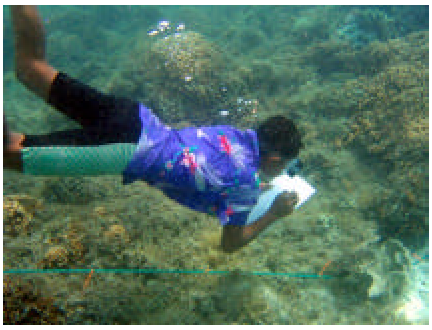
FIJI CORAL REEF CONSERVATION PROJECT

2ND ANNUAL REPORT



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CORAL CAY CONSERVATION Expeditions

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EXECUTIVE SUMMARY

- Much of Fiji's wealth is generated by its extensive marine resources, which provide, for example, protein based food from fishing and income from tourism. However, a suite of factors currently threatens the ecological balance and health of Fiji's reef ecosystems.

- Following on from the successful pilot project (MCRCP), stakeholders in the Mamanuca Islands invited CCC (CCC) to continue working in the region, leading to the implementation of a full CCC project entitled *'Fiji Coral Reef Conservation Project* (FCRCP). This report outlines the progress of the FCRCP over the first two year of operations (March 2002 – October 2004).

- Fieldwork during year two of the FCRCP has followed on from that in year one; focusing on gathering data from a number of allocated survey sectors over a wide range of geographical locations and habitat types using: baseline transects for habitat mapping and Reef Check surveys to assess reef health.

- One of the most significant developments in marine conservation initiatives in the Mamanuca Islands has been the formation of the Mamanuca Environment Society (MES) in March 2003. CCC have been working in close collaboration with the MES on community education and environmental awareness programs. CCC believe MES to be ideally suited to become the lead agency in implementing Marine Protected Areas recommended by CCC and continuing management initiatives in the Mamanucas. It is vital that environmental education goes hand in hand with the management programs for the Mamanucas so that awareness of its importance is known and clearly understood by all stakeholders in the region.

- Results from year two of the FCRCP showed a range of detrimental anthropogenic influences to be present in the Mamanuca Islands. In particular coral bleaching, sedimentation and the combination of nutrient elevation and over exploitation of marine resources are subjects that require attention in the region. Perhaps the most obvious of these impacts was the mass coral bleaching event, which occurred in early 2000, with a second smaller event in 2001. However Reef Check results of hard coral cover indicate that some recovery has taken place (see separate CCC report; Walker *et al.*, 2002).

- Survey progress in the Mamanucas has been rapid during year two of the FCRCP. A total of 1461 survey dives on 337 CCC Baseline transects have been completed. A satellite site established between June and October 2003 on Kadavu Lailai Island to the East of the Mamanucas allowed this area to be extensively surveyed. One key aim of the next year of the FCRCP is to survey the area of the Northern Mamanucas.

- This data is analysed using extensive and exhaustive techniques.

- The analysis methods involved are based initially around the definition of discreet habitats found in the coral reef system of the Mamanuca Islands.

- A habitat map outlining the zonation of the coral reef areas studies is presented and allows visualisation, quantification and analysis of the reef system.

- Developed during year one of the FCRCP, the technique of assigning Conservation Management Value Ratings to coral reef areas has been extended this year to produce a Geographic Information System density image of relative management importance. As a culmination of all data analysis techniques, recommendations for additional areas for establishment as Marine Protected Areas are made in this report.

- Research indicates that 20% of the reefs of an area should be 'no-take' in order to maximise the chances of sustaining the fisheries and given that the reefs delineated on the habitat map cover approximately 90 km^2, the eventual aim should be to protect 18km^2 of shallow (<30 m) benthic habitat within the Mamanuca Islands from fishing.

- In addition to the recommended areas for Marine Protected Area designation in year one, presented in this report are six more recommended sites.

- The areas recommended for protection are Sunflower, Nuku, Lau, Motuse, Namoa and Nukuwasiga. Together with those recommended in year one they comprise 11.38km^2 of coral reef habitats found in the Mamanucas. This is 65% of the total 18km^2 suggested for protection.

- Despite these areas being identified, the development of the Geographic Information System as an easily visually interpretable medium is aimed at allowing stakeholder input into the designation of Marine Protected Areas, whilst still retaining a scientific basis in the decision framework.

- A number of recommendations are made both for aims of CCC for the remaining duration of the FCRCP and also for the program of MPA implementation. These include;

Coral Cay Conservation

<u>Recommendation 1</u>- Continue Baseline and Reefcheck data collection in the Mamanucas

<u>Recommendation 2</u>- Expand the area of survey to the reefs and islands that comprise the Northern Mamanucas that are at present un-surveyed. It is an expectation that once surveyed, these areas will form an important and integral role in the Marine Protected Area network for the Mamanucas

<u>Recommendation 3</u>- Continue community capacity building activities in close collaboration with the Mamanuca Environment Society. These activities include school workshops, dive operator networks, resort and guest education initiatives and best practice guidelines. Of key importance here is the inclusion of all stakeholder groups in the Mamanucas.

<u>Recommendation 4</u>-Continue to develop and refine habitat definitions for the Mamanucas to derive a comprehensive breakdown of all reef types found in the area.

<u>Recommendation 5</u>-Develop more advanced Geographic Information Systems and habitat mapping techniques to aid in the efficient dissemination of data to all stakeholders

Recommendation 6- Act, if invited, in an advisory capacity to support the appointed lead agency in the process of Marine Protected Area implementation. To provide assistance in areas such as the development of a monitoring scheme and educational workshops aimed at the integration of MPAs.

Marine Protected Area Implementation

Recommendation 1- Coral Cay Conservation recommends that the Mamanuca Environment Society be invited to take lead role in the implementation of Marine Protected Areas

Recommendation 2- Act, if invited, in an advisory capacity to support the appointed lead agency in the process of Marine Protected Area implementation. To provide assistance in areas such as the development of a monitoring scheme and educational workshops aimed at the integration of MPAs.

Recommendation 3- Without delay, application be made to acquire a UN-GEF Medium Sized Grant with which to progress the implementation process

Recommendation 4- Support be sought from all levels of administration to forward the development of a legislative framework upon which to base MPA implementation

Recommendation 5- Sources of infrastructure support for MPAs be evaluated. Infrastructure needs to include patrol bases, offices and community education and environmental interpretation facilities

Recommendation 6- Specific and targeted workshops be conducted to inform all stakeholders of the importance of Marine Protected Areas and conservation

Recommendation 7- Data derived from Coral Cay Conservation's work and the recommendations are not definitive. Using techniques such as the GIS developed for this report, all stakeholders be invited to a consultation process to refine MPA location and function. Without consensus from all stakeholders, any Marine Protected Areas will fail to be successfully implemented

Recommendation 8- Studies be undertaken on the socio-economic and demographic factors that may affect successful MPA implementation. The findings of these studies enter both early on in defining suitable MPA sites as well as providing a feedback monitoring program to detail the success of implemented MPA programs

Recommendation 9- A monitoring program be established to identify changes in the coral reef communities of the Mamanucas as a result of the implementation of Marine Protected Areas

Recommendation 10- Any MPAs and management planning be dynamic enough to respond to feedback from both socio-economic and biological monitoring programs

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1. INTRODUCTION

Fiji is one of the wealthiest countries in the South Pacific, partly because of its extensive marine resources, which provide important services such as protein from fishing and income from tourism. The country is made up of approximately 844 volcanic islands and is dominated by the Viti Levu and Vanua Levu platforms which account for 87% of the total land area (Vuki *et al.*, 2000). Fiji has a moderate tropical climate and hence reefs are well developed around all of the islands.

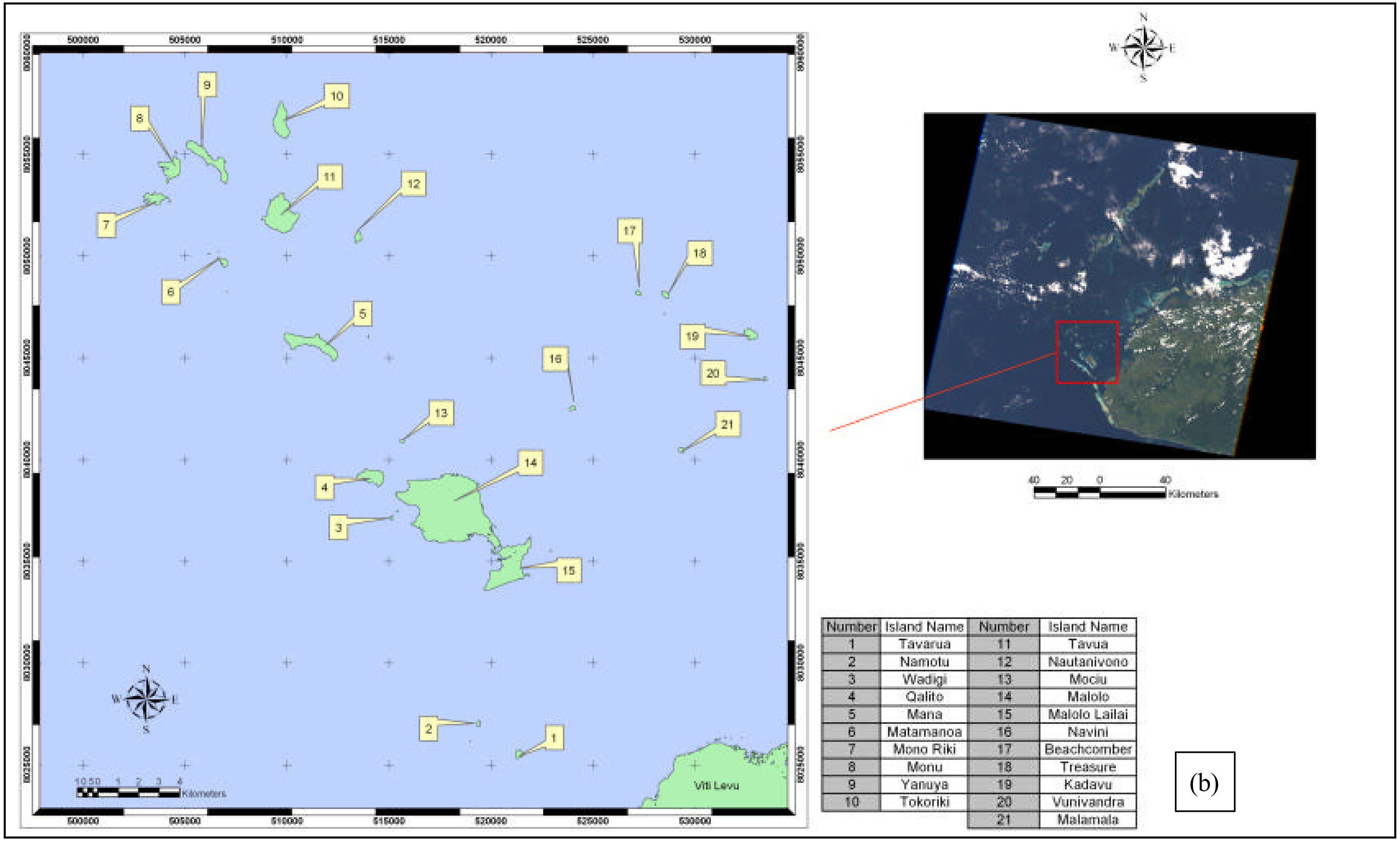
Although the tropical forests and coral reefs of Fiji are of vital importance, both ecologically and economically, they are threatened because of rapid economic and population growth. Fiji's natural forests are now under serious threat from land-use conversion activities such as logging and agricultural development (Spalding *et al*, 2001). Similarly, the countries' coral reef ecosystems are being adversely affected by a range of anthropogenic activities including over-fishing, destructive fishing, sedimentation, eutrophication and pollution, which has resulted in extensive loss of coral reefs and inducement of coral diseases. Recent coral bleaching events and storm damage have exacerbated these effects by acting synergistically to reduce reef health further. Such impacts represent substantial long- and short-term threats to the ecological balance and health of reef ecosystems which, if left unchecked, will ultimately lead to reduced income for coastal communities and other stakeholders relying on fishing and marine-based tourism.

Effective coastal zone management, including conservation of coral reefs, requires a holistic and multi-sectoral approach, which is often a highly technical and costly process and one that many developing countries cannot adequately afford. With appropriate training, non-scientifically trained, self-financing volunteer divers have been shown to be able to provide useful data for coastal zone management at little or no cost to the host country (Hunter and Maragos, 1992; Mumby *et al.*, 1995; Wells, 1995; Darwall and Dulvy, 1996; Erdmann *et al.*, 1997; Harding *et al.*, 2000; Harborne *et al.*, In press). This technique has been pioneered and successfully applied by Coral Cay Conservation (hereafter referred to in this report as CCC), a British not-for-profit organisation.

Founded in 1986, CCC is dedicated to '*providing resources to protect livelihoods and alleviate poverty through the protection, restoration and sustainable use of coral reefs and tropical forests*' in collaboration with government and non-governmental organisations within a host country. CCC does not charge the host country for the services it provides and is primarily self-financed through a pioneering volunteer participatory scheme whereby international volunteers are given the opportunity to join a phase of each project in return for a financial contribution towards the project costs. Upon arrival at a project site, volunteers undergo a training programme in marine life identification and underwater survey techniques, under the guidance of qualified project scientists, prior to assisting in the acquisition of data. Finances generated from the volunteer programme allow CCC to provide a range of services, including data acquisition, assimilation and synthesis, conservation education, technical skills training and other capacity building programmes. CCC is associated with the CCC Trust (the only British-based charity dedicated to protecting coral reefs) and the USA-based CCC Foundation.

The Mamanuca Islands in western Fiji (Figures 1 a and b) have been the focus of tourism development in Fiji for many years and the industry is very much aware of the value of conserving the coral reefs and fostering sustainable development. During 2000, CCC was invited to the Mamanuca Islands by local tourism operators, the Ministry of Tourism and Transport and the Fiji Visitors Bureau to determine the current status of the coral reefs and threats to their integrity and suggest possible conservation initiatives. Following two technical preparatory missions (December 2000 and March 2001), CCC and local Fijian counterparts decided to implement a three-month pilot project entitled '*Mamanuca Coral Reef Conservation Project – Fiji 2001*' (MCRCP).

Figure 1(a). The Fiji islands, showing the project area (dashed line) for the FCRCP. *Source*: Fiji Visitors Bureau.



Number	Island Name	Number	Island Name
1	Tavarua	11	Tavua
2	Namotu	12	Nautanivono
3	Wadigi	13	Mociu
4	Qalito	14	Malolo
5	Mana	15	Malolo Lailai
6	Matamanoa	16	Navini
7	Mono Riki	17	Beachcomber
8	Monu	18	Treasure
9	Yanuya	19	Kadavu
10	Tokoriki	20	Vunivandra
		21	Malamala

Figure 1 (b) Major islands within the Mamanucas

The pilot project, which ran from June 8th to August 30th 2001, aimed to demonstrate the longer-term role that CCC could play within the Mamanuca Islands and provide preliminary data on the marine resources of the area and their status. A comprehensive account of the pilot project (Harborne *et al*., 2001) is available from the CCC website and as hard copies on request from the CCC-UK office. The resounding success of the FCRCP led to the commencement of the full CCC project in the Mamanucas region, named the Fiji Coral Reef Conservation Project (FCRCP), in March 2002. A three-year Memorandum of Agreement was signed by CCC and The Ministry for Tourism (formerly the Ministry of Tourism and Transport) of Fiji in order to carry out a more comprehensive and detailed survey programme, whilst also expanding the environmental education and awareness work amongst the local communities of the Mamanucas Islands.

This report documents the results and conclusions of the second year of marine surveying of the FCRCP and offers recommendations for both conservation initiatives and future work in the project area in the coming year. A summary of the environmental community programme is also presented.

2. PROJECT BACKGROUND

2.1 The coastal zone of Fiji

The shallow coastal zone of Fiji is comprised of three major, interrelated habitat types: marine algae and seagrass; large areas of mangroves; and extensive coral reefs. The marine resources include approximately 1000 coral reefs with representatives of all major reef types (Vuki *et al*., 2000). Although marine biodiversity is lower than the 'coral triangle' of Indonesia, the Philippines, Papua New Guinea and northeastern Australia, Fiji does support approximately 200 species of coral (Veron, 2000). Furthermore it has been estimated that Fiji has approximately 1200 marine fish species (Vuki *et al*., 2000). Since taxonomic research in the country has been limited, further research will extend the known biodiversity of all marine taxa considerably.

Fiji's current population is approximately 775,000 and increasing rapidly (South and Skelton, 2000). Since much of this population is concentrated around the coast, the expanding development of coastal areas and exploitation of the reefs are resulting in a suite of threats to the coral reefs including siltation, eutrophication and pollution (Vuki *et al*., 2000). For example, some of the natural landscape has been converted for agriculture, particularly sugar cane, which impacts the coastal environment via soil erosion leading to elevated sediment loads smothering coral colonies. Further erosion is also caused by the removal of mangroves to re-claim land for urban development. Such expansion of urban areas has also led to pollution of the coastal zone because of inadequate sewage treatment and waste disposal. Industrial point sources have also been shown to contribute to decreasing water quality.
A recent study of nutrient levels along the Coral Coast of Viti Levu (Mosley and Aalbersberg, 2002) found that levels for nitrate and phosphate exceeded thresholds considered harmful to coral reef ecosystems. Furthermore nutrient levels were highest at sites located near hotels, other populated coastal locations and in rivers.

In addition to coastal development, fishing in Fiji, which occurs at both traditional subsistence and commercial scales, has significantly reduced the populations of many species. Although data are scarce, even traditional techniques, such as hand-lines, fish traps and gill nets, in combination with commercial catches have led to over-fishing of many reef areas. For example, a study by Jennings and Polunin (1996) found low abundances of certain highly targeted fish species, such as groupers and emperors. Over-fishing of prized invertebrate species, such as *Tridacna* clams and sea cucumbers, has also been reported close to urban areas and is thought to have increased since the introduction of SCUBA apparatus and escalating demands of foreign markets (Vuki *et al*., 2000). Fiji is the world's second largest exporter of live reef products for the aquarium trade (Wilkinson, 2002) with a well-established industry that has been operating for over 16 years exporting coral reef fishes and curio coral (Lovell, 2001).

The anthropogenic threats to reef health have been compounded by natural and semi-natural threats such as storm damage, outbreaks of the coral eating crown-of-thorns starfish (*Acanthaster planci*) and coral bleaching events. Bleaching events occur during occasional periods when climate conditions raise seawater temperatures and solar irradiance and cause a paling of coral tissue from the loss of symbiotic zooxanthellae (summarised in Brown, 1997 and Westmacott *et al*., 2000). A major

coral bleaching event occurred in Fiji in March and April 2000 and had large-scale effects throughout the country, including the Mamanucas region. For example, South and Skelton (2000) reported bleaching of up to 90% of coral colonies with up to 40% mortality (Sulu *et al*.; in Wilkinson, 2002), although there was significant spatial variation in its severity throughout Fijian waters. There is evidence that many of the corals recovered but mortality was certainly significant although it is difficult to quantify because of the limited long-term monitoring data available. A second less severe bleaching event occurred in the Mamanucas in April 2002 but did not significantly alter the % cover of live hard coral (Walker *et al*., 2002).
Fiji is also affected by a severe cyclone every 3-4 years (Vuki *et al*., 2000), causing significant coral damage in shallow water. Population explosions of Crown-of-Thorns starfish (CoTs) have also been recorded since 1979 (South and Skelton, 2000).

Conservation in Fiji has been limited because of conflicts between proposed Marine Protected Areas and local communities' ownership of customary fishing rights. Marine reserves have, therefore, until recently been limited to several privately owned sanctuaries where, for example, resorts have reached an agreement with the holders of fishing rights. Expansion of this network of reserves could be achieved by payment of adequate compensation to those who currently own the rights and rely on them for their livelihoods. There is also a growing network of locally owned and managed MPA's under the umbrella of the Fiji Locally Managed Marine Areas Project (FLAMMA) initiated by USP. This advocates the use of conservation education to highlight the advantages of voluntarily established marine reserves, such as increased fish catches and tourist revenue, to local communities.

2.2 The Mamanuca Islands

Along with most other areas of Fiji, the reefs of the Mamanuca Islands suffered from a mass coral bleaching event in March 2000. Local dive operators and resorts reported high mortality of reef building corals, but the extent and scale of the damage has not been quantified. Bleaching was again reported for the Mamanuca Islands in March 2001 and April 2002. The 2001 bleaching event was just prior to Cyclone Sosa passing close to the east coast of Viti Levu and the Mamanucas. The cyclone created substantial waves up to 25 feet high on the Outer Malolo ('Ro Ro') Barrier Reef (Craig Flannery, pers. comm.) and caused physical damage to the reefs at many different sites. Interestingly, there is anecdotal evidence that the water movements caused by Cyclone Sosa may have reduced sea-surface temperatures and allowed some bleached corals to recover. Furthermore, an outbreak of crown-of-thorns starfish was reported in the Mamanucas in 1996 (South and Skelton, 2000). A number of recent CoTs sightings have been reported at Mothui Island in March 2003 although the scale of this event is as yet unknown.

Natural stressors, for example bleaching and cyclones, act synergistically with anthropogenic disturbances such as sedimentation from land development, over-fishing and pollution, which are known to be present in the area. Initiatives are however being taken in the Mamanuca archipelago to prevent much of the anthropogenic degradation of the coral reef resources of the area. The Mamanucas hosts the oldest private sanctuaries in Fiji, established by "Beachcomber Cruises" in the 1970s, which are found around Tai (Beachcomber) and Lovuka (Treasure) Islands. A new MPA or tabu are has recently been established on the fringing and patch reef around Malolo Island through the work of Partners in Community Development Fiji (PCDF) and there are current plans to demarcate a secondary tabu area around Yanuya Island, again as a result of the community based initiatives of PCDF. The establishment of these tabu areas is based on a system modelled on the Fijian customary marine tenure scheme. Recently, the formation of the Mamanuca Environment Society has added impetus to the coordinated efforts occurring towards to Marine Resource management in the Mamanucas. The MES are ideally placed to act as the coordinating agency in these initiatives.

2.3 Aims and Objectives

Following the successful pilot survey programme undertaken in 2001 by CCC (CCC) and local Fijian counterparts a set of ten recommendations were drafted. These involved, but were not necessarily limited to; monitoring, education, setting up a Mamanucas management group, data base acquisition to set up a fully-functional GIS, and to set up multi-user Marine Protected Areas.

The marine science and environmental awareness programmes run during the second year of the FCRCP were designed to enhance and expand on the information collected during both the first year of the full project and the initial pilot phase. A programme of surveys, training and conservation education were undertaken aimed at continuing the assessment of the status of local reefs and improving environmental awareness amongst neighbouring communities.

2.3.1 Project Activities and Timetable

Three sections are highlighted within the work-plan timetable – Data acquisition and Management: Environmental Monitoring and Counterpart Training/Conservation Awareness.

Data Acquisition and Management (Table 1)

1. Systematic surveys of all reefs within the project area from Tokoriki Island in the north west to Tavarua Island in the south east for key biological criteria such as corals, reef fish and invertebrates that are indicators of biodiversity and health of the reefs in the area. Overlay collected data into a GIS package to highlight key hotspots of biodiversity. This will be accomplished by using UK recruited volunteers, and local counterparts to survey the reefs using the *CCC Baseline Survey Technique*.
2. Assess the environmental impacts and physical oceanography of the coastal areas on the local coral reefs from The Mamanucas and mainland coastline adjacent to Nadi. Again, this will be carried out using divers that have been trained during the *CCC Skills Development Programme* Table 4)
3. Repeat a series of Reef Check surveys initially carried out in 2001 to assess the status and potential recovery of the regions reefs in terms of reef health, particularly live hard coral cover.

Environmental Monitoring (Table 1)

1. Begin the establishment of a biological monitoring programme for the Mamanucas Islands. Arrange meetings and workshops with local dive schools in order to co-ordinate training and monitoring of their own dive sites. Monitoring will involve undertaking Reef Check surveys at a number of different locations to continue and expand upon the effort from the project.

