish	*Bodianus axillaris*
bandcheek wrasse	*Oxycheilinus diagrammus*
barred thicklip wrasse	*Hemigymnus fasciatus*
bicolor cleaner wrasse	*Labroides bicolor*
bird wrasse	*Gomphosus varius*
blackedge thicklip wrasse	*Hemigymnus melapterus*
blackfin hogfish	*Bodianus loxozonus*
bluestreak cleaner wrasse	*Labroides dimidiatus*
checkerboard wrasse	*Halichoeres hortulanus*
cigar wrasse	*Cheilio inermis*
clown coris	*Coris aygula*
crescent wrasse	*Thalasomma lunare*
diana's hogfish	*Bodianus diana*
dotted wrasse	*Cirrhilabrus punctatus*
humphead wrasse	*Cheilinus undulatus*
jansen's wrasse	*Thalassoma jansenii*
Jordan's tuskfish	*Choerodon jordani*
mesothorax hogfish	*Bodianus mesothorax*
nebulous wrasse	*Halichoeres nebulosus*
new guinea wrasse	*Anampses neoguinaicus*
pinstriped wrasse	*Halichoeres melanurus*
red shoulder wrasse	*Stethojulis bandanensis*
red-banded wrasse	*Cheilinus fasciatus*
rockmover wrasse	*Novaculichthys taeniourus*
sixbar wrasse	*Thalassoma hardwicke*
slingjaw wrasse	*Epibulus insidiator*
southern tubelip wrasse	*Labropsis australis*
sunset wrasse	*Thalassoma lunare*
threespot wrasse	*Halichoeres trimaculatus*
tubelip wrasse	*Labrichthys unilineatus*
tripletail wrasse	*Cheilinus trilobatus*
twotone wrasse	*Halichoeres prosopeion*
weedy surge wrasse	*Halichoeres margaritaceus*

yellowtail coris	*Coris gaimard*

APPENDIX 2

Hard coral genuses (genera) currently identified on Gau are:

Acropora
Astreopora
Anacropora
Coscinarea
Euphyllia
Diploastrea
Fungia
Favia
Favites
Goniopora
Goniastrea
Montipora
Montastrea
Alveopora
Pocillopora
Stylophora
Seriatopora
Platygyra
Symphylia (spelling)
Turbinaria
Tubastrea
Pavona