Counterpart Training and Conservation Awareness Programmes (Table 2)

1. Provide scientific and SCUBA training for project counterparts and regional representatives. This will allow the local dive community to carry out their own surveys in the area and empower both local and regional communities to undertake their own reef monitoring and educational tours for fishermen and local children.
2. Establish a schools curriculum for conservation education by participating and joining schools in the Mamanucas areas with presentations, classes and interactive practicals on the local marine environment. Production of educational posters will provide an initial resource to help promote reef conservation at an early stage.
3. Establish a formalised 'diver briefing' lecture for the local dive community to make tourist divers more aware of the fragile nature of the coral reefs of The Mamanucas.

Training of local project counterparts and stakeholders ran concurrently with the CCC survey programme when applicable. Educational days involved the CCC Project Scientist travelling between the CCC project base camp, and local communities in the Mamanucas. CCC field science staff gave lectures and practical demonstrations of the importance of mangroves and coral reefs. A beach clean up was also organised each time a school was visited. Competitions with school children were incorporated into educational visits in order to encourage villagers to keep their beaches clean.

The scientific, training and outreach programme on each CCC project is co-ordinated by the CCC Project Scientist (PS) and Science Officer (SO). The primary responsibilities of the PS are to train volunteers and local counterparts in marine life identification, survey techniques and other supporting skills and to co-ordinate and report upon all field survey programmes. The PS is also responsible for representing CCC at in-country meetings and conferences and ensuring the data are precise and consistent. The SO works closely with the PS and the role involves teaching, survey planning and co-ordinating data management. Both the PS and SO will work with full-time CCC-UK staff on data analysis and report writing and dissemination.

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Table 1. Planned activities for the *Fiji Conservation Project March 2003- August 2004*. - Marine Surveys.

ACTIVITY - Marine																			**ASSUMPTION**
Data Acquisition and Management	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	
1. Development of a comprehensive classification scheme for all Mamanucas reefs	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	Local partners facilitate CCC staying at various satellite locations to enable sites further a field to be surveyed. Surveys carried out with all equipment functioning correctly. Local GIS facility identified and collaborates with on-site activities.
Baseline surveys – GIS database updates (ongoing)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
Environmental Monitoring																			
Reef Check – Advanced surveys (CCC style) - repeat monitoring of last years sites	•	•	•	•															Repeat survey sites are located accurately.
Reef Check – Advanced surveys (CCC style) – new locations			• *		• *		• *		• *		• *		• *		• *		• *		*New sites year round as and when Baseline surveys completed in survey areas
2. Recommendations																		•	Marine Protected Area recommendations to be accepted and actioned by all stakeholders
Initial application of protected area boundaries and zoning schemes associated with these areas.																			Co-operation of all stakeholders, identification of implementing agency, external funding sources
3. Reporting																			
Updates on web	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	Data are made available to CCCUK staff.
Summary reports			• *		• *		• *		• *		• *		• *		• *		• *		* Update reports to be produced as and when Baseline transects in an area completed

Table 2 Planned activities for the *Fiji Conservation Project March 2003- August 2004*. - Outreach activities.

ACTIVITY	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	ASSUMPTION
Counterpart Training																			Appropriate individuals are identified
Baseline surveys	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	Counterparts are fit to dive and make themselves available. Funds made available by counterparts to travel to and from the CCC operations base.
Reef Check surveys			•*		•*		•*		•*		•*		•*		•*		•*		*New sites year round as and when Baseline surveys completed in survey areas
Report Production	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	Reporting to Ministry of Tourism
Conservation Awareness																			
Educational Poster production																			Ongoing activity dependent upon British High Comission, Fiji for support.
Schools visits	•	•	•								•	•	•	•	•				Acceptance of local schools to facilitate visits by CCC staff.
Report Production				•												•			All materials are made available to CCCUK staff.
Collaboration with Mamamuca Environment Society	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	MES sustain environmental education initiatives

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2.3.2 Habitat mapping and Geographic Information Systems

One of the major planned outputs of the full FCRCP was a more detailed marine habitat map than the preliminary one produced during the FCRCP in 2001. Coastal habitat maps are a fundamental data requirement in establishing coastal management plans (Cendrero, 1989). In the context of conserving reef diversity, habitat maps provide an inventory of habitat types and their statistics (Luczkovich *et al.*, 1993; Spalding and Grenfell, 1997), the location of environmentally sensitive areas (Biña, 1982), allow representative networks of habitats to be identified (McNeill, 1994), identify hotspots of habitat diversity, permit changes in habitat cover to be detected (Loubersac *et al.*, 1989), and allow boundary demarcation of multiple-use zoning schemes (Kenchington and Claasen, 1988). Furthermore, the conservation of marine habitats may serve as a practicable surrogate for conserving other scales of diversity including species and ecosystems (Gray, 1997). In essence, coastal habitats are manageable units and large-scale maps allow managers to visualise the spatial distribution of habitats, thus aiding the planning of networks of Marine Protected Areas and allowing the degree of habitat fragmentation to be monitored. As Gray (1997) states, a mosaic of marine habitats must be protected if complete protection of biodiversity is to be achieved.

Habitat maps are generally created using remotely sensed imagery, such as satellite images or aerial photography, in combination with field data. Despite limitations such as cloud cover and limited water penetration (typically <25 m), remotely sensed imagery has the advantage of facilitating the cost-effective extrapolation of field data to large spatial scales. For example, a 'Landsat' satellite image covers an area of 185 km by 185 km, much larger than could be covered by survey divers alone. Satellite imagery consists of rows of square 'pixels', typically covering hundreds of square metres, that are characterised by the reflectance of blue, green and red light. Field data can then be used to characterise each 'spectral signature'. For example, if field data shows that a pixel with a high reflectance of red light is present in an area of habitat type A, computer software can be used to classify each pixel with a high reflectance of red light as habitat type A. Repetitions of this process for each habitat type will rapidly generate a map of habitat distributions across the whole satellite image. Readers are referred to Green *et al.* (2000) for further information on remote sensing for tropical coastal management.

In addition to the creation of the habitat map, one of the main planned outputs for the FCRCP was the creation of a fully integrated Geographic Information System (GIS) on the coral reef resources of the Mamanuca Islands. Essentially, a GIS is visual representation of a database that allows user to query the data set and display the results in a graphical representation. Data entered into a GIS is geographically and spatially linked in that each data point in the underlying database is linked to a point in space on the ground and also in the system display. A fundamental inclusion of any GIS is a base map or image over which data can be laid; in the case of the FCRCP, a satellite image is used. GIS have the great advantage in that the data they include is firstly linked to geographically identifiable sites as well as allowing data representations to be made graphically; a medium which is far more easily interpreted than a list of numbers in a conventional database.

3. METHODS

3.1 Survey strategy

Since the area encompassed by the FCRCP is extensive the survey strategy focused on gathering detailed data from a wide range of geographical locations in order to build on the information collected during the FCRCP in 2001. The main aim was to generate data from a broad range of habitat types that represent most reef types of the area and hence provide more solid recommendations for MPA designation in the Mamanucas.

The Concept Of 'Survey Sites'

During years one and two of the FCRCP, CCC volunteers collected data from a series of 'survey sites', which correspond to a particular island's reef or part of a reef depending on reefal area shown in Figure 2. Surveys at each site will generate a standardised data set that will facilitate characterisation of each area and also powerful comparisons at a range of spatial scales. Sites were chosen to represent: (1) popular diving areas; (2) the 'best' reefs of the project area; (3) the 'worst' reefs of the project area; (4) a range of reef (and hence habitat) types. Site selection was based on a combination of existing data, local information (e.g. dive resorts), local biologists and initial assessments (e.g. snorkelling). A total of 31 sites were designated for potential surveying during the FCRCP (Figure 2). Reaching the further sites (e.g. 7-13 or 31) requires the establishment of satellite camps away from the main field station on Qalito Island. Data from the full project will be added to the data collected during the pilot phase in order to increase the resolution of information and produce a more accurate assessment of both the type, and location of particular subtidal habitats around the Mamanucas.

Two survey techniques were used during years one and two of the FCRCP: CCC baseline transects for habitat mapping; and Reef Check surveys to assess reef health.
Firstly, standard *CCC Baseline Survey Technique* transects were surveyed to provide general data on each habitat type present. The exact number of transects at each site varied, depending on the topography of the reef (e.g. fewer transects at those sites with a wide or deep reef profile), but usually numbered between 3 and 20, depending on the scale and size of each survey site (refer to Fig. 2).
Secondly, modified 'Reef Check' surveys were used to collect quantitative data on the health of survey sites. Reef Check[1] is an established method for rapidly assessing reef health and was designed specifically for non-specialist researchers. CCC have adapted the standard Reef Check technique to record a further level of detail in terms of benthic habitats, hard coral and reef fish targets. In addition to these key techniques, further data such as compiling species lists and assessing water quality will be undertaken concurrently.

Baseline transects were completed throughout all months of years one and two. Reef Check surveys were undertaken at the same sites visited in 2001 for the FCRCP. These sites were close to the paths of the baseline transects so that the data sets would be complimentary and could be analysed in conjunction.

[1] http://www.ReefCheck.org/

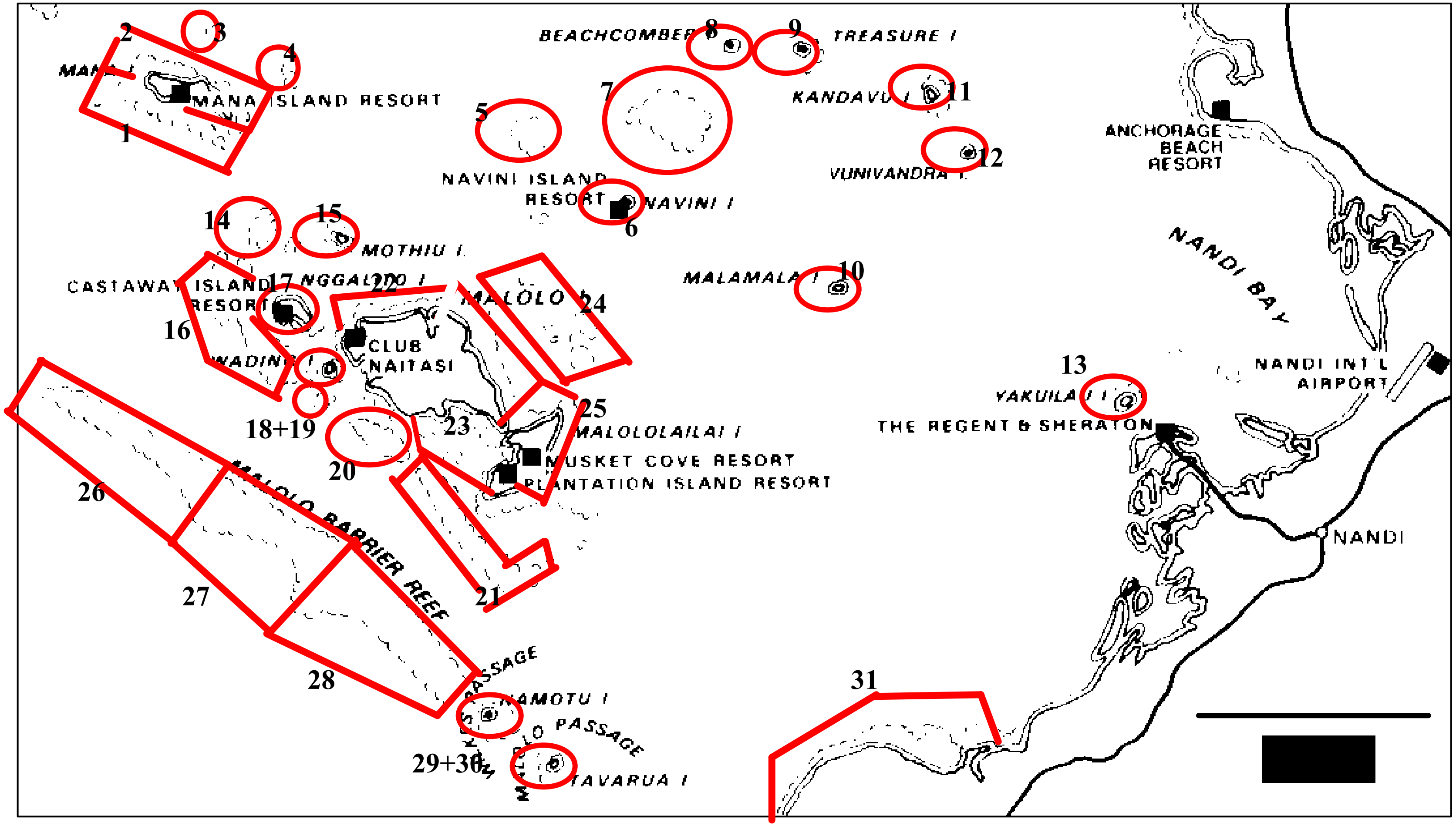

Figure 2. Location of the different 'Survey sites' within the Mamanucas. Thirty one sites are highlighted in red.

3.2 Volunteer training

Efficient and effective training is a vital component of any volunteer programme in order that participants quickly gain the required identification and survey skills that allow them to collect accurate and useful data. During the FCRCP, CCC used an intensive two-week training programme, which is outlined in Table 3. The programme was designed to provide volunteers, who may have no biological knowledge, with the skills necessary to collect useful and reliable data. The primary aim of the lecture programme was to give volunteers the ability to discern the specific identification characteristics and relevant biological attributes of the species that they would encounter during their diving surveys. The training programme was co-ordinated by the Project Scientist (PS) and Science Officer (SO) and involved two lectures and two dives or snorkels each day along with de-briefings and evening audio-visual presentations. Volunteers were also encouraged to snorkel and utilise identification guides to ensure a thorough understanding of the information provided in the lectures.

An important component of the training schedule was a series of testing procedures to ensure that each volunteer had reached a minimum acceptable standard. Hence the training programme concluded with a series of tests, which ensured that the volunteers had reached an acceptable standard of knowledge. These tests used both 'flash-cards' or slides and in-water identification exercises for corals and fish. Furthermore, to assess the quality of data collected by CCC volunteers during actual survey work, two validation exercises were undertaken. The benthic validation exercise used a test transect survey set up and thoroughly surveyed by the PS and SO to collate a reference data set. During Phase 1, test transects were conducted in buddy pairs with one person recording coral and the other soft corals, invertebrates and algae (as performed by Divers 3 and 4 during surveys; Section 3.3). During Phase 2, each person surveyed the transect line as during an actual Reef Check transect. Data were then transferred to recording forms and entered into a spreadsheet where the results from each pair were compared to the reference using the Bray-Curtis similarity coefficient (Equation 1; Bray and Curtis, 1957).

Equation 1:

$$\text{Bray - Curtis Similarity, } S_{jk} = \left[1 - \frac{\sum_{i=1}^{p} \left| X_{ij} - X_{ik} \right|}{\sum_{i=1}^{p} \left(X_{ij} + X_{jk} \right)} \right]$$

Where X_{ij} is the abundance of the *i*th species in the *j*th sample and where there are *p* species overall.

Since it is impossible to compare volunteer fish data to a reference, validation of fish surveys were conducted by measuring the consistency between pairs of surveyors. It is then assumed that if surveyors are consistent they are also accurate. Therefore, both divers within a buddy pair independently survey the whole fish list and each surveyor fills out their own survey form and enters it onto a spreadsheet. As with the benthic validation, the pairs of results were compared using the Bray-Curtis similarity coefficient. These assessments were similar to the critical assessment conducted by CCC in Belize in 1993 to test the accuracy of volunteer divers conducting baseline transect surveys (Mumby *et al.*, 1995).

Table 3. CCC Skills Development Programme timetable for CCC volunteers and local counter-parts during the Fiji Coral Reef Conservation Project.

	Day +1 (Sat)	Day +2 (Sun) No diving	Day +3 (Mon)	Day +4 (Tue)	Day +5 (Wed)	Day +6 (Thur)	Day +7 (Fri)	Day +8 (Sat)	Day +9 (Sun) No diving	Day +10 (Mon)	Day +11 (Tue)
⇩ AM	**Transfer** New vols (i.e. trained scuba divers) to Castaway **Survey dive** (Trained Volunteers only - see note 2) **Orientation** ►Welcome & tour of facilities ►Expedition life & duties ►General health & safety ►CCC rules & regulations **Practical** ►Scuba kit allocation ►PADI AOW Elective Dive: PPB (6m) with new diver volunteers	**Lecture 2** ►Dangerous animals! **Safety briefs** ►PADI MFA: Ac mods 1+2 ►O_2 therapy ►PADI tables & quiz (OW mods 4+5) ►CCC dive standards ►Radio use ►Emergency procedures ►Boat safety ►Boat marshalling ►Use of boat safety kit	**Lecture 3** ►Intro to coral reef ecology **Practical** ►Reef orientation (scuba-18m) ► **PADI AOWD Training** Elective Dive 3 (18m)	**Lecture 6i** ►Hard coral ID – target grps **Practical** ►Hard coral ID (scuba-18m) **Lecture 6ii** ►Hard coral ID	**Lecture 11i** ►Fish families and species ID **Practical** ►Fish ID – Families (18m) **Review** ►Fish ID – Families	**Lecture 11iii** ►Fish ID – target species **Practical** ►Fish ID – target species (scuba-18m) **Review** ►Fish ID – target species	**Lecture 13** ►Invert. ID **Practical** ►Invert. ID (scuba-18m) **Review** ►Invert. ID	**Lecture 15** ►Intro to CCC Reef Survey Technique **Practical** ►CCC Reef Survey methods (dry run) ►CCC Reef Survey methods practice (scuba-18m) **Review** ►CCC Reef Survey technique	**Review** ►ID – coral, fish, inverts & algae **ID skills evaluation** ►Inverts & algae (slides & samples) ►Inverts & algae (snorkel)	**Lecture 17** ►CCC data validation **Skills refresher** ►Benthic validation (scuba-18m)	**Review** ►ID – hard & soft corals **(a) Skills validation** ►Coral trail (16m)
⇩ PM	**Safety briefs** ►PADI RD: Ac mods 1+2 **Practical** ►PADI RD: OW exc. 1 (surface only) ►OW exc. 2 (3m)	**Lecture 10** ►Marine plants & algae **Practical** ►Marine plants & algae ID (snorkel) ►Specimen ID – reference collections	**Lecture 4** ►Intro to hard coral biology **Practical** ►ID - coral life forms (scuba-16m) **Review** ►Coral life forms	**Lecture 7** ►Soft coral and sponge ID **Practical** ►Hard/soft coral ID (scuba – 16m) **Review** ►Hard/soft coral ID	**Lecture 11ii** ►Fish ID – target species **Practical** ►Fish ID – target species (16m) **Review** ►Fish ID – target species	**Practical** ►Fish ID – target species (scuba-18m) **Review** ►Fish ID – target species	**Review** ►ID – coral, fish, inverts & algae **Practical** ►ID – coral, fish, inverts & algae (scuba-16m) **Self-revision** ►ID – coral, fish, inverts & algae	**Lecture 16** ►Intro to CCC Reef Survey forms, habitat classifications and use of Abundance Scales **Practical** ►Practice survey (scuba-16m) ►Data entry onto CCC forms	**Practical revision** ► ID – all fauna and flora (snorkel)	**Skills validation** ►Coral trail (scuba-16m)	**Review** ►ID – fish **Skills validation** ►Fish (scuba-10m) **Review** ►Validation assessment
EVE	**Lecture 1** ►Fiji **Review** ►Expedition Skills Training schedule	**Review quiz** ►CCC health & safety regulations ►CCC dive standards ►Emergency procedures ►Local culture & customs	**Lecture 5** ►Coral biology and taxonomy	**Lecture 8** ►Intro to fish ecology & behaviour **Lecture 9** ►Intro to GPS	**Review** ►Coral & fish ID (pictionary) **Lecture 12** ►Ropes & knots	**Review** ►Coral, fish and algae ID (pictionary) **Review** ►GPS & knots	**ID skills evaluation** ►Corals **Lecture 14** ►CCC data: analysis & use	**Safety brief** ►Night-diving procedures **Practical** ►Optional night-dive (12m)		**ID skills evaluation** ►Fish (slides)	**ID skills evaluation** ►Re-takes (if required) **Lecture 18** ►Other survey methods

Table 3 (continued). CCC Skills Development Programme.

	Day +12 (Wed)	Day +13 (Thurs)	Day +14 (Fri)	Day +15 (Sat) End of training
AM ⇩	**Skills validation** **Retakes if required (fish or coral)** **review** **Coral and soft coral ID**	**practice CCC Reef Survey dive** **shore dive/boat dive** Followed by Data entry	**Data collation – practice CCC Reef Survey dive** **Validation retake if required** **ID skills evaluation if required**	Recreational dive – location as decided by volunteers **Departures** ▶2 week volunteers **PADI DM*** ▶Topic 1
PM ⇩	**Practice CCC Reef Survey dive from boat** **Lecture 19** ▶Data entry to CCC computer database – (groups of 4)	**Practice CCC Reef Survey - shore/boat dive** **Followed by Data entry** **PADI MFA*** ▶Mods 3+4	**Practice CCC Reef Survey dive** Validation retake if required Graduation! Congratulations on completing the CCC Skills Development Programme **PADI MFA*** ▶Mods 5+6	Recreational dive – location as decided by volunteers **PADI DM*** ▶Topic 2–pt1
EVE		**Lecture 20** ▶Marine reserves **retakes of ID skills if required**	**Lecture 21** ▶mangrove ecology **retakes of ID skills if required**	**Lecture 22** ▶threats to the reef Optional night dive **Party night**

3.3 Baseline transect technique

Years 1 and 2 of the FCRCP utilised the standard baseline survey techniques developed by CCC for the rapid assessment of biological and physical characteristics of reef communities by trained volunteer divers. Following an intensive training programme, CCC's techniques have been shown to generate precise and consistent data appropriate for baseline mapping (Mumby *et al*., 1995). All surveys were co-ordinated by the PS and SO to ensure accurate and efficient data collection.

CCC's standard baseline transect survey technique utilised a series of plot-less transects, perpendicular to the reef, starting from the 28 metre contour and terminating at the reef crest or in very shallow water. Benthic and fish surveys were focused on life forms or families along with a pre-selected number of target species that were abundant, easily identifiable or ecologically or commercially important. Stony corals were recorded as life forms as described by English *et al.* (1997) and selected corals were identified to species level. Fish were generally identified to family level but in addition, important target species were identified. Sponges and octocorals were recorded in various life form categories. Seaweeds were classified into three groups (green, red and brown algae) and identified to a range of taxonomic levels such as life form, genera or species.

Since most transects require two or more dives to complete, transect surveys were usually divided up into sections (or 'sub-transects') with surveys of each sub-transect carried out by a team of four trained divers divided into two buddy pairs (A and B) as shown in Figure 3. At the start point of each sub-transect, Buddy Pair B remained stationary with Diver 3 holding one end of a 10 m length of rope, whilst Buddy Pair A swam away from them, navigating up or along the reef slope in a pre-determined direction until the 10 m line connecting Diver 1 and 3 became taught. Buddy Pair A then remained stationary whilst Buddy Pair B swam towards them. This process was repeated until the end of the planned dive profile, when a surface marker buoy (SMB) carried by Diver 2 was deployed to mark the end of that sub-transect. The SMB acted as the start point for the next survey team and this process was repeated until the entire transect was completed. The positions of the SMB at the start and end of each dive were fixed using a Global Positioning System (GPS).

Diver 1 was responsible for leading the dive, taking a depth reading at the end of each 10m interval, and documenting signs of anthropogenic impact such as broken coral or fishing nets. Diver 1 also described the substratum along the sub-transect by recording the presence of six substrate categories (dead coral, recently killed coral, bedrock, rubble, sand and mud). Divers 2, 3 and 4 surveyed fish, hard corals and algae, soft corals, sponges and invertebrates respectively. Diver 3 surveyed an area of approximately 1 metre to each side of the transect line whilst Divers 1, 2 and 4 survey an area of approximately 2.5 metres to either side of the line.

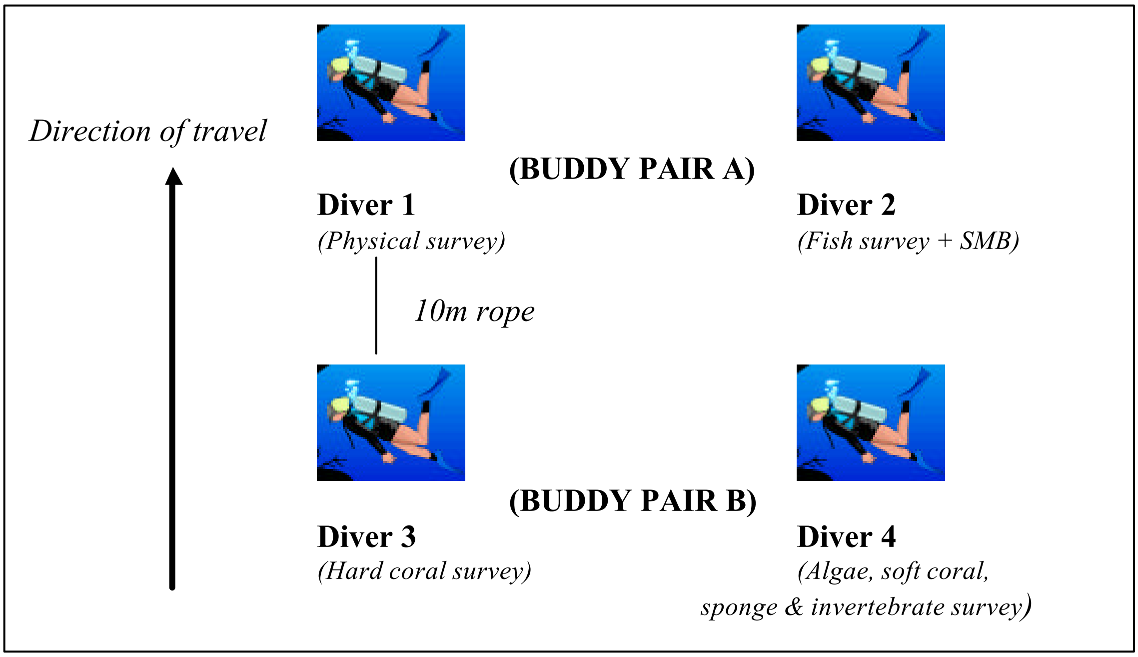

Figure 3. Schematic diagram of a baseline survey dive team showing the positions and data gathering responsibilities of all four divers. Details of the role of each diver are given in the text.

During the course of each sub-transect survey, divers may have traversed two or more apparently discrete habitat types, based upon obvious gross geomorphological (e.g. forereef, escarpment or lagoon) or biological differences (e.g. dense coral reef, sand or rubble; Figure 4). Data gathered from each habitat type were recorded separately for subsequent analysis.

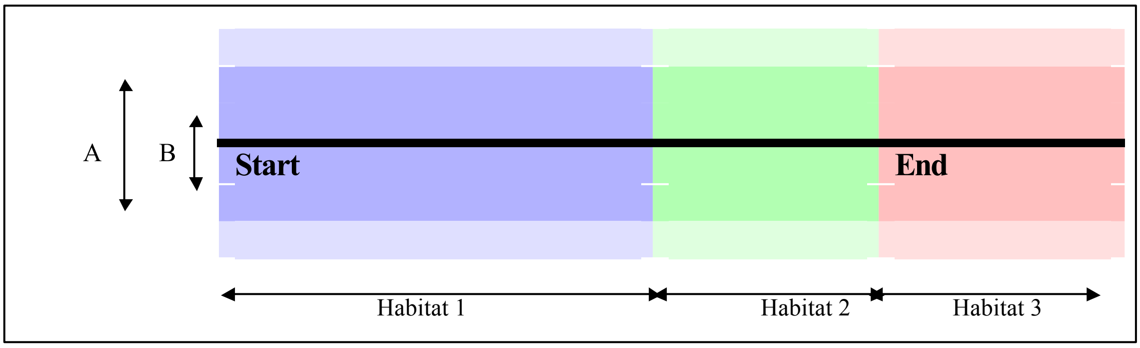

Figure 4. Schematic diagram (aerial aspect) of an example of a reef area mapped by divers during a sub-transect survey. Solid line represents imaginary sub-transect line. Dashed lines and shaded areas represent areas surveyed (A = 5m wide swathe surveyed by Divers 1, 2 and 4; B = 2 m wide swathe surveyed by Diver 3). Benthic data from habitats 1, 2 and 3 (e.g. reef, sand and rubble) are recorded separately.

Each species, life form or substratum category within each habitat type encountered was assigned an abundance rating from the ordinal scale shown in Table 4.

Table 4. Ordinal scale assigned to life forms and target species during baseline surveys.

Abundance rating	**Coral and algae**	**Fish and invertebrates (number of individuals)**
0	None	0
1	Rare	1-5
2	Occasional	6-20
3	Frequent	21-50
4	Abundant	51-250
5	Dominant	250+

During the course of each survey, certain oceanographic data and observations on obvious anthropogenic impacts and activities were recorded at depth by the divers and from the surface support vessel. Water temperature readings (±0.5°C) were taken from the survey boat using a bulb thermometer at the sea surface. The survey team also took the temperature at the maximum survey depth (i.e. at the start of the survey). Similarly, the salinity was recorded using a hydrometer and a water sample taken from both the surface and the maximum survey depth. Water visibility, a surrogate of turbidity (sediment load), was measured both vertically and horizontally. A secchi disc was used on the survey boat to measure vertical visibility through the water column (Figure 5). Secchi disc readings were not taken where the water was too shallow to obtain a true reading. Horizontal visibility through the water column was measured by divers' estimates while underwater. Survey divers qualitatively assessed the strength and direction of the current at each survey site. Direction was recorded as one of eight compass points (direction current was flowing towards) and strength was assessed as being 'None', 'Weak', 'Medium' or 'Strong'. Similarly, volunteers on the survey boat qualitatively assessed the strength and direction of the wind at each survey site. Direction was recorded as one of eight compass points (direction wind was blowing from) and strength was assessed using the Beaufort Scale.

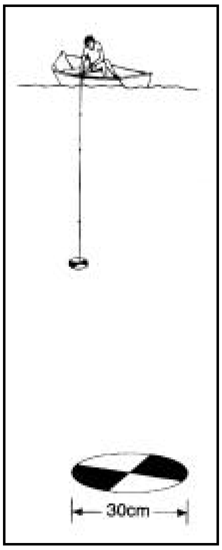

Figure 5. The use of a secchi disc to assesses vertical water clarity. The secchi disc is lowered into the water until the black and white quarters are no longer distinguishable. The length of rope from the surveyor to the disc is then recorded. *Source*: English *et al.* (1997).

Natural and anthropogenic impacts were assessed both at the surface from the survey boat and by divers during each survey. Surface impacts were classified as 'litter', 'sewage', 'driftwood', 'algae', 'fishing nets' and 'other'. Sub-surface impacts were categorised as 'litter', 'sewage', 'coral damage', 'lines and nets', 'sedimentation', 'coral disease', 'coral bleaching', 'fish traps', 'dynamite fishing', 'cyanide fishing' and 'other'. All information was assessed as presence / absence and then converted to binary data for analysis. Any boats seen during a survey were recorded, along with information on the number of occupants and its activity. The activity of each boat was categorised as 'diving', 'fishing', 'pleasure' or 'commercial'. Finally the divers recorded a general impression of the site during each survey. These ratings were completed for biological (e.g. benthic and fish community diversity and abundance) and aesthetic (e.g. topography) parameters. Both parameters were ranked from a scale of 5 (excellent), 4 (very good), 3 (good), 2 (average) or 1 (poor).

3.4 Reef Check

Reef Check was designed to be used by non-professional divers to assess reef health and hence generates relatively simple, but quantitative, information. During the FCRCP the standard Reef Check protocol was modified to collect more detailed data (e.g. via greater taxonomic resolution) and hence provide a better assessment of reef health. Such modifications were possible because all CCC volunteers received more intensive training than regular sport divers. Each Reef Check site was located close to a baseline transect in order that the data sets could be spatially linked together and hence analysed in conjunction.

The standard Reef Check survey protocol utilises two transects at depths of approximately 3 and 10 m but, during the FCRCP, deeper transects (e.g. 17 and 24 m) were conducted if the reef topography was appropriate. Similarly, since reef development in the Mamanuca Islands is generally in shallow water, the 10 m transect was not completed if there was minimal coral cover at this depth. Along each depth contour a 100 m transect was deployed and along it four 20 m long replicate transects were surveyed. The replicate transects followed the designated depth contour in sequence but the start and end points are separated by a 5 m space (Figure 6) i.e. the distance between the start of the first transect and end of the last transect was 20 + 5 + 20 + 5 + 20 + 5 + 20 = 95 m. By collecting data from each of the four 20 m sections, four replicates were collected per survey allowing the calculation of a mean per replicate and hence more powerful statistical analysis.

Five types of data were recorded via three surveys along each transect line at each depth. Firstly, a site description sheet was completed which included anecdotal, observational, historical, locational and other data. Secondly, four 5 m wide by 20 m long transects (centred on the transect line) were sampled for commercially important fish, for example those typically targeted by fisherfolk and aquarium collectors. Fish were only counted if they were less than 5 m above the transect line, giving a survey area for each transect replicate of 20 x 5 x 5 m = 500 m^3. CCC volunteers in Fiji recorded data on more fish species than specified by the standard Reef Check protocol. The divers assigned to count fish swam slowly along the transect and then stopped to count target fish every 5 m and then waited three minutes for target fish to come out of hiding before proceeding to the next stop point. Thirdly, four 5m wide by 20 m long transects (centred on the transect line) were sampled for invertebrate taxa typically targeted as food species or collected as curios. Quantitative counts were made of each species. In addition, the invertebrate surveyors noted the presence of coral bleaching or unusual conditions (e.g. diseases) along the transects.

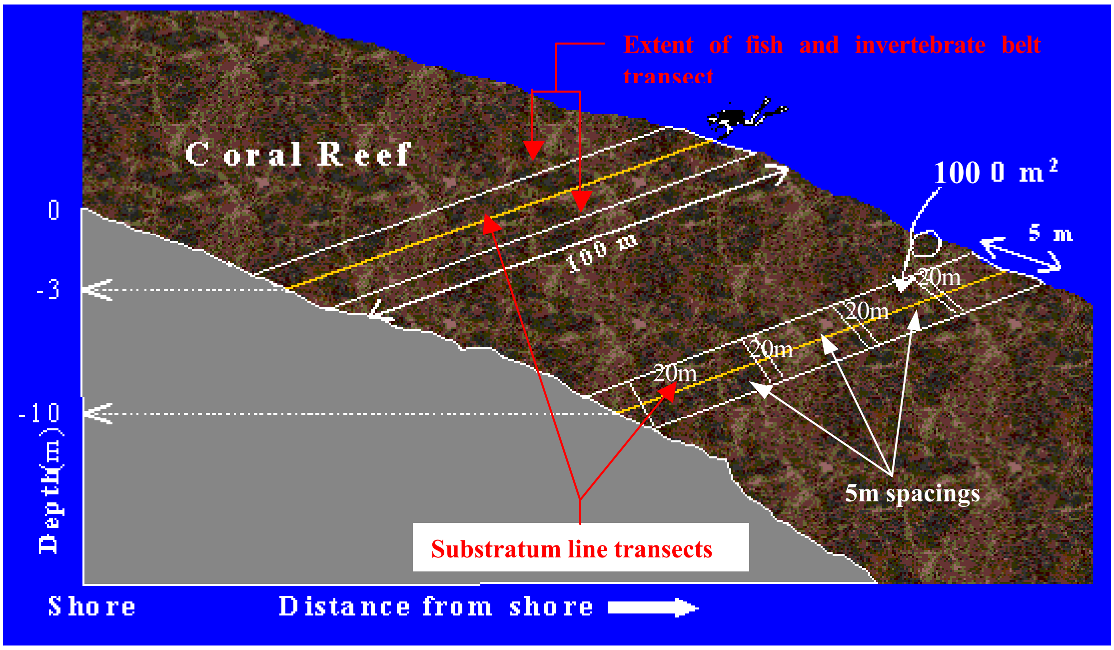

Figure 6. Schematic diagram showing the position of the transect lines during a Reef Check survey. 100 m transect is divided into four 20 m replicates so area of each belt transect is 20 x 5 m = 100 m^2. In addition to the standard 3 and / or 10 m transects, CCC used one or more deeper transects when appropriate. *Source*: modified from figures on http://www.reefcheck.org.

Finally, four 20 m long transects were point sampled at 0.5 m intervals to determine the substratum types and benthic community of the reef. The diver looked at each point and noted down what lay under each of those points. The standard Reef Check protocol specifies that the categories recorded under each 50 cm point are: hard coral, soft coral, recently killed coral, dead coral, fleshy seaweed, sponge, rock, rubble, sand, silt / clay and 'other'. However, CCC volunteers recorded hard corals to life form level (along with target species), soft corals to life form level and five categories of algal cover (mixed assemblage, coralline, *Halimeda*, 'macro' and 'turf'). Finally, the substratum surveyors recorded coral damage from anchors, dynamite, or 'other' factors and trash from fishing nets or 'other'. Divers rated the damage caused by each factor using a 0-3 scale (0 = none, 1 = low, 2 = medium, 3 = high). All data were transferred to specially designed recording forms (Appendix 2).

Reef Check data collected during the year two of the FCRCP is currently being analysed for presentation in a separate report and so is not replicated here. Reef Check surveys will be made available to the global and national databases, hence increasing the impact of the project.

3.5 Data analysis

Note on statistical conventions: during this report the results of statistical tests are given by showing the 'p' (probability) value of the test. Under statistical conventions, a p value of less than 0.05 is regarded as 'significant'(the error of the test is less than 1 in 20) and a p value of less than 0.01 is regarded as 'very significant'.
Note on Map outputs: all maps presented in this report are displayed on a Universal Transverse Mercator (UTM) grid (zone 60, Southern Hemisphere). Throughout, a WGS84 Geodetic Datum is use for projection.

3.5.1 Oceanographic, climate and anthropogenic impact data

Data on water temperature, salinity, visibility, the strength and direction of currents and wind, natural and anthropogenic impacts, the presence of boats and the biological and aesthetic ratings were summarised graphically and via univariate statistics, along with more detailed examination of the data using Analysis of Variance (ANOVA) and subsequent least significant difference multiple range tests. Data were either summarised for the whole project area or for each of the five reef complexes as appropriate.

3.5.2 Benthic data

In order to describe the reefal habitats within the project area, benthic and substratum data were analysed using multivariate techniques within PRIMER (Plymouth Routines in Multivariate Ecological Research) software. Data from each Biological Form (which represents a 'snap-shot' of the benthic community from either part or all of a habitat type distinguished by the survey team) are referred to as a Site Record. Multivariate analysis can be used to cluster the Site Records into several groups, which represent distinct benthic classes. Firstly, the similarity between benthic assemblages at each Site Record was measured quantitatively using the Bray-Curtis Similarity coefficient without data transformation (Equation 1; Bray and Curtis, 1957). This coefficient has been shown to be a particularly robust measure of ecological distance (Faith *et al.*, 1987).

Agglomerative hierarchical cluster analysis with group-average sorting was then used to classify field data. Cluster analysis produces a dendrogram grouping Site Records together based on biological and substratum similarities. Site Records that group together are assumed to constitute a distinct benthic class. Characteristic species or substrata of each class were determined using Similarity Percentage (SIMPER) analysis (Clarke 1993).

To identify characteristic features, SIMPER calculates the average Bray-Curtis similarity between all pairs of intra-group samples (e.g. between all Site Records of the first cluster). Since the Bray-Curtis similarity is the algebraic sum of contributions from each species, the average similarity between Site Records of the first cluster can be expressed in terms of the average contribution from each species. The standard deviation provides a measure of how consistently a given species contributes to the similarity between Site Records. A good characteristic species contributes heavily to intra-habitat similarity and has a small standard deviation. The univariate summary statistics of median abundance of each species, life form and substratum category were also used to aid labelling and description of each benthic class.

Finally, the benthic class of each Site Record was combined with the geomorphological class assigned during the survey to complete the habitat label. The combination of a geomorphological class and benthic class to produce a habitat label follows the format described by Mumby and Harborne (1999).

To implement this protocol for the analysis of data collected during year two of the FCRCP, the habitat groupings already identified from the data and presented in the year one report were used. This has the advantage that analysing additional data in this manner ensures consistency between one years data set and the next and is important in the process of developing an exhaustive classification scheme for the entire coral reef area (Mumby and Harborne 1999). Using the year one data set as a multivariate training set, discriminate analysis was performed on the data. In this process, a new data set was compared to all of the data representing each of the habitat classes defined previously (i.e. from year one data). Using the same Bray Curtis similarity measure, it was then possible to place the new data set into one of the predefined benthic classes to which it is most similar. For some data points however, this method of best fit was not appropriate. This was quantified using a confidence value where any value <95% and the data set cannot be fitted confidently into any one of the predefined benthic classes. Where this occurred with the data point, the point was then extracted from the data set, and was then re-clustered using the hierarchal agglomerative cluster analysis technique described above. By iteratively using discriminate analysis together with re-clustering of data points that do not fit into an already represented benthic class, it was possible to improve the systematic classification scheme already begun in year one.

3.5.3 Fish and invertebrate data

Fish and invertebrate data were summarised graphically and via univariate statistics, along with more detailed examination of the data using Kruskal-Wallis (KS) and ANalysis Of SIMilarity (ANOSIM, a routine within PRIMER). ANOSIM tests for differences between groups of community samples, defined *a priori*, using randomisation methods on a similarity matrix produced by cluster analysis. Data were either summarised for the whole project area and for each of the survey sectors. Note that the ordinal scores for fish and invertebrates cannot be standardised for transect length.

3.6 Habitat Mapping

A Landsat 7 ETM+ satellite image produced by the U.S. Geological Survey (USGS) was purchased for use in the FCRCP. Landsat 7 carries the Enhanced Thematic Mapper plus (ETM+) sensor in support of research and applications activities. Further details are available from the USGS website[2]. The image was acquired on 18th May 2001.Image processing was carried out in conjunction with the University of Nottingham.

Prior to the image being used in the production of a thematic habitat map, a three-fold correction and masking technique was carried out.

The initial step of the process was to atmospherically correct the image. The process of atmospheric correction accounts for the angle at which the sun was at the time of the capture of the image, commonly referred to as sun zenith angle. The model used, called the MsixS model, is a radiative transfer model that accounts for the path of light from the subject (coral reef) to the satellite sensor through the atmosphere, and the influence of interference of the atmospheric gases on the reflected light (Green *et al*., 2000). The resulting corrected image was then at a stage where the influence of the atmosphere had been removed and instead the reflected light had simply passed through a vacuum.

The second image processing stage was to mask areas of land from the image that were not to be used in the classification of reef areas in the habitat map. The masking technique employed calculates a ratio between bands 1 and 5 in the satellite image (infra-red and blue areas of the spectrum respectively). The methodological background to such a technique is based on the difference in absorption of light of different wavelengths in water; with infra-red being absorbed entirely by very shallow water and therefore none being reflected and blue light being reflected by all but the deepest and most turbid water bodies. The resulting output image clearly differentiates between areas of land and sea and was used to identify areas of the image containing land and then to subsequently use these as a mask to remove land areas from the image. Removal of land areas in this manner has the advantage that the remaining water bodies containing the target coral reef areas can then assume a much wider range of colours in the image and therefore can aid in the process of correctly identifying different habitat classes comprising the coral reef.

The final stage in the pre-processing of the Landsat image prior to classification was to perform a water column correction technique with the aim to remove the effect that the overlying water column has on the spectral composition of the light reflected by the coral reef. The purpose behind the employment of this technique is that frequently the effect of the water column on the attenuation of light from a coral reef target is far greater than the difference in reflected light caused by the different coral reef types; upon which the classification of habitats is based. The particular technique employed is known as the Lyzenga or band ratioing technique (Lyzenga, 1981). The first step in this process was to extract values of irradiance from sites known from field data to have similar reflectance values prior to the interference of the water column on the reflected light. In this instance, sand sites of different depths were chosen throughout the image. Once these values of light intensity have been log transformed, they can be used to produce ratios of the bands present in the Landsat sensor. In this technique, ratios of the following Landsat bands were calculated; 1/2, 1/3, 2/3. Plotting radiance values from each band against the band to which

[2] http://eosims.cr.usgs.gov:5725/DATASET_DOCS/landsat7_dataset.html

they are being ratioed and then extracting information on both the gradient and y-intercept of the regression line around these plotted points allows for the calculation of a value representative of the differential effect of the water column between these two bands. The final step was then to use these values to perform a calculation on the bands comprising the image data to produce one depth invariant band for each of the band ratios used. The resulting depth invariant bands were now representative not of the reflectance characteristics of the underlying target coral reef together with the interference of the water column overlying them, but instead only represent the reflectance values of the coral reef target itself. The use of water column corrected imagery in the classification and production of habitat maps has been shown to produce a statistically significant increase in habitat map accuracy (Green *et al*., 2000).

An unsupervised classification, where the computer classifies each pixel into a number of classes prior to the user overlaying field data, was chosen in preference to a more traditional ‘supervised classification’. During a supervised classification field data are used to classify the raw spectral signatures of each pixel i.e. areas with a high reflectance of blue light are classified as habitat C. All pixels with a high reflectance of blue light are then classified as habitat C and so on for each habitat type. The process of unsupervised classification simply places each pixel of the satellite image into one of a user defined number of bins based on its reflectance characteristics across the entire spectrum sampled by the remote sensor. Overlaid onto the resulting output image was then the GPS coordinates of survey transect sections classified into each benthic class. Using this information, each of the classes identified by the image processing technique could be assigned to one of the benthic classes to produce the final habitat map. This technique of marrying field data with that information collected by the remote sensor is a form of visual interpretation.

Ideally, a supervised classification would be used to produce the habitat map, however, due to issues of spectral confusion the resulting output maps were of lower accuracy that the map produced by unsupervised classification and visual interpretation described in the previous paragraph. Accordingly, the unsupervised classification technique was used throughout to produce the output habitat maps.

An accuracy assessment was carried out on the output map to ensure its consistency throughout. This assessment was conducted using the output map and then locating sites of known habitat classification from 150 field collected data points. If the map indicated the site to be the same habitat as that indicated by the field data, then this site was given a score of 1; if classified incorrectly, the site was given a score of zero. By simply producing a ratio of correctly classified points to incorrectly classified ones; an assessment of overall accuracy was obtained.

3.7 Conservation Management Ratings and Geographic Information System

In order to examine the relative health, diversity and status of the coral reef areas in the Mamanucas, an innovative method of calculation has been devised. The theoretical basis behind the conservation management rating system is that areas of coral reef around which Marine Protected Areas should be established to maximise their benefit should be as biodiverse, productive and representative of all habitats. This technique combines many of these variables based upon the classification of coral reef areas that have been surveyed and subsequently classified into a habitat.

Once all survey records had been assigned to one of a discreet number of benthic classes, further analysis based on these subsets of data was performed. The total number of species and Shannon-Weiner diversity indices have been calculated on both the benthic community as well as on the fish communities that were recorded by CCC divers at the site of each Survey Record. Finally, values of average hard coral cover from the detailed habitat descriptions for each habitat were also extracted. Average values for each of these biological indicators of reef health were then calculated across the entire data set.

To quantify the spatial distribution of areas of reef, each Survey Record was assigned a rating from one to five. A score of zero on this rating scale equates to the Survey Record belonging to a habitat or benthic class where none of the five univariate reef health indicator variables were above average across all the Survey Records analysed. By contrast, a Survey Record with a score of five belongs to a benthic class where all five variables were above the average value calculated.

Each transect surveyed during the CCC Baseline technique is comprised of a composite of more than one Survey Record, each of which may belong to different benthic classes and therefore have differing degrees of reef health. By splitting each transect into its constituent parts, and weighting the composition of each transect according to the length surveyed, it was possible to construct an overall reef health statistic for that survey transect ranging from 0-5. To facilitate easy interpretation of these values, the following scale was used; where transects scored an overall rating >4.5 they were classified as of high management potential, from 3.5-4.5 as moderate management potential and finally below 3.5 of low management potential. With each of these transects being spatially locatable data sets, a map to show the relative management potential of each transect surveyed thus far has been constructed.

The resulting map illustrates point data sources but does not allow the overall interpretation of conservation value of areas surrounding these transect points. To allow this, a unique mapping procedure was performed. The first stage in this methodology was to produce a density grid over the survey area that illustrates the density of the both transects and also the relative management value of these transects. It was realised however that areas of high density could be as a result of higher survey effort in a reef area and not as a result of high management potential rating. To overcome this, another density grid of survey effort was created, the units of which, although arbitrary, represent the number of transects per reef unit area. Finally, by performing a calculation on the raster layers in a Geographic Information System to divide the density grid of management value combined with survey effort and the grid of survey effort alone, the output density grid is weighted for survey effort and represents only the density of management value.

This output image was contained in a Geographic Information System that allows users to query and delineate areas of high conservation and management value, to calculate the geographic area comprising these sites and to add, for example, buffer zones of a set distance around each of these sites of interest.

The production of this map is the culmination of the work conducted by CCC thus far in the FCRCP. It has huge potential of use for all stakeholders; allowing a degree of flexibility in the choice of Marine Protected Area sites .It is upon this map that the Marine Protected Area recommendations contained in this report were identified.

3.8 Environmental Awareness and Community work

3.8.1 Mamanuca Environment Society

The Mamanuca Environment Society was formed in March 2003. MES aims to encourage stakeholders within the Mamanuca region to act in a responsible manner and employ best practice with regards to the environment. The main focus of MES work is to educate local resource users and resource owners, building capacity within the local communities, to achieve long-term conservation of the Mamanuca area.

The creation of an organisation such as MES, with a long-term commitment to conservation in the Mamanuca region, was a recommendation made by CCC early on in the FCRCP. It is vital that once CCC has completed surveys of the Mamanucas and moved on, there will still be an organisation present in the region to continue with and develop the ongoing environmental awareness and community work. MES now fills this important role for the Mamanucas. CCC is currently working very closely with MES over all environmental awareness and community projects undertaken in the Mamanuca region.

3.8.2 Dive into Earth Day, April 2004

Earth Day is an international scheme organised annually by the Coral Reef Alliance (CORAL) in conjunction with the Earth Day Network and PADI Aware Foundation, which aims to encourage people to participate in marine conservation activities in an attempt to raise public awareness of conservation issues.

Rubbish pollution poses a substantial threat to the reef systems of Fiji. To highlight this problem and also undertake a useful and beneficial activity in support of Earth Day, a large scale clean up of the beach, tidal zone and shallow reef area outside the front of Solevu village, Malolo Island was organised in 2003. Over 200 people participated in the event, and over 1 tonne of rubbish was collected and disposed of. Figures 7 and 8 show just some of the participants and rubbish collected during these days.

Figure 7. Participants in the Dive into Earth Day on Yanuya Island.

Figure 8. CCC Project Scientist with children of Yanuya Island at the Dive into Earth Day cleanup activity

This year the programme was expanded and organised by MES, with similar clean ups being conducted at all four villages of the Mamanucas: Solevu and Yaro on Malolo Island, and Yanuya and Tavua in the northern Mamanucas. Participants included the village communities as well as local Dive Operators, tourists from local resorts, and staff and volunteers from both CCC and MES. Before each clean up began a brief talk was given, covering how long various litter items could be expected to persist in the environment, how to dispose of rubbish more responsibly, and the threat posed by litter to the marine environment.

Navini Island resort provided bin bags and plastic gloves for the litter pickers. Overall approximately 250 bags of rubbish were collected. Items found ranged from batteries and cigarette butts to tyres, linoleum and PVC piping. The collected rubbish was taken on a barge for proper disposal at processing facilities on the mainland. Malolo Island resort also took rubbish from the beach clean ups held at Solevu and Yaro villages.

3.8.3 Environmental Awareness Teaching at Local Schools

In the early stages of the FCRCP an environmental education programme was implemented at Malolo District School, Solevu. Six sessions were conducted for class 8 students to highlight the importance and threats to reefs, coastal zone management issues and strategies. Following the success of the initial programme CCC were invited to conduct a similar programme at the start of the new school year. A ten-week programme was developed to coincide with the term time and was again directed at class 8 students. The course focused on introducing reef ecology and biology concepts to highlight the fragile nature of the reef systems and the need for management, thereby increasing the environmental awareness of the children. Concepts were promoted through worksheet exercises, word games, drama, art, group debates, and physical exercises such as litter surveys. The workshop scheme was very successful and the children's grasp of general marine science and English language improved notably over the duration. The children reacted well to the varied teaching methods and enjoyed the subject matter. A selection of photographs of the School Environmental Awareness teaching activities are shown as figures 9 and 10.

Figure 9. School children from Namamanuca Primary School on Yanuya Island undergoing classroom based-education

Figure 10. The value of practical experience- a school pupil from Namamanuca Primary School on Yanuya Island gaining practical experience in coral reef monitoring.

This year the same programme was taught again at Malolo District School to Class 8 students. Teaching ran throughout the term from January to May 2004, culminating in a field trip to Solevu house reef on a coral viewing (glass bottom) boat kindly loaned for the occasion by Castaway Island Resort. This trip allowed the children to see their own reefs at close quarters, which of the species they had learned about could be found there, and what impacts were affecting the reef. None of the children had even snorkelled before, so it was the first time they had seen a living reef in the water. All of the children then received certificates signed by CCC and by their headmaster for completing the course.

More recently, CCC has had the opportunity to teach at Namamanuca Primary School on Yanuya Island in the northern Mamanucas. A new school programme, based around the same concepts as that taught at Malolo District School, has been designed by MES in conjunction with CCC to fit the longer thirteen-week term. A summary of the new programme of teaching can be found in Table 5 below. Permission has been granted by the village elders to set aside a small 'tabu' or protected area on the back reef next to the village, at least for the duration of the school course and perhaps beyond. The course incorporates learning about the use of protected areas as a conservation tool, and also learning to survey using a basic version of the Reef Check technique. Teaching the simple survey protocol enables the children to monitor their 'tabu' area over the course of the school programme. This also builds the future capacity of the village with the youth having a greater understanding of environmental issues that the village may face. The twenty children being taught are all in Classes 7 and 8, ranging in age from 11 to 13 years old.

Table 5. Marine Environment Programme schedule for Namamanuca Primary School

WEEK	ACTIVITY SCHEDULE
1	**Introduction to MES, CCC and Reef Check.** Teach Reef Check survey technique, survey the proposed tabu area Collate data from surveys, discuss implications of data
2	**What is the coastal zone?** Description of the coastal zone Forests, mangroves, seagrass beds; their importance to humans and to other ecosystems Brainstorming session: types of trees found in Fijian upland forests
3	**Coral reefs as part of the coastal zone** Description of coral reefs, where they are found globally and why What corals need to grow, what corals eat Structure of a coral polyp Common types of reefs
4	**Importance of reefs and coastal zone interaction** Why coral reefs are important to humans and to other ecosystems How the four communities of the coastal zone are interlinked
5	**Threats to the coastal zone** Threats facing forests, mangroves, seagrass beds, and reefs Brainstorming session: natural and anthropogenic threats to reefs
6	**Animals on the reef** Introduction to 10 animals found on the reef: coral polyp, lobster, octopus, sponge, sea urchin, crown of thorns, sea cucumber, parrotfish, triton trumpet shell and giant clam. Activities: various activities based around these animals
7	**Food webs** How energy is transferred through a coral reef ecosystem Symbiotic relationships on the reef Activity: construct a coral reef food web, what happens if certain elements are removed
8	**Human impacts on coral reefs – litter** How long litter persists in the environment Brainstorming session: why litter might be bad for the reef Litter survey: collection of litter on the beach, followed by discussion of what was collected Suggestions on how to minimise littering The theory of composting Activity: making and tending a compost heap
9	**Human impacts continued – fishing** Good and bad fishing practices Minimum catch sizes for important food fishes Activity: fish questionnaire – impacts of fishing
10	**Human impacts continued – sediment, sewage, tourism, villages** Causes and effects of reef sedimentation, effects of sewage disposal, tourism and village communities on the reef Brainstorming sessions: how tourism-related activities might harm the reef, what activities within a village community may harm the reef

Table 5 (cont). Marine Environment Programme schedule for Namamanuca Primary School

WEEK	ACTIVITY SCHEDULE
11	**Skits on threats and benefits to reefs** Acting out 10 brief skits on threats to and benefits of reefs: fishing for the family, fishing for income, tourists enjoying the reef, reef protecting the village, variety of marine life, overfishing, land pollution, sewage, pollution, working together for a better future
12	**What are Marine Protected Areas?** The difference between a Marine Protected Area (MPA) and a tabu area What is an MPA, why set one up Advantages of MPAs

3.8.4 Best Practice Guidelines Workshops for Water Sports Activities

Through the request of the Mamanuca Hoteliers, MES and CCC teamed up again to conduct a workshop on Best Practice Guidelines for Watersports Activities. 13 workshops were held with Watersports and Activities staff at various resorts and other tourism operators in the Mamanuca area – Captain Cook Cruises, Malolo Island Resort, South sea Cruises, South Sea Island, Sea Spray Cruise, Tavarua Island Resort, Namotu Island Resort, Wadigi Island Resort, Castaway Island Resort, Tokoriki Island Resort, Matamanoa Island Resort, Mana Island Resort, Beachcomber Island Resort, Subsurface Diving, over the period from late October 2003 until early January 2004.

These workshops were designed to educate staff about coral reefs, their importance and threats and the animals that could be found on the reefs, so that they in turn could educate the guests coming to the resorts. Therefore the workshops also covered subjects such as 'best practice' guidelines for water sports and particularly snorkelling, and how to give an environmental briefing for guests. Ill-informed tourists can cause a lot of damage to a reef, mostly through accidental breakage of corals and removal of shells and other creatures from the reefs. It is particularly important to ensure that resort staff are knowledgeable about coral reefs and the potential impacts of tourism, and that they are comfortable using this knowledge to guide their guests in their use of the reefs.

MES has then organised Refresher courses that were held six months later with all of the participants to follow up from the initial training. These served to check how much of the information had been retained, whether staff were putting the knowledge they had learnt in the first session into practice. Staff were also encouraged to speak up on practices that were currently in place within the operation that they felt needed modifying in order to comply with Best Practices.

3.8.5 Introductory Reef Awareness Talks for Resort Guests

Simplistic and informative talks were given to guests at Castaway Island Resort. These talks introduced CCC, their aims and objectives and the work being carried out by CCC in the Mamanucas. They then covered a basic introduction to coral reef ecology, reef types and coral biology, as well as an introduction to the coastal zone and description of the interaction between the communities found there. The talks also covered the importance of and threats to reefs, particularly those threats created or exacerbated by tourism. These talks were advertised at the beginning of the day on the activities board at the Resort, and were open to all interested guests.

3.8.6 The Mamanuca Dive Operators Reef Check Network

As part of the first year of the FCRCP, marine ecology workshops for diving professionals working in the Mamanuca Islands were conducted. The objective of these workshops was to give participants a general background to coral reef ecology, whilst emphasising conservation issues. Participants were given information in a format that could easily be passed on later to their students and clients.

Following on from this series of workshops, this year saw the inception of the Mamanuca Dive Operator Reef Check Network. Workshops for all of the mainland and island Dive Operators operating within the Mamanuca region were held over the course of four weeks by MES in conjunction with CCC. The primary objective was to establish a permanent network of Reef Check sites across the Mamanucas that could be monitored annually by the local Dive Operators. This serves the double purpose of education and capacity building within the local community, and also providing an annually updated data set that should yield information about the status of reef health throughout the Mamanucas. MES had successfully applied for a PADI Aware grant, which covered the cost of workshop materials and the equipment necessary for setting up permanent survey sites. For more detail on the actual workshop content, see Table 6 below and images of these workshops; Figures 11 and 12.

Table 6. Content of workshops held with the Mamanuca Dive Operators

WEEK	WORKSHOP CONTENT
1	Introduction to the concept of a Dive Operators Network, and why it is important General background to the ecology and biology of coral reefs Importance of coral reefs and threats to reefs Group mapping exercise on bleaching, crown-of-thorns, sedimentation within the Mamanucas
2	Best Practice Guidelines, environmental briefings Introduction to the theory of carrying capacity for dive sites, discussion of how this is useful in the context of the Mamanuca dive sites Environmentally-friendly mooring buoys: what they are and where they are needed in the Mamanucas
3	Introduction to Reef Check as a survey methodology Teaching methods and indicator species Vision for the Reef Check network in the Mamanucas
4	Recap on Reef Check methods and indicator species ‘Dry run’ practice Reef Check survey Choosing permanent sites for dive operators to monitor.

Figure 11. Dive Operators undertaking tuition in marine life identification as part of the Mamanuca Dive Operators Reefcheck Network.

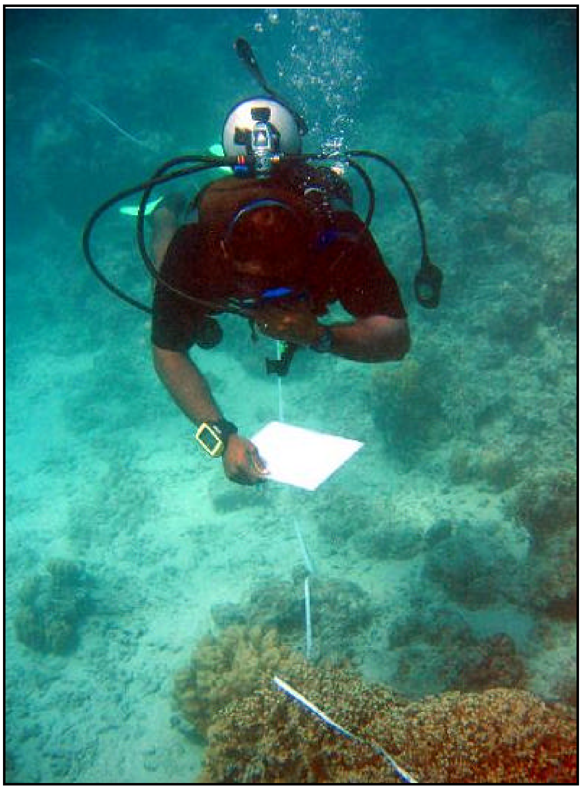

Figure 12. Dive industry employee gaining value practical experience in coral reef monitoring protocols as part of the Dive Operators Reefcheck Network

Participants in the workshops included staff from 12 of the Dive Operators working in the Mamanuca region: Aquacadabra, Sonaisali Diving, Plantation Resort Diving, Subsurface Beachcomber, Subsurface Musket Cove, Aqua-Trek Nadi, Aqua-Trek Matamanoa, Aqua-Trek Mana, Castaway Diving, Inner Space Adventures, AquaBlue Fiji, Wahoo Watersports and a local independent interested in protecting the Mamanuca reefs. By the end of the series of workshops all participants were successfully trained in Reef Check survey technique, and a total of seventy permanent Reef Check sites were agreed upon. Following the series of workshops, the agreed permanent Reef Check sites were set up with the Dive Operators. Sites were marked for future resurveying by driving stakes into the reef at the beginning and end of each transect. An initial survey was conducted as the site was set up. These sites will now be monitored annually and the data collated and analysed by MES. A feedback report can then be produced, outlining the state of the reefs in the Mamanucas.

There were several other outcomes from this series of workshops aside from the setting up of the Reef Check survey sites. There was an agreement that fish feeding would be limited to one or two reefs in the area only, and feeding would be accomplished using more 'natural' food substances such as fish rather than bread. With input from all of the Dive Operators attending the workshops, a list of the top twenty dive sites of the Mamanucas (in terms of frequency of use) was produced. It was agreed that environmentally-friendly mooring buoys would be put in at all of these sites, and also that Dive Operators would keep track of how many divers they sent to each of these sites over a month, submitting these figures to MES. From these figures, some estimate of the intensity of use these sites are subjected to can be obtained. This can then be related to the condition of the reef there, to indicate whether some of these more popular sites are becoming overused. Perhaps the most important achievement of the workshops was to bring the Dive Operators together to talk to one another, discuss environmental issues and start to think about working together to take responsibility for the reefs they use.

3.8.7 Video Presentations to Local Villages

During June and July 2004, CCC and MES presented some underwater video footage to the local communities of Solevu and Yaro on Malolo Island in conjunction with a small visiting company, Wild Action Video (WAV). WAV were visiting Fiji to film a documentary on the reefs of the Mamanuca region. As a side project while they were filming, they also put together a short video presentation showing healthy and unhealthy reefs in the area, and some of the impacts affecting the villages' own 'house' reefs.

Many of the people living in these villages had not seen their own reefs before, let alone other reefs in the area. A primary aim of the presentations was therefore merely to introduce the people of Solevu and Yaro to footage of their own reefs. Introductory information about coral and fish biology, and the importance of and threats to reefs was also imparted. A second aim of the presentations was to enable the people to see the effects that certain impacts were having on the reef (such as sedimentation, over fishing, coral breakage due to anchor damage) and to follow this up by teaching them about how to lessen these impacts and take better care of the reefs. The opportunity was also taken to introduce the concept of Marine Protected Areas as a conservation tool, and to show footage of some of the reef areas that CCC have recommended for protection as a result of their data collection so far.

Presentations were held in the evening, to ensure that as large an audience as possible from the village would attend. There was also one afternoon presentation at Malolo District School, Solevu. Turn out for the presentations was generally good, and all those who attended really enjoyed being able to see footage of their own reefs. The same presentation was also given by WAV to the Tui Lawa (chief) of the Malolo Tikina, Ratu Jeremiah Naitauniyalo.

3.8.8 Community Workshops in the Mamanucas

Following on from CCC's recommendations for the establishment of Marine Protected Areas (MPAs) in the Mamanucas, MES and CCC are conducting a series of workshops aimed at introducing the concept of MPAs as a conservation tool to the communities living within and around the Mamanucas. The aim is to reach all four villages of the Mamanucas, as well as those mainland villages that have a stake in the region (for example those that own the traditional rights to fishing grounds within the area).

So far workshops have been conducted with three mainland villages, and more are planned with the island villages for the near future. A local Fijian working for MES translated during the course of the workshop, thereby ensuring better comprehension from the participants. The workshops are held in the evening to ensure that all of the village members are able to attend.

The initial workshop content begins with an introduction to the coastal zone and the four ecosystems within it (forest, mangrove, sea grass, coral reef), as well as details of how these communities interact and depend upon one another. It then focuses in more closely on the ecology of coral reefs in particular, the biology of certain reef creatures, the importance of reef habitats, and the threats they face today. Most importantly, the workshops cover how we can protect reefs, focusing on the use of Marine Protected Areas.

The communities of Fiji have traditional rights over the fishing grounds and the reefs, and so it is of particular importance that they have access to full information about how to protect these valuable resources. Any effective decision about protection will have to come from within the community. The purpose of these workshops is to educate the village communities about the potential of using MPAs to protect their reefs, and to provide them with the recommendations of the best areas for MPA establishment, based upon the results of CCC's work in the Mamanucas.

4. RESULTS

In this report, analysis has been conducted at two levels; data on anthropogenic impact and oceanographic observations as well as fish and invertebrate population studies is analysed at the level of analysis sectors identified in Table 7 and Figure 14. This data has then been combined to examine the benthic classes or habitats throughout the whole study area, upon which calculations of biodiversity, habitat cover and conservation value have been conducted towards the identification of suitable Marine Protected Areas. The analysis of the data is schematically presented in Figure 13.

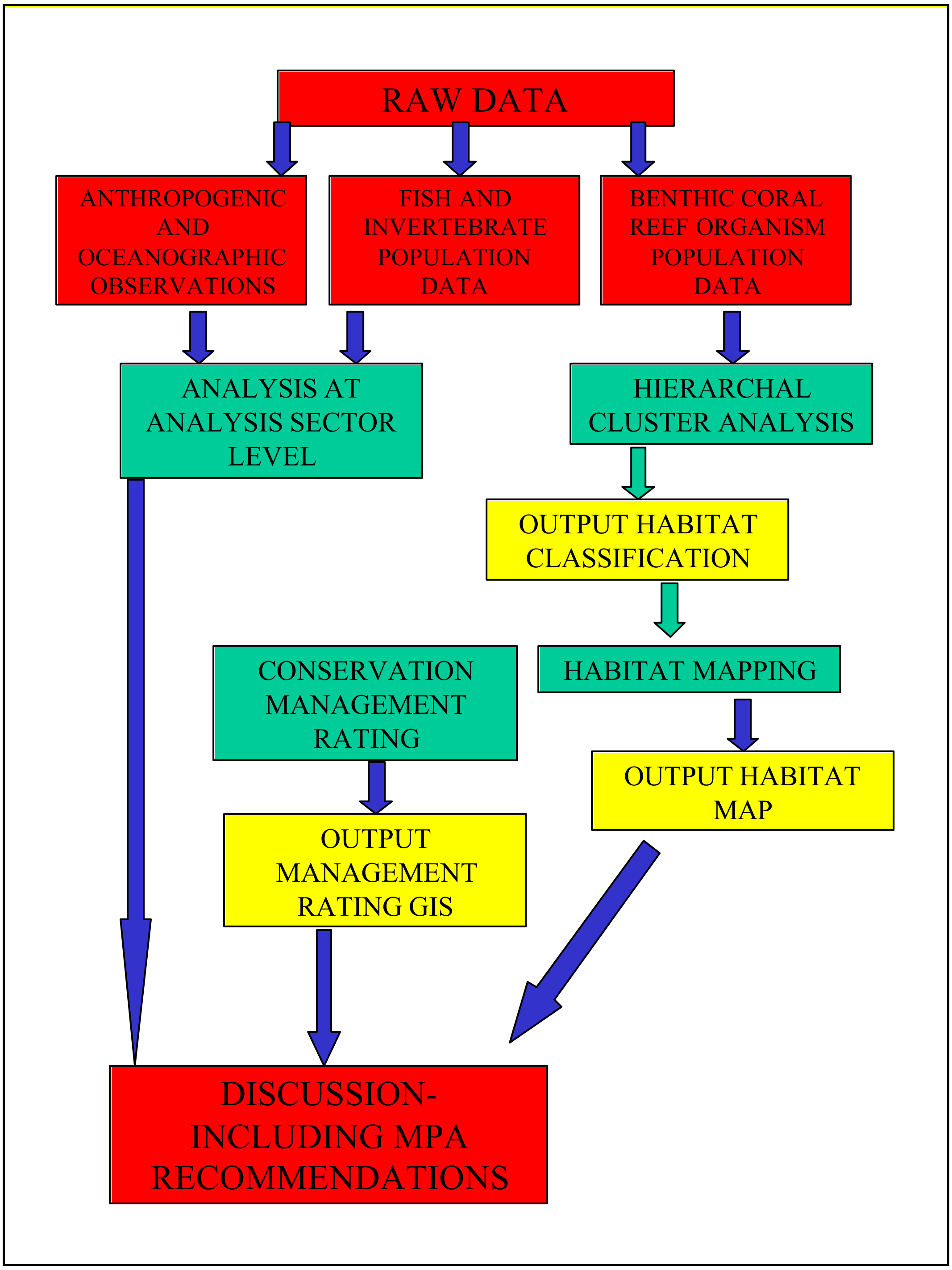

Figure 13. Schematic representation of data analysis techniques employed in this report.

Table 7. Assignment of completed survey sectors into nine analysis sectors.

Analysis Sector	Incorporated Completed Survey Sectors (and number)
Castaway Reef Complex	Castaway (17), Mothui (Honeymoon) (15), Castaway Inner Barrier (16), Yalodrivi (14), K's Patch (K)
Malolo	Malolo North (22), Malolo South (23), Malolo Patch Reef (24), Lau Reef (33)
Malolo Lailai	Malolo Lailai (25), Sunflower (34)
Mana	Mana (02), Motuse (32), Jaluk (32J)
Navini	Navini (06)
Wadigi reef complex	Wadigi Island (18), Wadigi Patch Reef (19), Lana Patch Reef (20), Nuku Reef (21)
Namoa	Namoa (07)
Bounty Reef Complex	Beachcomber (08), Treasure (09), Malamala (10), Bounty (11), Vunuvadra (12)
Malolo Outer Barrier	Outer Barrier (26) Tavarua (30)

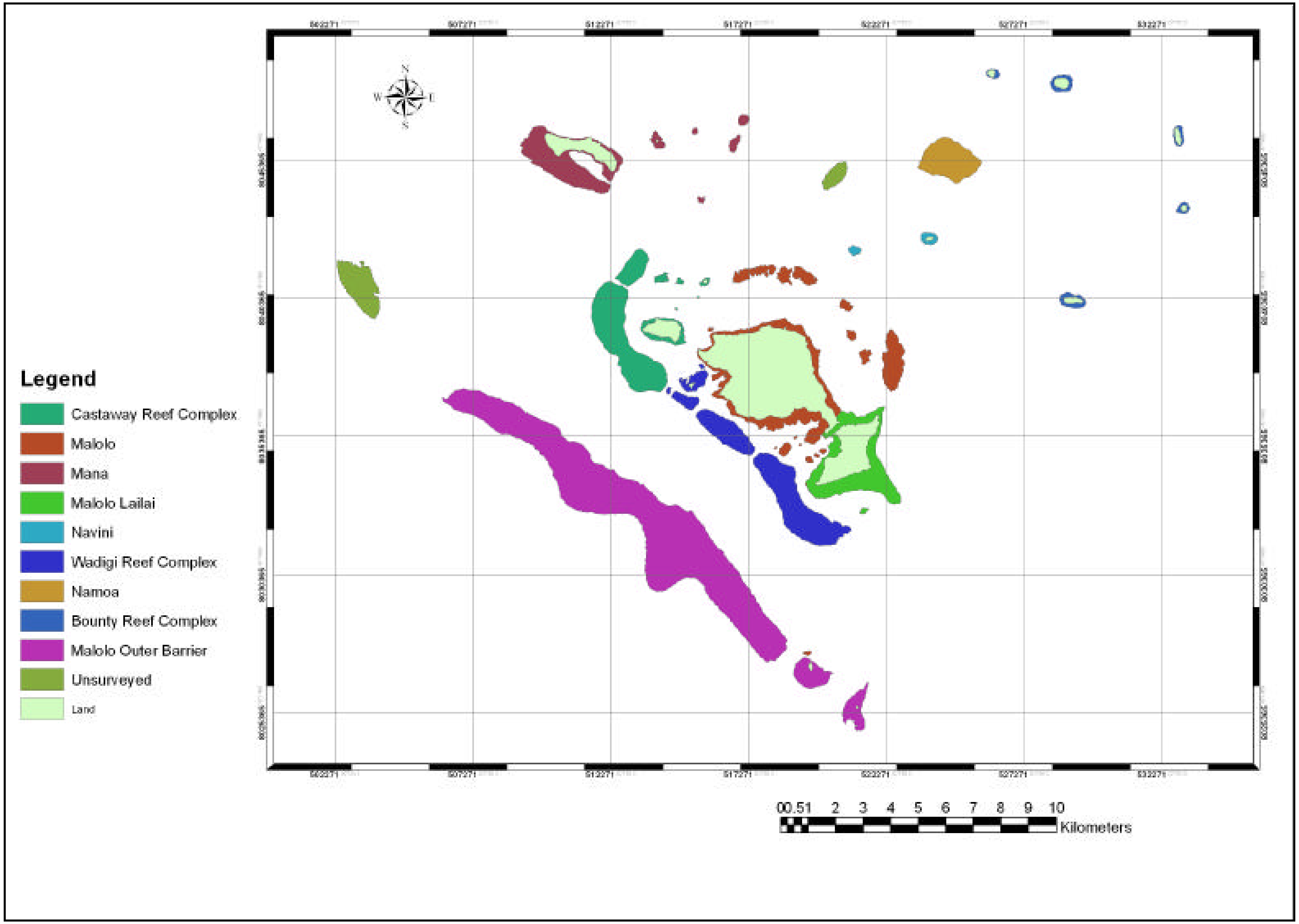

Figure 14. The nine analysis sectors of reefs and reef complexes presented in this report.

4.1 Survey Progress

Of the thirty survey sites originally outlined, twenty-seven have been completely surveyed on completion of the second year of the FCRCP (Table 8). All of the data derived from these survey sectors have been analysed and reported in this document. A chronological breakdown of the survey effort is included in Table 8. The sector numbers in the table refer to those outlined in Figure 2, Section 3.1.

Thus far a total of 1461 survey dives have been conducted along 337 transects. This equates to 900 survey team hours, and with one baseline survey team consisting of four divers; 3603 man-survey-hours. With baseline surveys collecting species abundances of approximately 300 target species and substrates, volunteers taking part in the FCRCP have made 438,300 *in situ* recordings. The start positions of all Baseline surveys conducted to data are shown in Figure 15 and a chronological breakdown of survey effort during both years one and two of the FCRCP is given in table form as Table 8.

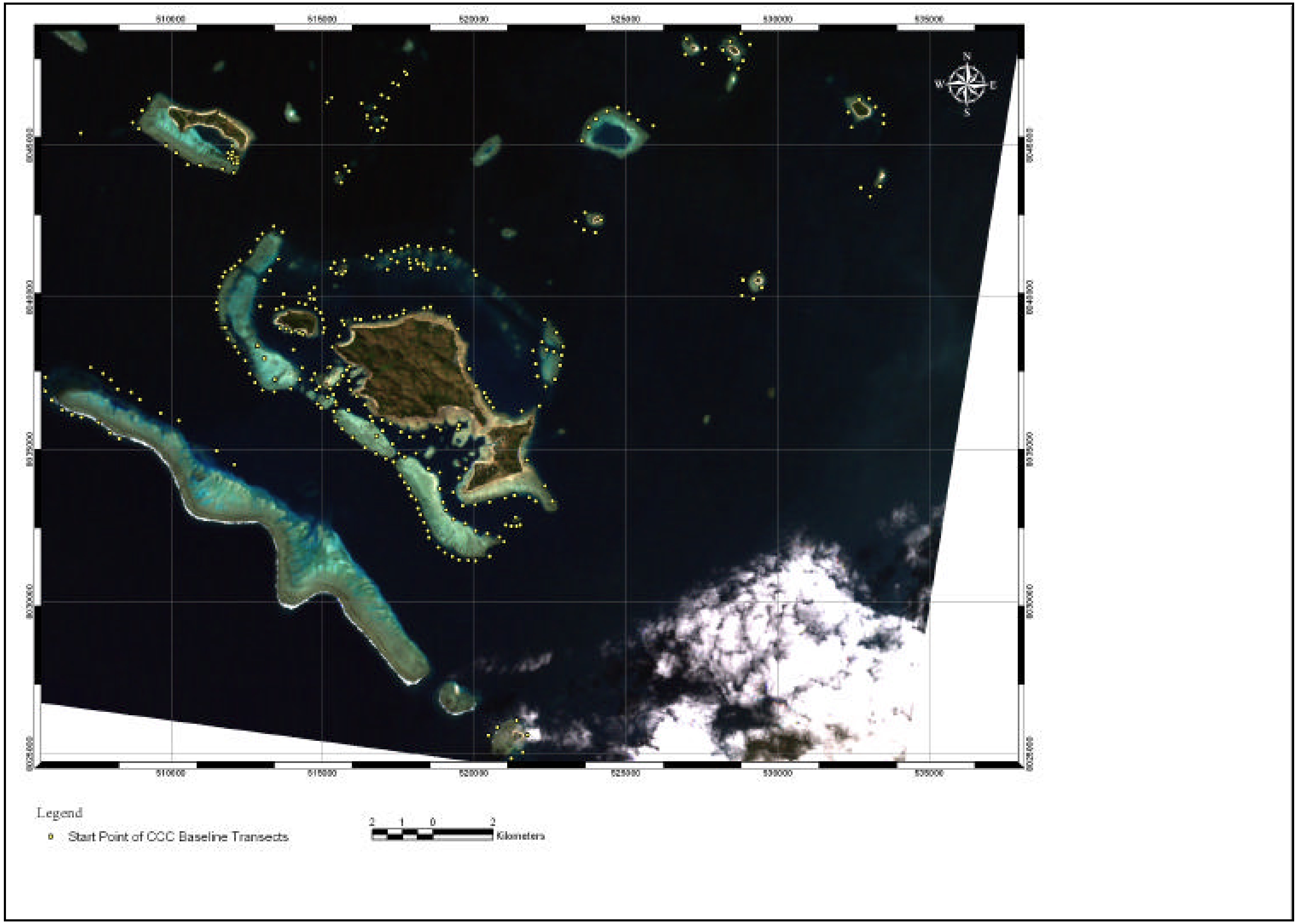

Figure 15. Start points of all Baseline survey Transects conducted by CCC during years one and two of the FCRCP.

Table 8. Chronological CCC Baseline Survey progress during years one and two of the Fiji Coral Reef Conservation Project.

Month	Sector Number	Sector Name	Transects Completed	Transect Codes
March '02	17	Castaway Island	6	1701-1706
			Total = 6	
April '02	17	Castaway Island	9	1707-1715
	22	Malolo North	15	2201-2215
	15	Mothui	1	1501
	16	Castaway Barrier	3	1601-1603
			Total = 28	
May '02	22	Malolo North	5	2216-2220
	15	Mothui	4	1502-1505
	16	Castaway Barrier	1	1607
			Total = 10	
June '02	16	Castaway Barrier	3	1608-1610
	15	Mothui	2	1506-1507
			Total = 5	
July '02	16	Castaway Barrier	8	1605, 1606, 1611-1613, 1615, 1616, 1618
	15	Mothui	2	1508-1509
			Total = 10	
August '02	16	Castaway Barrier	2	1614, 1617
	18	Wadigi Island	9	1801-1809
			Total = 11	
September '02	6	Navini	5	0601-0605
			Total = 5	
October '02	23	Malolo South	13	2301-2303, 2305-2306, 2308-2311, 2314
	15	Mothui	3	1503, 1506, 1609
			Total = 16	
November '02	19	Wadigi Patch	7	1901-1907
	23	Malolo South	1	2320
	25	Malolo Lailai	1	2501
	'K'	K's Patch	4	K01-K04
			Total = 13	
December '02	25	Malolo Lailai	13	2502-2303, 2506, 2508-2517
	23	Malolo South	7	2307, 2312-2313, 2315-2319
			Total = 20	
January '03	25	Malolo Lailai	3	2504, 2505, 2507
	14	Yalodrivi	8	1401-1408
			Total = 11	

Table 8 (cont.). Chronological CCC Baseline Survey progress during years one and two of the Fiji Coral Reef Conservation Project.

Month	Sector Number	Sector Name	Transects Completed	Transect Codes
February '03	20	Lana	12	2001-2012
	24A	Malolo Patch (A)	5	2401-2405
	24B	Malolo Patch (B)	6	24B01-24B06
			Total = 23	
March '03	24B	Malolo Patch (B)	2	24B07-24B08
	32J	Jaluk	1	32J02
	32	Motuse	1	32A01
			Total = 4	

(Second Year of the FCRCP)

April '03	30	Castaway Inner Barrier	2	1619, 1623
	21	Nuku Reef	1	2134
	30	Tavarua	2	3001, 3006
	32	Motuse	1	32A04
	32J	Jaluk	1	32J01
			Total = 7	
May '03	16	Castaway Inner Barrier	7	1620-1622, 1624-1629
	30	Tavarua	2	3003, 3005
	32	Motuse	2	32A05-32A06
			Total = 11	
June '03	10	Malamala	5	1001-1005
	12	Vunuvadra	2	1202, 1204
	32	Motuse	3	32A03, 32B02-32B04
			Total = 10	
July '03	02	Mana	2	1201, 1203
	30	Tavarua	2	3002, 3004
	32	Motuse	1	32B05
			Total = 5	
August '03	07	Namoa	1	0704
	09	Treasure	3	0901, 0904-0905
	11	Bounty	1	1101
	21	Nuku Reef	4	2101-2104
	32	Motuse	1	32B01
			Total = 10	
September '03	07	Namoa	6	0701-0703, 0705-0707
	09	Treasure	1	0902
	11	Bounty	1	1102
	21	Nuku Reef	1	2105
	32	Motuse	1	32A02, 32B06
			Total = 11	

Table 8 (cont.). Chronological CCC Baseline Survey progress during years one and two of the Fiji Coral Reef Conservation Project.

Month	Sector Number	Sector Name	Transects Completed	Transect Codes
October '03	07	Namoa	1	0708
	08	Beachcomber	4	0801-0804
	09	Treasure	3	0903, 0906-0907
	11	Bounty	5	1103-1107
	21	Nuku Reef	1	2106
	26	Outer Barrier	1	26I04
	32	Motuse	2	32B07-32B08
	33	Lau Reef	5	3301-3304, 3006
			Total = 22	
November '03	33	Lau Reef	11	3305, 3307-3308, 3320, 3313-3319
	26	Outer Barrier	1	26I05
	32	Motuse	5	32B09-32B10, 32C02-32C04
			Total = 17	
December '03	21	Nuku Reef	4	2108-2110, 2113
	33	Lau Reef	6	3309, 3311, 3312, 3321, 3323-3324
	26	Outer Barrier	2	26I02-26I03
	32	Motuse	1	32C01
			Total = 13	
January '03	21	Nuku Reef	1	2112
	33	Lau Reef	1	3320
	26	Outer Barrier	1	26I01
			Total = 3	
February '03	21	Nuku Reef	3	2114, 2116, 2124
	26	Outer Barrier	2	26I06-26I07
			Total = 5	
March '04	21	Nuku Reef	9	2111, 2115, 2117-2120, 2122, 2118, 2130
	26	Outer Barrier	1	2610
	33	Lau Reef	3	3325-3327
	34	Sunflower	4	3401-3404
	26	Outer Barrier	3	26I09-26I11
			Total = 20	
April '04	21	Nuku Reef	7	2121,2123,2125-2127, 2129, 2132
	26	Outer Barrier	2	2611-2612
	34	Sunflower	2	3405, 3406
			Total = 11	

4.2 Oceanographic, climate and anthropogenic impact data.

4.2.1 Water Temperature

Water Temperatures recorded during the second year of the FCRCP have been summarised in Figure 16. Average surface temperatures for the study area measured 28.62 °C (standard deviation 2.20 °C; n = 1451). Water temperatures collected by survey teams at the maximum survey depths were summarised in 5m depth classes (0.1-5 m, 5.1-10 m, 10.1-15 m, 15.1-20 m, 20.1-25 m, 25.1-30 m). There was some evidence of temperature variation throughout the water column, with a general decrease in temperature with increasing depth. The greatest decrease occurred between 10 m and 20 m, below which average temperatures were relatively similar throughout the remaining depth classes.

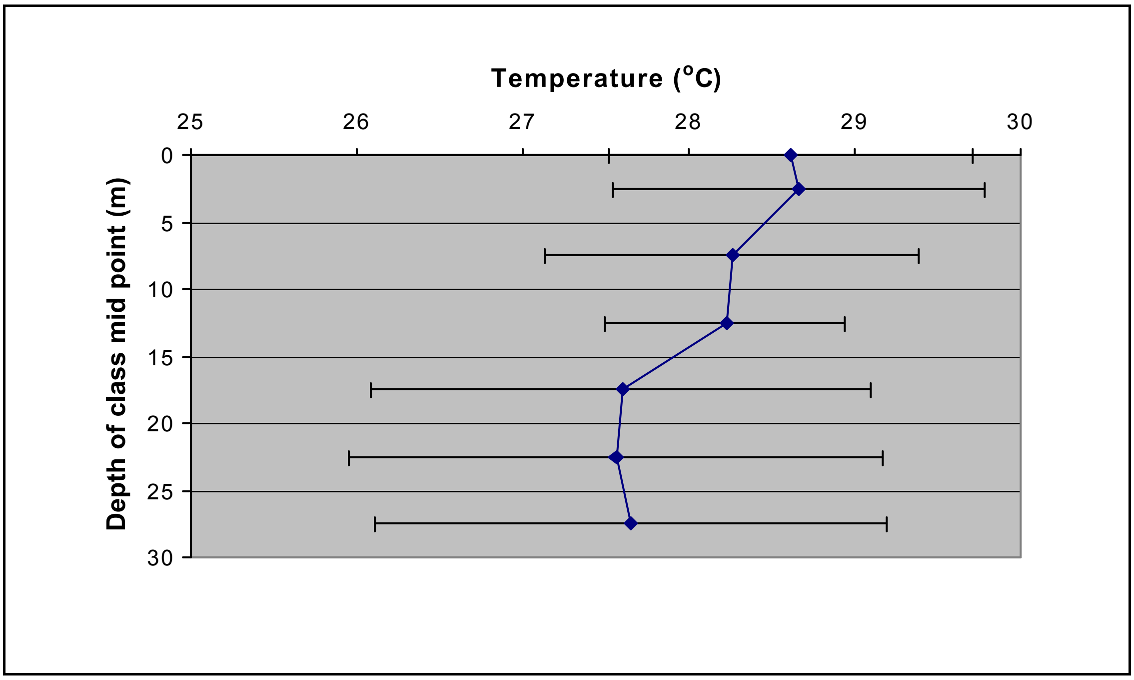

Figure 16. Mean water temperatures for all surveys in the project area in 5 m depth classes throughout the water column. Bars represent standard deviation. Sample sizes: Surface Water = 1302, 0.1-5 m = 292, 5.1-10 m = 224, 10.1-15 = 249, 15.1-20 m =270, 20.1-25 m = 211, 25.1-30 m = 131.

4.2.2 Water Salinity

Salinity measurements collected by survey teams during the second year of the FCRCP show little variation in salinity between the nine analysis sectors. Further analysis of the data revealed a degree of variation in salinity with depth, as shown in Figure 17. Salinity measurements taken vertically through the water column are summarised in 5 m depth classes (0.1-5 m; 5.1-10 m; 10.1-15 m; 15.1-20 m; 20.1-25 m and 25.1-30 m). Between 0 m and 30 m, average salinity fluctuated between 32.5‰ and 33.5‰. Below this levels exceeded 34.50‰. Variations in salinity measurements were greatest in shallower waters, the widest variation occurring within 5 m of the surface (standard deviation >2‰; n = 1582).

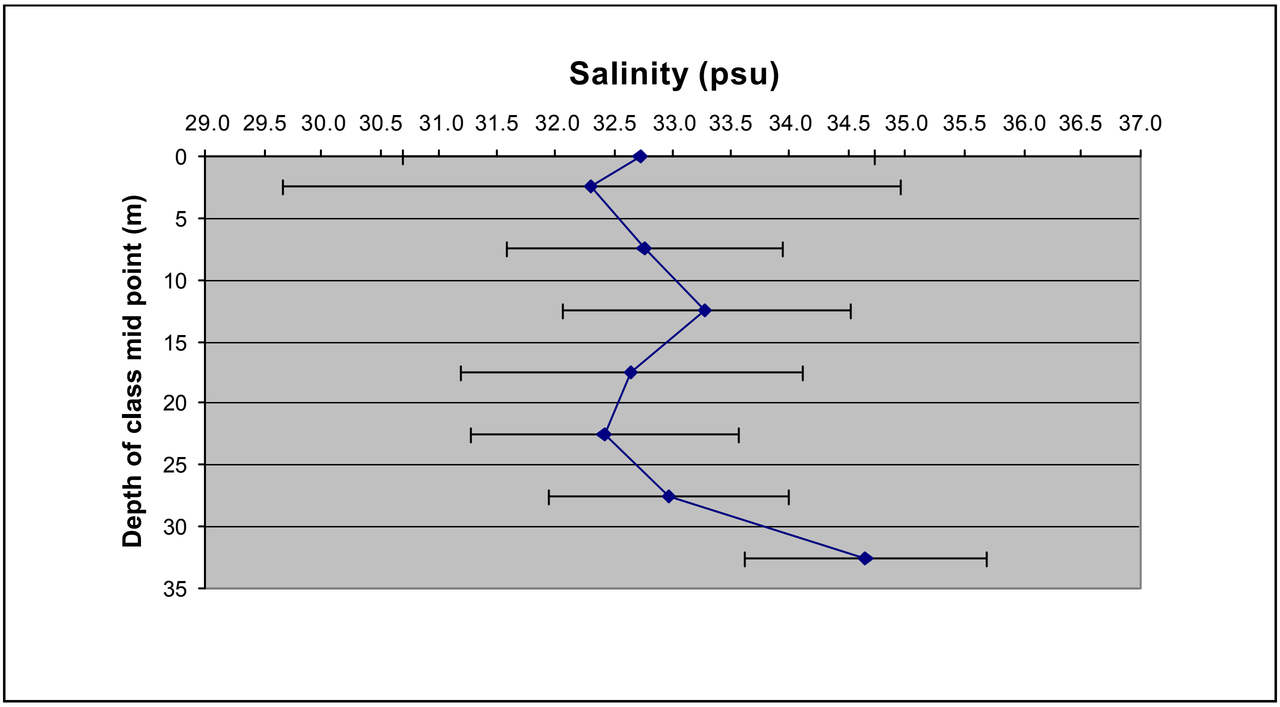

Figure 17. Mean water salinity for all surveys in the project area in 5 m depth classes throughout the water column. Bars represent standard deviations. Sample sizes: Surface Water = 1374, 0.1-5 m = 267, 5.1-10 m = 181, 10.1-15 = 222, 15.1-20 m =243, 20.1-25 m = 190, 25.1-30 m = 2.

4.2.3 Water visibility

A summary of inverse secchi disc readings of vertical underwater visibility is shown in Figure 18. Visibility varied between analysis sectors from greater than 15 m in Navini (standard deviation 3.41; n = 29) to less than 8 m at the Bounty Reef Complex (standard deviation 1.67; n = 153). Malolo, Malolo Lailai and Bounty Reef Complex had relatively low water visibility in comparison to other analysis sectors in the study area. Variations in visibility measurements within sectors were greatest for the Waidigi Reef Complex and the Outer Barrier (standard deviations varying between 1-2 m).

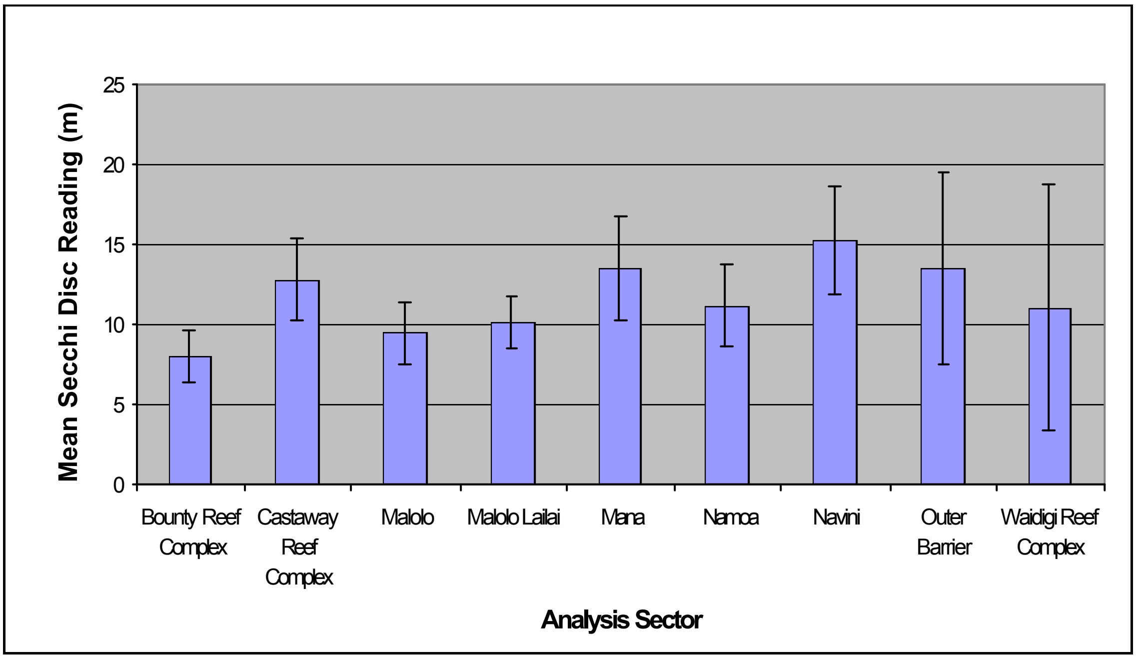

Figure 18. Mean Secchi Disc recordings of vertical water visibility in metres. Bars represent standard deviation for each analysis sector. Sample sizes: Bounty Reef Complex = 153, Castaway Reef Complex = 285, Malolo = 266, Malolo Lailai = 69, Mana = 210, Namoa = 34, Navini = 29, Outer Barrier = 187, Waidigi Reef Complex = 228.

4.2.4 Wind Strength and Direction

The direction and strength of prevailing winds during the second year of the FCRCP are presented in Figure 19. Estimates of wind were recorded on 89.6% of 1310 surveys with the remaining 10.4% experiencing calm weather (no wind). Southeasterly winds were most prevalent with 314 recordings. Wind strength was generally light, with 89.48% of the observations between 1 and 3 on the Beaufort scale.

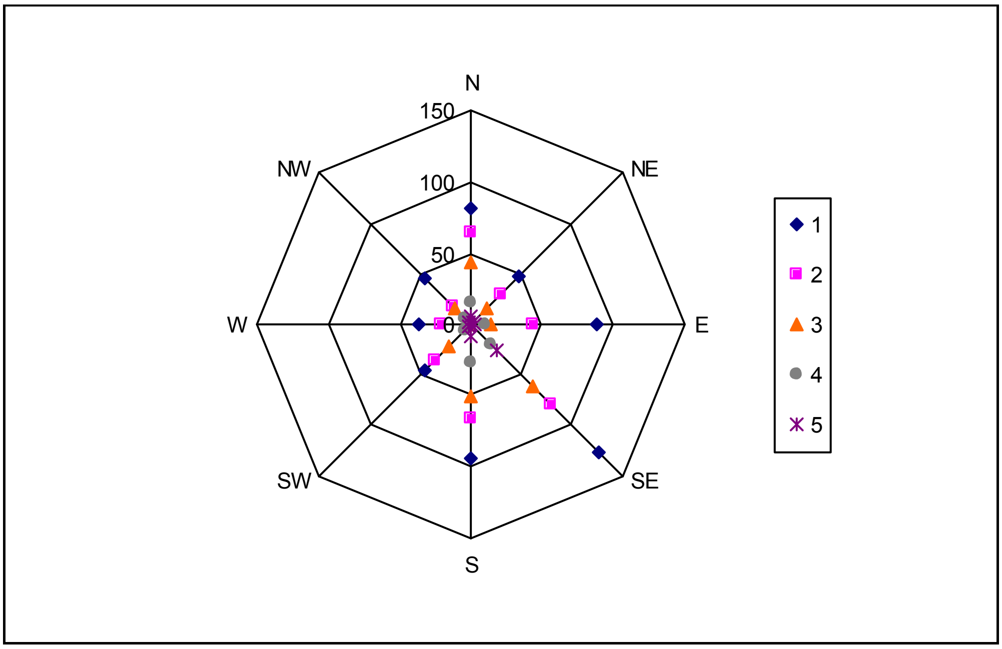

Figure 19. Radar diagram showing the prevailing winds recorded during year 2 of the FCRCP. Points represent the frequency of occurrence of combinations of wind direction and strength. Symbols represent wind strength measured using the Beaufort scale.

4.2.5 Current Strength and Direction

Recordings of current direction and strength during the second year of the FCRCP are summarised in Figure 20. Currents were observed on 60% of surveys on a scale of weak to strong. No current was observed during the remaining 40% of surveys. Current direction varied considerable during the study period with an almost equal number observed from each compass point. Generally currents were light with 71.60% of observations recorded as weak in strength. Only 4.7% of surveys observed current to be strong.

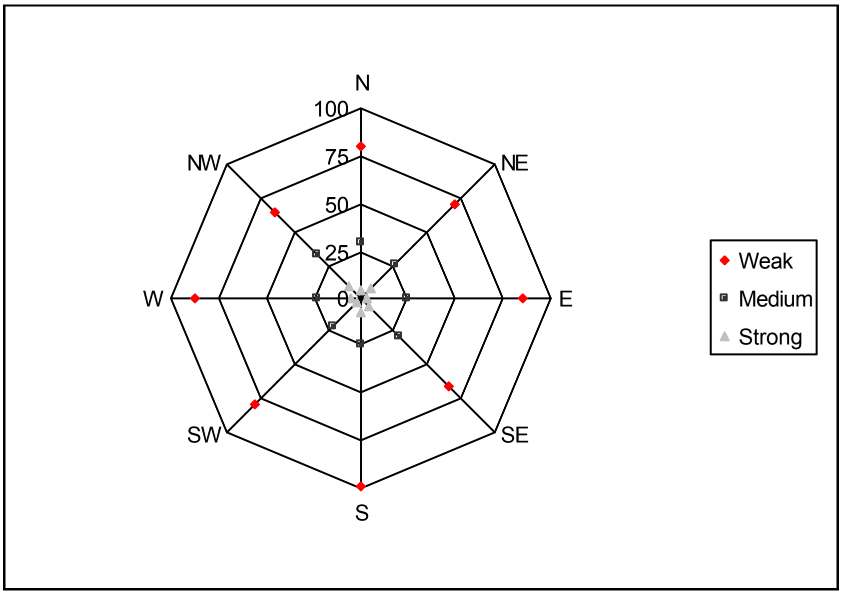

Figure 20. Radar diagram showing mean underwater current recorded in the Mamanuca Islands during year 2 of the FCRCP. Points represent the frequency of occurrence of current strengths from different directions. Symbols represent current strength on a scale of weak to strong.

4.2.6 Surface Impacts

Surface impacts for the whole survey area recorded over the second year of the FCRCP are presented in Figure 21. The most commonly recorded impact was the presence of drifting clumps of macroalgae, particularly at the Outer Barrier, Qalito (Castaway), Wadigi and Malolo Island and to a lesser extent at Bounty, Malolo Lailai, Mana and Navini. Litter and driftwood were the next most prevalent impacts being observed at the Outer Barrier, Manoa, Qalito, Wadigi and Malolo with the greatest frequency of litter (over 30%) being observed at Bounty. Most fishing nets were recorded at Malolo, Malolo Lailai and Qalito. Evidence of sewage was seen at four of the sites, a significant increase on findings from 2003, and being observed mainly at Malolo and Malolo Lailai.

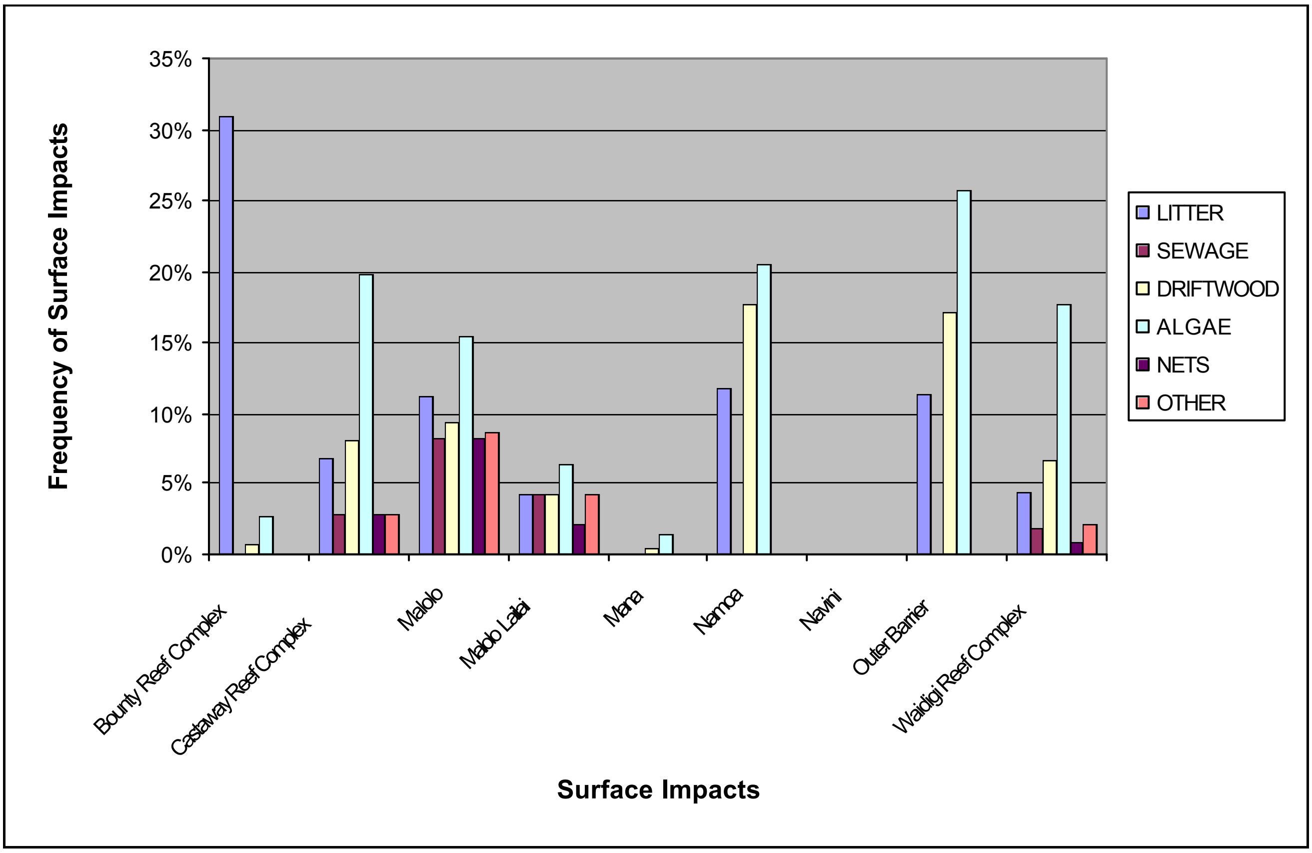

Figure 21. Frequency of observation of surface impacts recorded during year 2 of the FCRCP.

4.2.7 Sub-surface Impacts

Figure 22 shows the frequency of occurrence of sub-surface impacts for the nine analysis sectors. The most frequently observed impacts were sedimentation, coral damage, coral bleaching and litter. These four main impacts were recorded at all analysis sectors. Highest frequencies were all found at Bounty Reef Complex, Outer Barrier, Waidigi Reef Complex and Malolo for sedimentation, coral damage, coral bleaching and litter. The occurrence of lines and nets saw an increase from the previous year with recordings in excess of 5% at Malolo, Malolo Lailai, Bounty and Waidigi. Coral disease was also recorded at a higher proportion of analysis sectors approaching a frequency of 10% at Malolo and exceeding 5% at Bounty and Castaway. Sewage, fish traps, and other sub-surface impacts were low (<5%) for all reef complexes with the exception of Malolo where frequencies in excess of 5% for each of the impacts being recorded, was observed. Both dynamite and cyanide fishing impacts were recorded at Malolo, Malolo Lailai, castaway and Waidigi Reef Complex with frequencies exceeding 5% at Malolo. This result is surprising as both fishing types are not practised in the region and were not found on the pilot study in 2001 and only at low levels at Malolo during the 2003 studies.

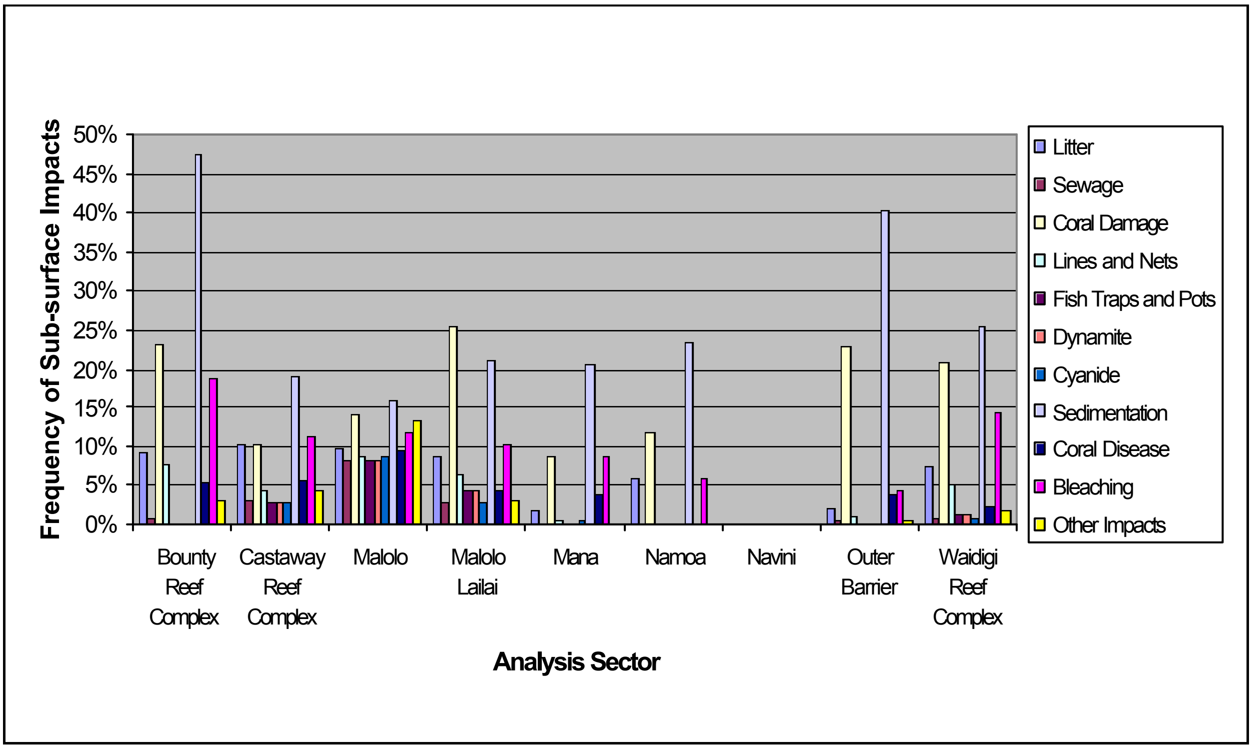

Figure 22. Frequency of observation of sub-surface impacts recorded during year two of the FCRCP.

4.2.8 Boat Frequency and Activity

A total of 775 boats were observed during 1461 surveys over the second year of the FCRCP. Mean boat activity (Figure 23) was greatest around Malolo Lailai and Bounty Reef Complex. Mean observations in all other analysis sectors were below 0.55 per dive showing a reduction over 2003 data at Castaway, Malolo and Waidigi. The vast majority of boats observed around both Malolo Lailai; Waidigi Reef Complex, Namoa and Bounty Reef Complex were related to the tourism industry, either diving or pleasure boats (Figure 24). Fishing was recorded most often at the Outer Barrier, Namoa, Castaway Reef Complex and Wadigi Reef Complex areas. Commercial boat traffic was located mostly around Malolo Island, Mana, Castaway Reef Complex and Bounty Reef Complex. The analysis sectors affected least by tourism activity were Malolo, Mana and Castaway Reef complex.

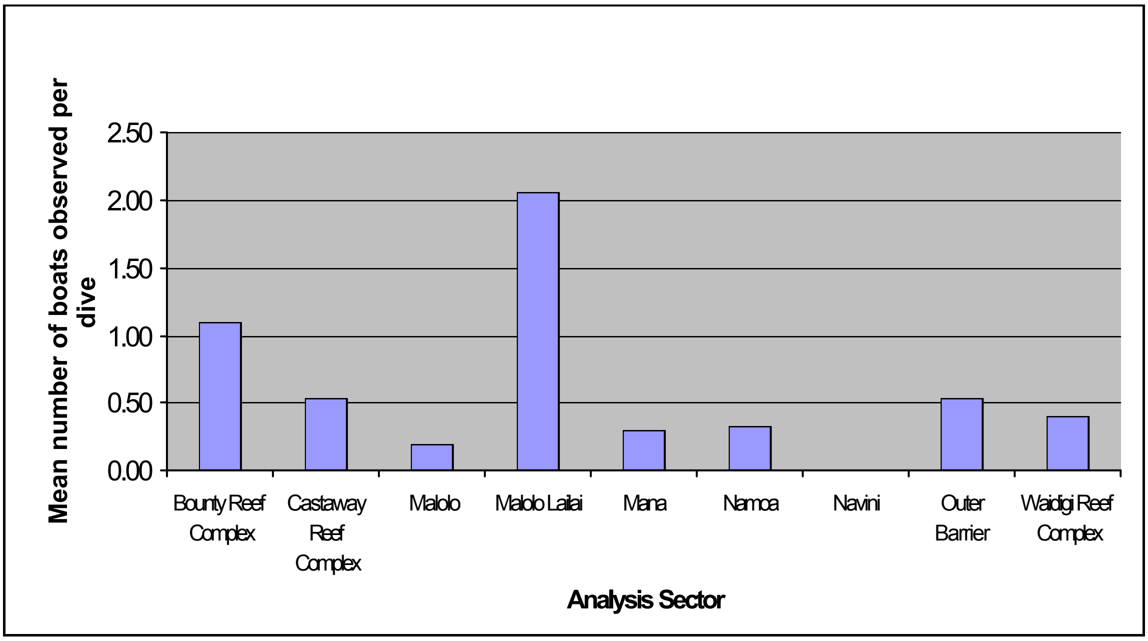

Figure 23. Mean number of boats observed per survey dive during year 2 of the FCRCP. Sample sizes: Bounty Reef Complex = 153, Castaway Reef Complex = 285, Malolo = 266, Malolo Lailai = 69, Mana = 210, Namoa = 34, Navini = 29, Outer Barrier = 187, Waidigi Reef Complex = 228.

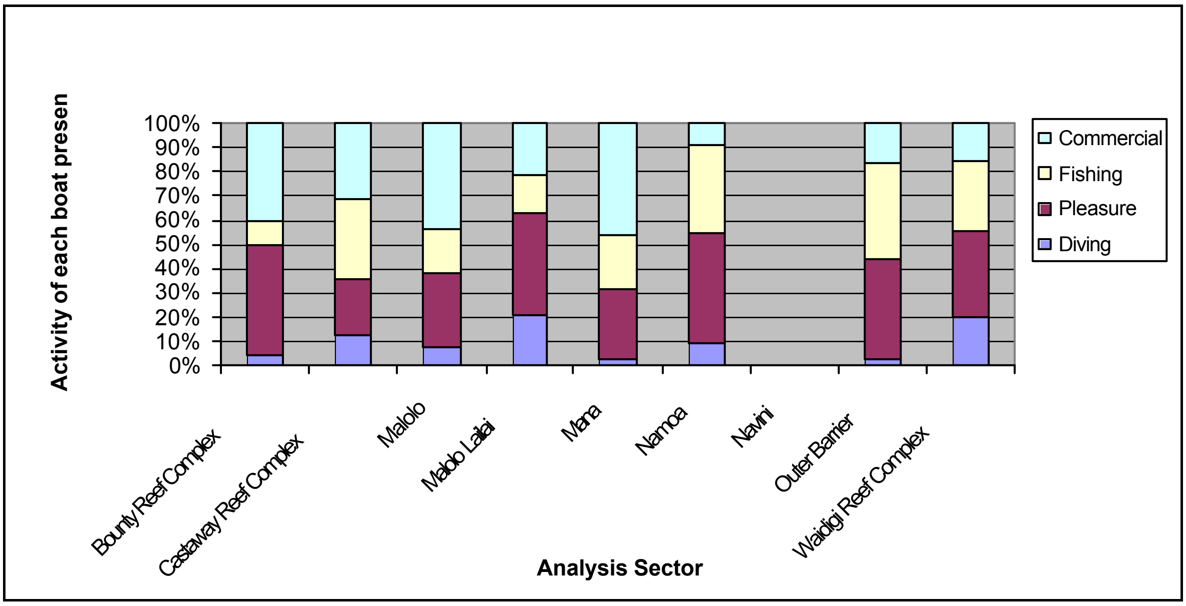

Figure 24. Summary of boat activities observed in each analysis sector during year 2 of the FCRCP. Sample sizes: Bounty Reef Complex = 153, Castaway Reef Complex = 285, Malolo = 266, Malolo Lailai = 69, Mana = 210, Namoa = 34, Navini = 29, Outer Barrier = 187, Waidigi Reef Complex = 228.

4.2.9 Aesthetic and Biological Impressions

A summary of aesthetic and biological ratings across all habitat types in each reef area is shown in Figure 25. Aesthetic values were assigned depending on, for example, interesting reef topography, and biological values reflected the abundance and diversity of the fauna and flora. Whilst the overall impressions of divers following diving a site are, by their nature, subjective, this information does provide a gross indicator of the condition of sites. Both ratings were assigned by divers using a scale from 0 (poor) to 5 (excellent). The sites that recorded the lowest biological diversity (nearly 40% 'poor'), Waidigi Reef Complex, Castaway Reef Complex and Malolo Lailai, also recorded the poorest aesthetic values, almost 80% 'poor' or 'average' ratings. Malolo Lailai was the least appreciated Analysis Sector with over 80% of ratings in both Biological and Aesthetic being 'poor' or 'average'. The analysis sectors that showed the highest percentage of 'good' and better (50% or more) ratings are Malolo, Mana, Namoa and Navini, with Malolo receiving approximately 30% 'excellent' ratings. It is interesting to note that the ratings for aesthetic value closely shadow those of biological diversity whereby increased biological diversity leads to increased aesthetic appeal.

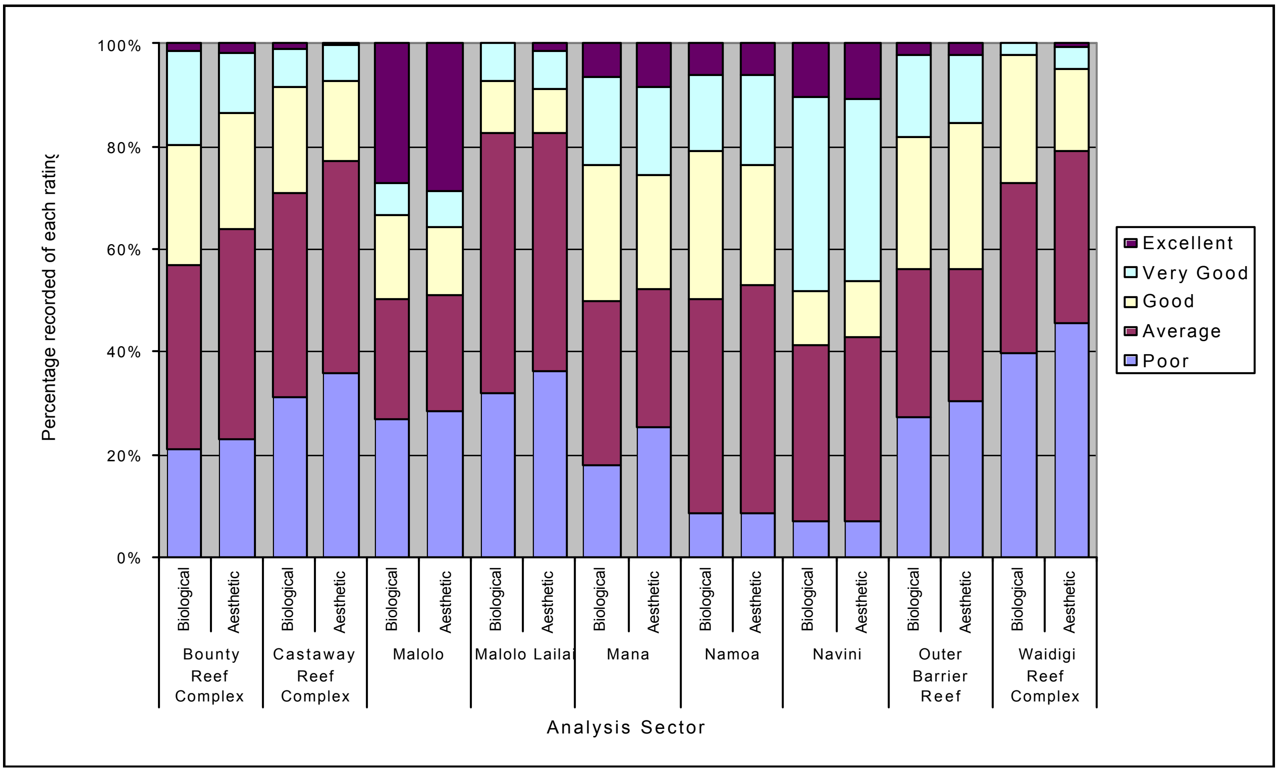

Figure 25. Summary of aesthetic and biological ratings in each analysis area. Ratings assigned from a scale 0-5 where 0 is poor and 5 is excellent. Sample sizes: Bounty Reef Complex = 153, Castaway Reef Complex = 285, Malolo = 266, Malolo Lailai = 69, Mana = 210, Namoa = 34, Navini = 29, Outer Barrier Reef = 187, Waidigi Reef Complex = 228

4.3 Multivariate analysis and benthic habitat definitions

A total of fifteen discreet Benthic Classes or habitat types have been identified using the procedure of agglomerative hierarchal clustering using the data collected in the first year of the FCRCP and then comparing the data collected during the second year of the program with these habitats using discriminant analysis.
The dendrogram produced from the process of hierarchal cluster analysis is shown as Figure 26.
The habitat types are quantitatively described below in Table 9. A breakdown of the main biological and substratum classes that characterise each of these benthic habitats is given.

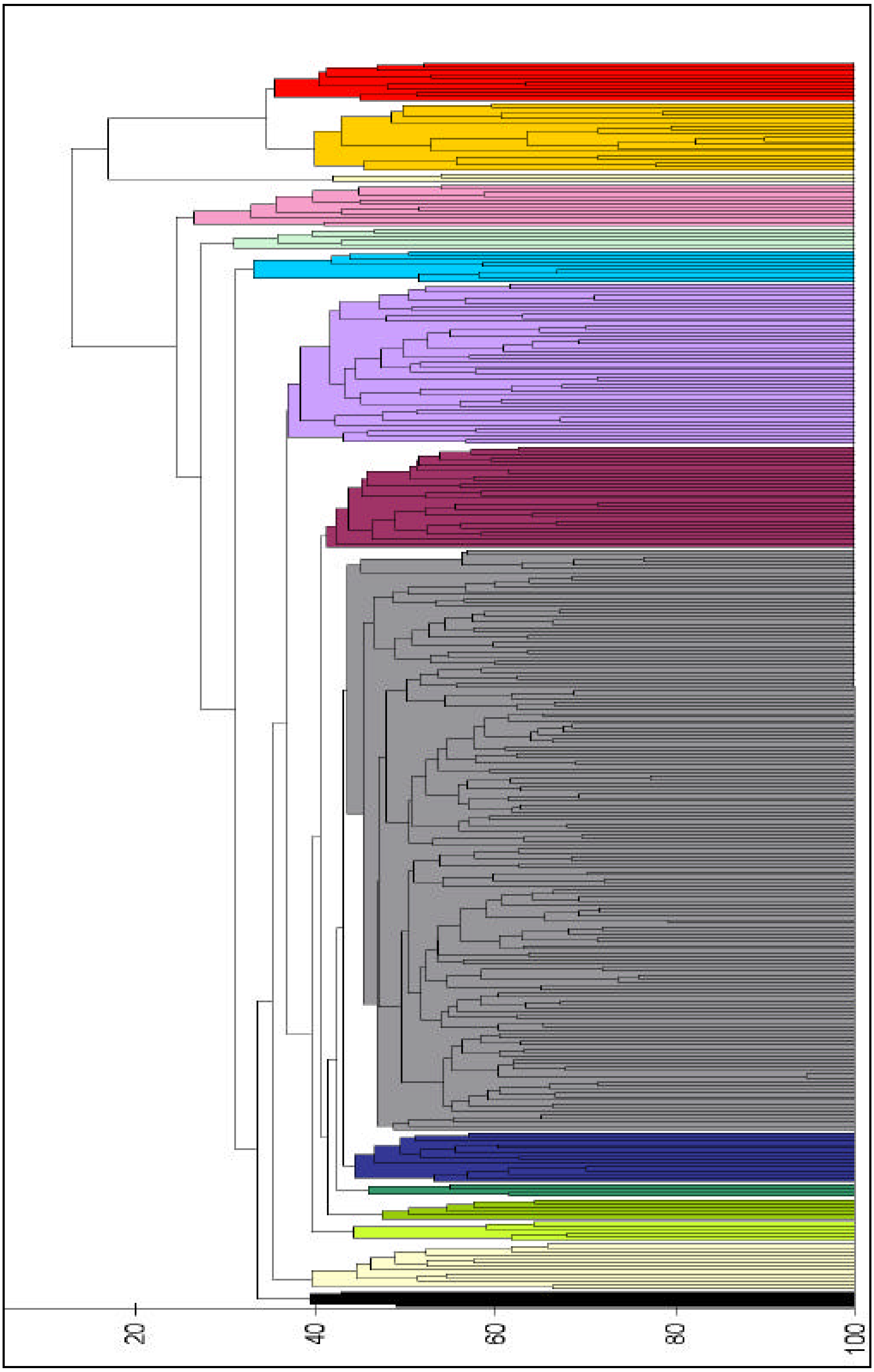

Figure 26. Dendrogram produced from cluster analysis of a sub sample of CCC baseline survey data collected in year one of the FCRCP. Each line represents benthic and substratum data from each Site Record. The different colours highlight the major clusters representing the benthic classes discriminated. Horizontal axis represents similarity as calculated with the Bray- Curtis coefficient (%). Year two data was then compared against the Benthic Classes identified to produce a comprehensive set of habitat types found in the Mamanuca Islands.

Table 9. Quantitative description of the fifteen benthic classes defined from the data collected in years one and two of the FCRCP. Figures in parenthesis indicate mean observational abundances from the DAFOR (0-5) semi-quantitative scale as used during CCC Baseline surveys

Habitat	# Surveys	Average depth	Substratum	Hard Corals	Octocorals	Invertebrates	Sponges	Algae/ Seagrass
1- Sheltered upper reef slope supporting stress tolerant massive corals	33	7.2	Sand (2.1), Dead coral with algae (1.5)	LHC (2.1), Acropora branching (2.0), Porites massive (1.6)	Total cover (1.6), Sarcophyton sp. (0.9), Sinularia (0.5)	Black corals (1.6), Feather star (1.2)	Total cover (1.6), Lumpy (1.2)	Cover green algae (1.4), Green calcareous algae (1.0), Halimeda (0.6)
2- Macroalgae dominated shallow back reef area of bedrock and sand	48	3.3	Sand (2.8), Bedrock (2.2)	LHC (1.6), Acropora branching (1.2), Porites massive (0.8)	Total cover (0.5), Sarcophyton (0.4), Sinularia (0.2)	Linckia laevigata (1.1), Synaptid sea cucumber (0.8)	Total cover (0.8), Lumpy (0.5), Encrusting (0.3)	Sargassum (3.3), Brown filamentous algae (2.2)
3- Lower reef slope community on sand with a hard coral community dominated by foliose corals	18	19.1	Sand (2.3), Dead coral with algae (0.8)	LHC (3.0), Acropora branching (2.5), Mycedium elephantotus (1.2), Pachyseris speciosa (1.2)	Total cover (1.5), Xenia sp. (1.3)	Feather star (1.5), Black coral (1.3)	Total cover (1.3), Lumpy (1.2)	Green algae (1.9), Green filamentous algae (1.7), Brown filamentous algae (1.5)
4- Lower reef slope with significant bare bedrock, a diffuse coral community and frequent black coral	21	17.6	Bedrock (2.1), Sand (1.5)	LHC (2.3), Favites (1.5), Mycedium elephantotus (1.2), Favia (1.0),	Total cover (2.3), Sarcophyton (1.5), Dendronepthya (1.3), Gorgonaicea (1.3)	Black coral (3.2), Feather star (1.8)	Total cover (2.7), Lumpy (2.3), Branching (1.7)	Red coralline algae (2.2), Green calcified algae (2.0), Halimeda (1.8)
5- Shallow upper reef slope areas of predominately sand and rubble substrate with low coral and high macroalgae cover	36	6.7	Sand (3.0), Rubble (1.3)	LHC (1.5), Acropora branching (1.3), bottlebrush Acropora (1.3), Porites massive (1.3),	Total cover (1.5), Sarcophyton (1.0), Sinularia (1.0)	Basket star (1.3), Diadema urchin (1.0),	Total cover (1.5), Lumpy (1.5), Branching)-.2)	Brown filamentous algae (2.5), Green algae (1.8), Blue green algae (1.8)
6- Shallow upper reef slope community with a significant presence of rubble and opportunistic Acroporid corals	100	5.3	Rubble (1.5), Sand (1.5), Bedrock (1.2),	LHC (2.6), Non-Acropora submassive (1.6), Acropora branching (1.4), Porites rus (1.9), Diploastrea heliopora (1.1)	Total cover (1.1), Sinularia (0.8), Sarcophyton (0.6)	Linckia laevigata (1.7), Feather star (1.7)	Total cover (1.2), Lumpy (1.2)	Green algae (1.4), Green calcareous algae (1.0), Brown filamentous algae (1.0)
7- Shallow upper reef slope with frequent hard coral cover, mainly branching Acropora. Occasional soft corals and sponges also present	705	9.6	Sand (2.5), Dead coral with algae (1.6), Rubble (1.2)	Total cover (2.6), Acropora branching (2.0), Non-Acropora encrusting (1.5), Massive Porites (1.2), Favites (1.1),	Total cover (1.8), Sinularia (1.0), Xenia (0.9)	Feather star (1.3), Black coral (0.7), Hydroid (0.7)	Total cover (1.7), Lumpy (1.5), Encrusting (0.8)	Green algae (1.7), Green calcareous algae (1.5), Halimeda (1.2), Tydemania (1.2)
8 Lower reef slope dominated by sand and rubble with occasional hard coral and sponges	167	17.1	Sand (2.5), Rubble (1.8), Dead coral with algae (1.5)	Total cover (1.7), Acropora branching (1.3), Acropora encrusting (0.9), Favites (0.6),	Total cover (1.3), Sinularia (0.6), Dendronepthya (0.5)	Black coral (0.7), Hydroid (0.4)	Total cover (1.7), Lumpy (1.6), Encrusting (0.7)	Blue green algae (1.3), Red/ brown branching algae (0.9), Red coralline algae (0.6)

Table 9 (cont.). Quantitative description of the fifteen benthic classes defined from the data collected in years one and two of the FCRCP. Figures in parenthesis indicate mean observational abundances from the DAFOR (0-5) semi-quantitative scale as used during CCC Baseline surveys

Habitat	# Surveys	Average depth	Substratum	Hard Corals	Octocorals	Invertebrates	Sponges	Algae/ Seagrass
9 Sand dominated lower reef slope with sparse coral cover but frequent calcified green algae	340	14.6	Sand (3.5), Rubble (0.9)	Total cover (1.6), Non-Acropora Encrusting (1.0), Favites (0.7), Seriatopora hystrix (0.3)	Total cover (1.3), Sinularia (0.6), Xenia (0.5)	Feather star (0.8), Black coral (0.6)	Total cover (1.6), Lumpy (1.3), Encrusting (0.7)	Green calcified algae (2.1), Green algae (1.5), Halimeda (1.6), Brown filamentous algae (1.3)
10 Lower reef slope with frequent coral cover dominated by encrusting and massive corals and soft corals	58	9.8	Sand (1.7), Dead coral with algae (1.2)	Total cover (2.3), Acropora branching (2.0), Non-Acropora encrusting (1.7), Favites (1.0), Diploastrea heliopora (0.9)	Total cover (1.6), Sinularia (1.3), Xenia (0.8)	Hydroid (1.3), Synaptid sea cucumber (0.6), Bryozoan (0.6)	Total cover (1.8), Lumpy (1.8)	Red coralline algae (1.6), Green algae (0.9), Green filamentous algae (0.9)
11 Lower reef slope of sand and mud with sparse hard coral cover dominated by branching Acropora	42	11.2	Sand (3.3), Mud (2.2)	Total cover (1.5), Acropora branching (1.2), Non-Acropora encrusting (0.8), Favites (1.0), Brain- small (0.5)	Total cover (0.5), Dendronepthya (0.3), Sinularia (0.2), Xenia (0.2)	Tunicates (0.5), Hydroid (0.5), Anemone (0.3)	Total cover (0.3), Lumpy (0.3)	Green algae (0.8), Seagrass (0.5), Red brown branching algae (0.5), Coralline algae (0.5)
12 Mid reef slope with sand and rubble. Sparse hard coral cover and mixed green algal assemblage	132	8.2	Sand (2.8), Rubble (1.9), Dead coral with algae (0.8)	Total cover (1.6), Non-Acropora encrusting (0.5), Acropora digitate (0.3), Acropora branching (0.3)	Total cover (0.7), Sinularia (0.3), Xenia (0.3)	Cone shell (0.2), Linckia laevigata (0.2), Feather star (0.2)	Total cover (0.5), Tube (0.2), Encrusting (0.2)	Green algae (2.3), Caulerpa (1.3), Brown filamentous (1.0), Green calcified algae (1.4)
13 Lower reef slope dominated by rubble and mud with sparse coral cover and red coralline algae	13	23.2	Rubble (2.3), Mud (1.7), Dead coral with algae (1.3)	Total cover (2.0), Acropora branching (1.3), Acropora digitate (1.3)	Total cover (1.3), Sinularia (1.3)	Nudibranch (0.7), Short spined urchin (0.7)	Total cover (0.7), Encrusting (0.7)	Red coralline algae (1.7), Green algae (1.7), Green calcified algae (1.7)
14 Largely bare lower reef slope substrates of sand and mud	352	16.2	Sand (3.1), Mud (1.8)	Total cover (0.6), Diploastrea heliopora (0.5), Porites massive (0.3)	Total cover (0.4), Sinularia (0.3)	Feather star (0.1)	Total cover (0.4), Lumpy (0.2), Barrel (0.1)	Blue green algae (0.7), Green algae (0.6), Green filamentous (0.4)
15 Mid reef slope dominated by sand with mixed disparate hard coral cover and filamentous algae	81	8.9	Sand (3.5), Dead coral with algae (0.8)	Total cover (1.4), Non-Acropora branching (0.6), Non-Acropora massive (0.6), Seriatopora hystrix (0.6), Pocillopora small (0.5), Favites (0.5)	Total cover (1.0), Sinularia (0.5), Sarcophyton (0.5)	Feather star (0.5), Synaptid sea cucumber (0.4)	Sponge (0.9), Lumpy (0.7)	Blue green algae (1.8), Green algae (1.4)

4.4 Biodiversity and Ecosystem Function of Benthic Habitat Classes

A number of univariate statistics can be used to represent the biodiversity, ecosystem function and productivity of the benthic habitat classes described from the data. The statistics presented here include the mean cover of live hard coral on the 0-5 DAFOR abundance rating, the total number of species of benthic organisms found and Marglef and $\log_e$ Shannon-Weiner diversity indices. The calculated values are presented in Table 10.

Table 10. Univariate biodiversity and ecosystem function statistics calculated for each benthic habitat class described from data collected during years one and two of the FCRCP

Habitat	Live hard coral cover	Total species	Marglef diversity index	Log_e Shannon-Weiner diversity
1	2.1	118	36.05	4.13
2	1.6	115	29.83	4.12
3	3.0	95	34.69	4.15
4	2.3	106	37.19	4.21
5	1.5	121	25.05	4.32
6	2.6	132	39.94	4.58
7	2.6	150	42.81	4.61
8	1.7	130	34.19	4.27
9	1.6	138	29.05	4.31
10	2.3	118	41.17	4.52
11	1.5	115	39.54	4.21
12	1.6	131	29.98	4.27
13	2.0	100	26.21	4.30
14	0.6	127	24.67	4.32
15	1.4	124	32.60	4.32

The three most diverse habitats classes described include habitats 6, 7 and 10. All of these three habitats have high live hard coral cover, with habitats 6 and 7 being found associated with the extreme upper reef slope. Habitat 10 by contrast is a mid- to low-reef slope habitat on bedrock that supports a diverse coral community.

4.5 Reef Fish Populations

Fish population data collected during baseline surveys in the FCRCP have been analysed in a number of ways. The data is presented firstly in a general format showing the:

- Most abundant fish recorded in all survey areas
- Mean abundance of the commonest and commercially most valuable families of fish in each of the fourteen survey sectors

Kruskal-Wallis comparisons indicate whether the variation observed between survey sectors represent significant statistical differences.

One commonly observed feature of coral reef fish assemblages is the relationship between the benthic habitat and the fish population found associated with it. This has high importance for management. Habitats with close statistical relations with fish populations should be conserved as a matter of priority, whilst seemingly excellent candidates for protection as indicated by benthic cover; but do not have a high fish assemblage association, may not be as high priority for management initiatives.

4.5.1 Fish Family and Selected Species Abundance

The ten most abundant reef fish categories found throughout the survey area are depicted in Table 11 in terms of mean abundance for all year two baseline surveys. Damselfish (Pomacentrids) were the most abundant reef fish family found during surveys conducted throughout the project area, followed by Surgeonfish (Acanthurids). A number of particular species of Damselfish were recorded most often (Table 12).

Table 11. Mean abundances of the most commonly observed fish families throughout all survey areas in year two of the FCRCP as recorded during baseline surveys. Mean abundances correspond to the semi quantitative 0-5 DAFOR scale.

Reef Fish Family		Mean Abundance
Damselfish	Pomacentrids	2.21
Surgeonfish	Acanthurids	1.49
Parrotfish	Scarids	1.39
Wrasse	Labrids	1.37
Snapper	Lutjanids	1.29
Butterfly	Chaetodontids	1.20
Angelfish	Pomacanthids	1.17
Goatfish	Mullids	1.13
Rabbitfish	Siganids	1.12
Groupers	Serranids	1.06
Triggerfish	Balistids	1.06

Table 12. Mean abundances of the most commonly observed Damselfish recorded throughout all survey areas in year two of the FCRCP as recorded during baseline surveys. Mean abundances correspond to the semi quantitative 0-5 DAFOR scale *Damselfish sp. include all non-target species of Damselfish. See appendix 1 for a list of target species of Damselfish.

Damselfish species	Mean Abundance
Damselfish sp*.	3.07
BG Chromis	2.58

The most notable point from Table 11 and Figures 27 and 28 is the general low abundance of many fish families recorded on baseline surveys. The relative abundance of fish families were similar, with most fish species recorded as more than frequent on the DAFOR scale. Of the Damselfish (Pomacentrids) which were recorded as most abundance, the two which were recorded most often all had a mean abundance of over 2. The highest abundance ratings for Damselfish were recorded at Malolo Lailai and Wadigi Reef Complex (Fig 28.). Many of the families targeted by fishers, such as Triggerfish (Balistids) and Groupers (Serranids), were very rarely seen, with abundance ratings close to 1 (Fig. 28.).

Kruskal-Wallis analysis of mean abundance between survey sectors indicates that of the fish families, only Damselfish differ significantly in their abundance (Table 13). The highest abundance of this family was observed around Malolo Lailai and Wadigi reef complex, whilst the lowest was recorded around the Navini analysis area. This corresponds closely with the coverage of hard corals and the abundance of bare hard substrata within these survey areas. Despite the lack of significance in all other fish populations, it should be remembered that the Kruskal-Wallis test is not a particularly powerful statistical test and that there may be more subtle differences that are not being displayed by this test. The overall low abundance of many families can also make statistical comparison difficult.

Table 13. Results of Kruskal-Wallis test comparing the abundance of major fish families between survey sectors. Degrees of freedom=8 for all tests. Results shown in bold indicate significance.

Fish Family	Kruskal-Wallis statistic (H)	P-value (adjusted for ties)
Chaetodontids	7.5	0.49
Pomacanthids	**12.1**	**0.03***
Acanthurids	7.7	0.47
Labrids	8.0	0.43
Bailistids	5.2	0.53
Serranids	7.9	0.42
Scarids	6.1	0.91
Lutjanids	2.5	1.00
Siganids	6.1	0.91

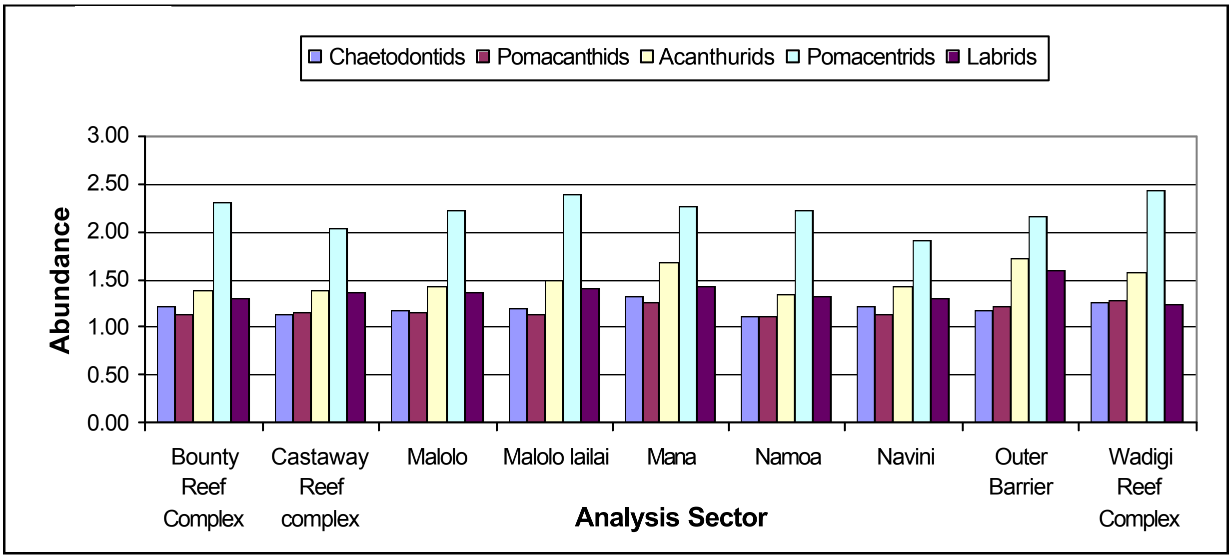

Figure 27. Mean abundance of commonly observed fish families by Survey Sector. Mean abundance refers to the values recorded on the 0-5 DAFOR semi quantitative abundance scale.

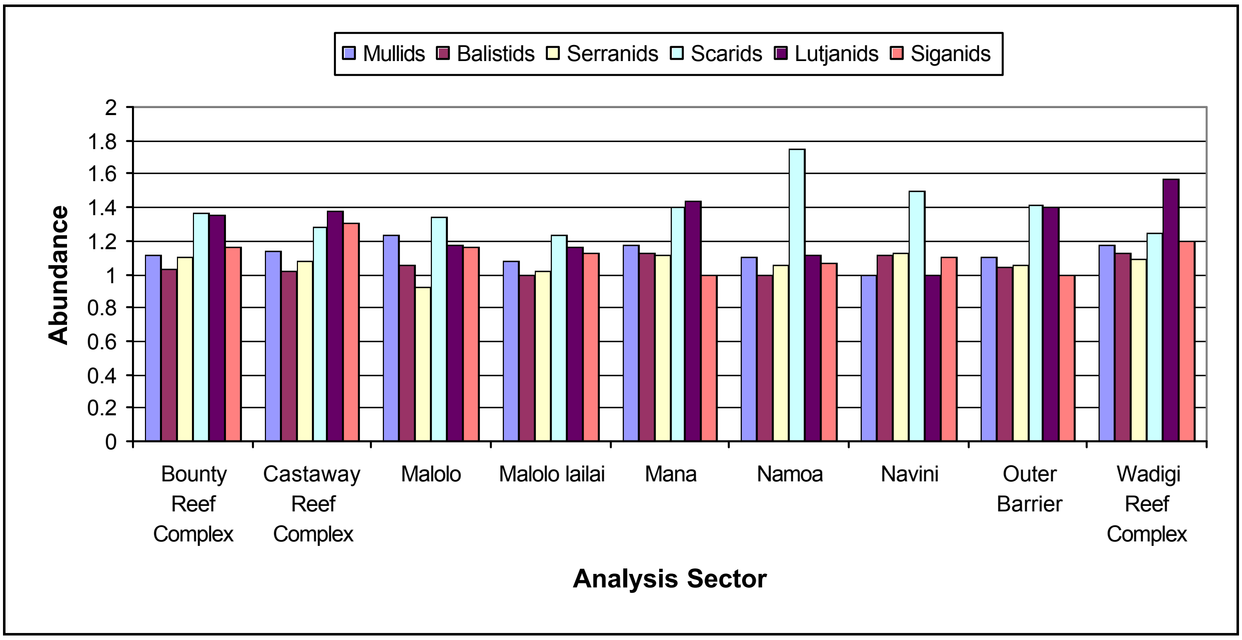

Figure 28. Mean abundance of commercially important fish families by Survey Sector. Mean abundance refers to the values recorded on the 0-5 DAFOR semi quantitative abundance scale.

4.5.2 Fish Assemblage Variation Between Analysis Sectors

Comparison between the fish assemblages found in the different analysis sectors indicates that there is highly significant difference overall (Global R0.6, p-value <0.01). More detailed analysis examining pairwise relationships between the fish assemblages found with each survey sector indicates that there is a significant difference between the assemblages found in all sectors.

4.5.3 Fish Assemblage Variation Between Habitats

ANOSIM analysis shows any significance in the fish assemblages found associated with different habitats. This is represented by the Global R and associated P-values in the following sections. More detailed pairwise analysis then indicates if there is a statistical difference in the fish assemblages found associated with each habitat individually. The results of this test are summarised in Table 14- in the following section.

ANOSIM analysis examining the overall difference in fish assemblage structure across all habitats defined within the Castaway reef complex analysis sector indicates that there is a highly significant difference in fish assemblages (Global R statistic= 0.41, P-value= <0.01).

The fish assemblages associated with habitats 6 and 7 are statistically different from the greatest number of assemblages found associated with other habitats. A comparison of biodiversity indices for the benthic identified in the Mamanuca region clearly shows that BC 7 (reef crest) is the richest habitat in terms of reef fish (Table 15). The number of fish species recorded in BC 7 was almost 25% greater than the next richest habitat (BC 15).

Table 14 Univariate biodiversity indices calculated for fish assemblages associated with each habitat defined from data collected years one and two of the FCRCP. The three most biodiverse habitats in terms of the fish assemblages associated with them are shown in bold.

Benthic Class	Species Number	Marglef Richness (d)	Pielous Eveness (J')	Log_e Shannon-Weiner (H')
1	118	16.5	0.86	4.11
2	103	18.1	0.83	3.82
3	86	11.1	0.87	3.90
4	91	17.4	0.88	3.95
5	109	15.3	0.86	4.02
6	**133**	**25.1**	**0.83**	**4.05**
7	**193**	**45.1**	**0.78**	**4.10**
8	149	30.2	0.81	4.04
9	152	34.1	0.81	4.05
10	**128**	**17.9**	**0.85**	**4.14**
11	116	13.1	0.85	4.05
12	131	10.7	0.83	4.05
14	80	15.2	0.89	3.90
15	154	16.8	0.79	4.00

Table 15. Results of pairwise analysis on the fish assemblages found associated with each habitat defined during analysis of data collected during year two of the FCRCP. Number in normal font represents R-statistic; figure in bold represents P-value. P-values marked with an asterisk indicate significant results. Note that 85 samples had to be removed as they contained a zero abundance of fish.

BC	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2	0.4 **0.004***													
3	0.3, **0.01***	0.4, **0.002***												
4	0.3, **0.024***	0.3 **0.008***	0.2, **0.06**											
5	0.2 **0.2**	0.1 **0.2**	0.2, **0.095**	0.2 **014**										
6	0.7 **0.002***	0.3 **0.001***	0.7, **0.001***	0.4, **0.002***	0.3 **0.06**									
7	0.1, **0.16**	0.07, **0.20**	0.3, **0.03***	0.03, **0.38**	0.01, **0.41**	0.2, **0.99**								
8	0.2, **0.041***	0.2, **0.007***	0.1, **0.21**	0.07, **0.26**	0.2, **0.14**	0.08, **0.11**	0.1, **0.046***							
9	0.07, **0.29**	0.021, **0.59**	0.02, **0.43**	0.02, **0.54**	0.08, **0.64**	0.009, **0.41**	0.2, **0.001***	0.04, **0.098**						
10	0.2 **0.11**	0.2 **0.02***	0.1, **0.8**	0.1, **0.88**	0.02 **0.4**	0.3 **0.003***	0.1, **0.1**	0.02, **0.39**	0.03, **0.56**					
11	0.3 **0.04***	0.5 **0.001***	0.1, **0.8**	0.2, **0.048***	0.3 **0.08**	0.8 **0.001***	0.4, **0.001***	0.3, **0.006***	0.02, **0.53**	0.1 **0.30**				
12	0.02 **0.395**	0.2, **0.008***	0.2, **0.97**	0.0, **0.42**	0.2, **0.92**	0.5, **0.001***	0.5, **0.001***	0.4, **0.003***	0.2, **0.03***	0.02, **0.314**	0.04, **0.62**			
13	1.0 **0.02***	1.0 **0.002***	0.9, **0.012***	1.0, **0.012***	0.9 **0.03***	1.0 **0.001***	1.0, **0.001***	0.9, **0.001***	0.6 **0.004***	1.0 **0.006***	0.9 **0.012***	0.4, **0.018***		
14	0.5 **0.002***	0.6 **0.001***	0.5, **0.002***	0.5, **0.001***	0.3 **0.07**	0.7 **0.001***	0.9 **0.001***	0.8, **0.001***	0.5, **0.001***	0.5 **0.001***	0.4 **0.006***	0.4, **0.004***	0.3 **1.0**	
15	0.2 **0.072**	0.43 **0.001***	0.2, **0.97**	0.3, **0.082**	0.02 **0.5**	0.6 **0.001***	0.7, **0.001***	0.6, **0.001***	0.2, **0.014***	0.2 **0.028***	0.1 **0.7**	0.03 **0.262**	0.02 **0.4**	0.2 **0.031***

4.6 Invertebrate Populations

The mean abundance ratings for the ten most commonly observed invertebrate taxa over the second year of the project for all analysis sectors combined are depicted in Table 16. All ratings were below a value of 1, equivalent to rare on the DAFOR scale. Echinoderms were the more abundant invertebrates observed on survey dives, particularly Feather Stars, the blue seastar *Linckia laevigata* and Tunicates. Very few giant clams and Crown-of-Thorns seastars were recorded.

Table 16. Mean abundances of the ten most commonly observed invertebrate groups recorded throughout all survey areas in year two of the FCRCP during baseline surveys. Mean abundances correspond to the semi quantitative 0-5 DAFOR scale.

Invertebrate Group	Mean Abundance
Featherstar	0.72
Tunicates	0.66
Linckia laevigata	0.57
Long spine	0.41
Synapta maculate	0.41
Short spine	0.27
Clam	0.21
Pereclimenes sp.	0.15
Nudibranch	0.14
Sea cucumber	0.14

Of the major invertebrate groups, Crustacea and Tunicates were the most abundant species observed at most sites, the only exception being Cephalopods at Mana and Malolo. These were, however, not observed at all at Malolo Lailai and Namoa. Analysis sectors exhibiting the highest incidence of Crustacea were Malolo, Mana and Outer Barrier, and of Tunicates were Mana, Castaway Reef Complex and Bounty reef complex. With the exception of Crustacea, the Outer Barrier Analysis Sector returned the lowest number of observations of all other invertebrate species. With abundance below 0.5 on the DAFOR scale (very rare) (Figure 29).

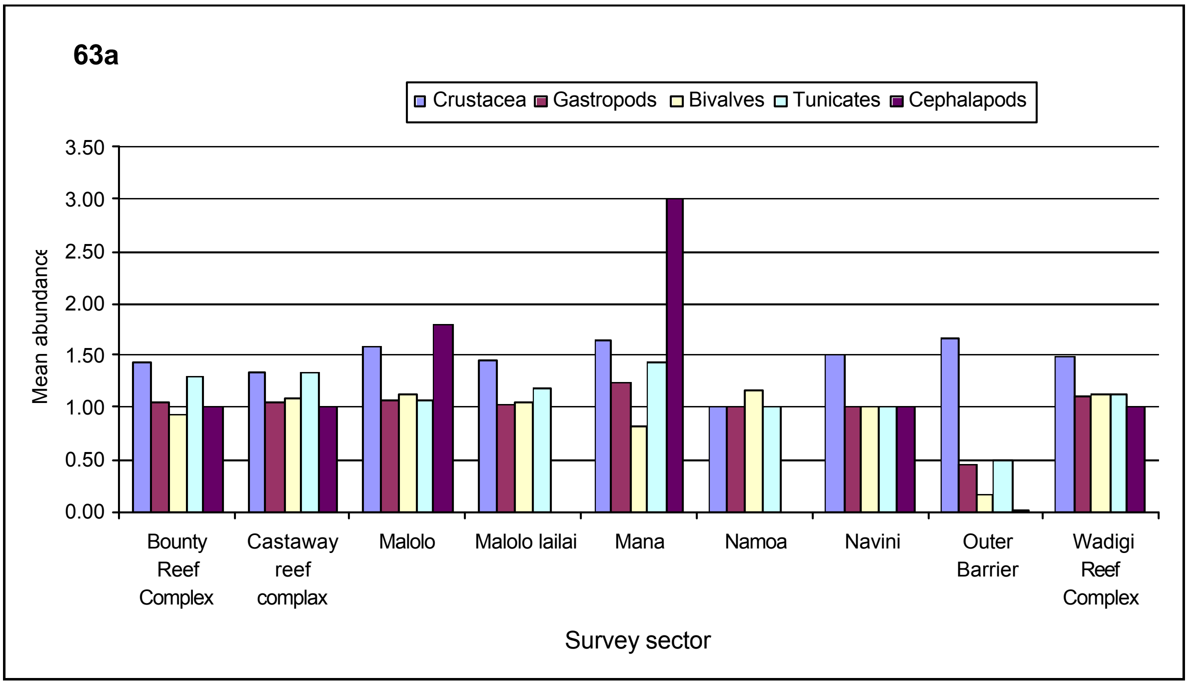

Figure 29. Mean abundance ratings for the major invertebrate groups recorded on CCC Baseline surveys for each analysis sector. Mean abundance refers to the values recorded on the 0-5 DAFOR semi quantitative abundance scale.

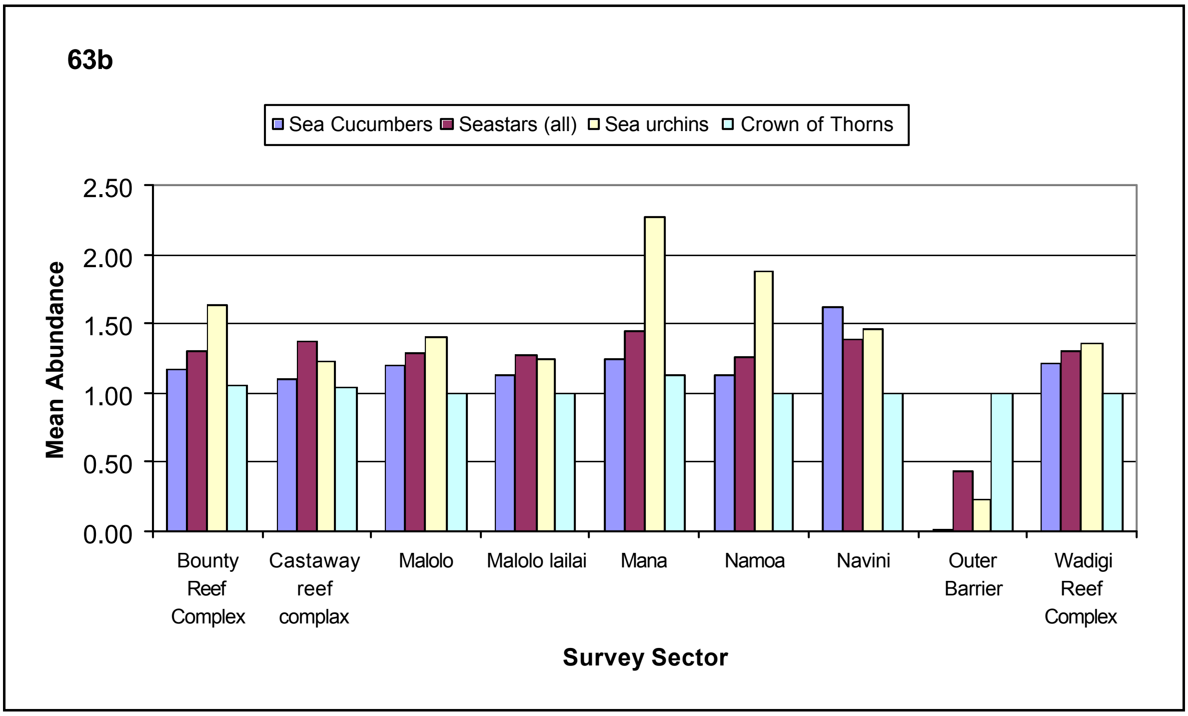

Figure 30. Mean abundance ratings for Echinoderms recorded on CCC Baseline surveys for each analysis sector. Mean abundance refers to the values recorded on the 0-5 DAFOR semi quantitative abundance scale.

Figure 30 shows the abundance of Echinoderms observed at each of the analysis sectors. Of the Echinoderms observed, Sea urchins were most abundant at most analysis sectors with highest abundances (over 1.50 on the DAFOR scale) seen at Mana, Namoa and Bounty Reef Complex. Sea stars were most abundant at Castaway Reef Complex, Malolo Lailai and Outer Barrier although ratings did not reach 1.50 (rare to occasional) on the DAFOR scale. Sea Cucumbers were most abundant at Navini, with a rating over 1.50, though they were not observed at the Outer Barrier sector. The occurrence of Crown of Thorns sea star is concentrated to Mana, Bounty Reef Complex and Castaway Reef complex, with mean abundances exceeding 1 on the DAFOR scale. (Figure 30)

Statistical comparison of mean abundance ratings between survey sectors for invertebrate groups indicates that only seastar abundance was significantly different between sectors (Table 17).

Table 17. Results of Kruskal-Wallis test comparing the abundance of major invertebrate taxa between survey sectors. Degrees of freedom= 13 for all tests. Results shown in bold indicate significance.

Invertebrate Group	Kruskal-Wallis statistic (H)	P-value (adjusted for ties)
Bivalves	8.4	0.69
Cephalopods	0.3	0.99
Crustaceans	0.9	1.00
Sea Cucumbers	16.4	0.75
Urchins	4.9	0.99
Seastars	27.1	**<0.01**
Gastropods	6.3	1.00

4.7 Habitat Mapping

One of the common problems with the production of habitat maps from satellite imagery is that the imagery itself is not of a sufficiently high resolution to allow accurate delineation of habitat areas. The greater the number of habitats identified in a habitat map there is a reduction in the overall accuracy and therefore usefulness of the map. There has therefore to be a trade-off between map complexity (the number of habitats) and map accuracy.

Analysis of the benthic cover data collected during the FCRCP identified a total of fifteen habitat types. However, when these were mapped, the overall accuracy of the resultant map was too low. A compromise has therefore been found where a total of nine habitats have been identified from the original 15 and it is these that have been mapped. The correspondence between the original 15 habitats or benthic classes and the ones mapped is shown in Table 18.

Table 18. Comparison of habitats identified by detailed analysis using hierarchal cluster analysis (presented in section 4.3) and those used in the production of the habitat map.

Habitats Defined by cluster analysis		Habitats mapped	
Number	Description	Number	Description
1	Sheltered upper reef slope supporting stress tolerant massive corals	5	Sand and small coral stands
2	Macroalgae dominated shallow back reef area of bedrock and sand	8/9	Sand with sparse algae and seagrass/ Sand and macroalgae
3	Lower reef slope community on sand with a hard coral community dominated by foliose corals	2	Lower reef slope predominately sand
4	Lower reef slope with significant bare bedrock, a diffuse coral community and frequent black coral	3	Bedrock and live hard coral
5	Shallow upper reef slope areas of predominately sand and rubble substrate with low coral and high macroalgae cover	7	Mixed substrate/ rubble and green calcified algae
6	Shallow upper reef slope community with a significant presence of rubble and opportunistic Acroporid corals	3	Bedrock and live hard coral
7	Shallow upper reef slope with frequent hard coral cover, mainly branching Acropora. Occasional soft corals and sponges also present	3	Bedrock and live hard coral
8	Lower reef slope dominated by sand and rubble with occasional hard coral and sponges	2	Lower reef slope predominately sand
9	Sand dominated lower reef slope with sparse coral cover but frequent calcified green algae	2	Lower reef slope predominately sand
10	Lower reef slope with frequent coral cover dominated by encrusting and massive corals and soft corals	3	Bedrock and live hard coral
11	Lower reef slope of sand and mud with sparse hard coral cover dominated by branching Acropora	2	Lower reef slope predominately sand
12	Mid reef slope with sand and rubble. Sparse hard coral cover and mixed green algal assemblage	4	Reef slope with patch coral bommies
13	Lower reef slope dominated by rubble and mud with sparse coral cover and red coralline algae	2	Lower reef slope predominately sand
14	Largely bare lower reef slope substrates of sand and mud	2	Lower reef slope predominately sand
15	Mid reef slope dominated by sand with mixed disparate hard coral cover and filamentous algae	3	Bedrock and live hard coral

The first thing of note from Table 18 is that two habitats that has been mapped are not represented in the fifteen originally identified by cluster analysis. Habitat 6, areas of intertidal or less than 1 meter deep sand and rubble flats was not surveyed by CCC divers during the duration of the first two years of the project. These flats can however be seen fringing Malolo and Malolo Lailai Islands and being exposed at low tide when the satellite

image was acquired. Habitat 1; the reef crest has not been surveyed during as these areas are often extremely wave exposed and shallow and are not therefore safe to access.
In addition, habitat 2 described by cluster analysis could assume two habitats on the map. This is because it is dependent on the ratio of macroalgae to bare bedrock and seagrass that cannot be easily and accurately differentiated.

Figure 31 is the habitat map produced for this report from data collected thus far in the FCRCP.

The overall accuracy of the map has been calculated as 67% with most confusion occurring in the deeper, lower reef slope habitats where the low ability of light to penetration through the water column limits the resolution to which these areas can be differentiated.

Areal statistics of the coverage of each habitat class are shown in Table 19. Unclassified areas are present as a result of the masking procedure utilised on the image to remove areas of deep water. The Landsat sensor can penetrate clear water to a depth of around 20m, below which, the effect of the water column prevents the use of this sensor to map coral reef habitats. Large areas of lower reef slope dominated by sand substrate (habitat 2) were found around many of the fringing and barrier reefs in the Mamanucas. The two main live hard coral supporting habitats (bedrock and live hard coral and reef slope with patchy coral bommies) had a combined coverage of 17.7 km^2.
Much of the reef structure of both the inner and outer barrier reefs of the Mamanucas is dominated by sand and macroalgae dominated habitats. On the seaward side of these reef systems is then a well defined and structured reef slope dominated by bedrock and live hard corals in shallower areas and then extending deeper to become replaced by a habitat classified as the reef slope with patchy coral bommies.
The shallow intertidal sand and rubble flats are constrained in location to around the coastline of Malolo and Malolo Lailai Islands where they form a band between the lagoonal reef environment and the land.

Table 19. Areal coverage statistics of each habitat mapped from data collected during years one and two of the FCRCP.

Habitat	Area (km^2)	Percentage of total area of all benthic classes
Lower reef slope, predominately sand	31.7	35
Bedrock and live hard coral	6.8	8
Reef slope with patchy coral bommies	10.9	12
Sand and small coral stands	14.0	15
Intertidal/ <1m deep sand and rubble flats	2.8	3
Mixed substrate/rubble and green calcified algae	10.1	11
Sand with sparse algae and seagrass	3.4	4
Sand and macroalgae	7.4	8
Reef crest	3.1	3
Total all Benthic classes	**90.2**	**100**
Unclassified	1679.6	
Total (whole project area)	**1768.9**	

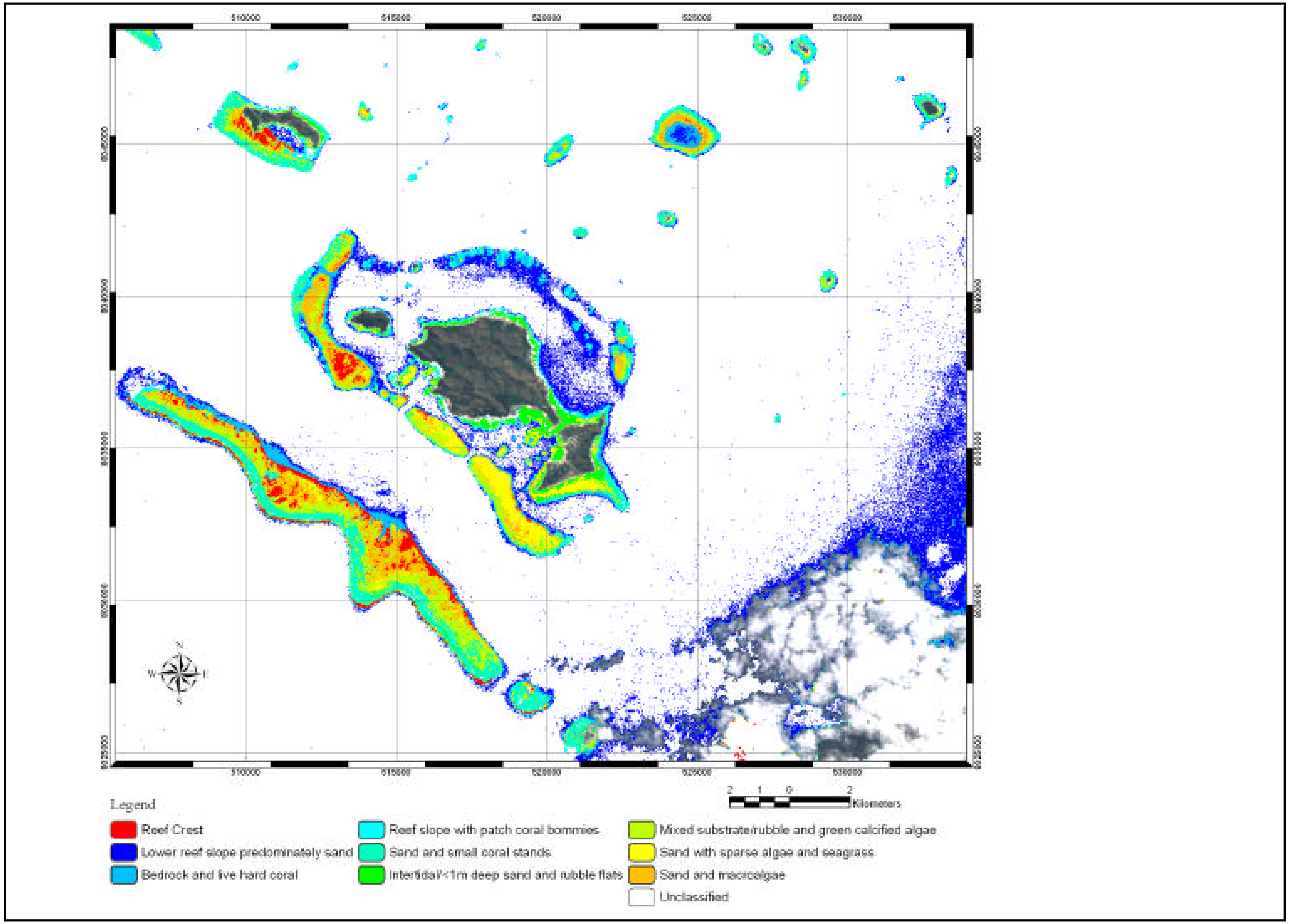

Figure 31. Habitat map produced from data collected by CCC during the FCRCP and integrated with a Landsat 7ETM+ image acquired on 18th May 2001.

4.8 Conservation Management Rating and Geographic Information System

The univariate biodiversity and ecosystem productivity statistics used in the calculation of all fifteen habitats identified by cluster analysis are shown in Table 20.

Table 20. Univariate biodiversity and ecosystem function statistics calculated for each of fifteen habitats defined by multivariate analysis. These values formed the basis of the calculation of Conservation Management Ratings for each Baseline transect conducted in years one and two of the FCRCP.

Habitat	Benthic community			Fish community	
	Live hard coral cover	Total species	Log_e Shannon-Weiner diversity	Total species	Log_e Shannon-Weiner diversity
1	2.1	118	4.13	118	4.11
2	1.6	115	4.12	103	3.82
3	3.0	95	4.15	86	3.90
4	2.3	106	4.21	91	3.95
5	1.5	121	4.32	109	4.02
6	2.6	132	4.58	133	4.05
7	2.6	150	4.61	193	4.10
8	1.7	130	4.27	149	4.04
9	1.6	138	4.31	152	4.05
10	2.3	118	4.52	128	4.14
11	1.5	115	4.21	116	4.05
12	1.6	131	4.27	131	4.05
13	2.0	100	4.30	80	3.90
14	0.6	127	4.32	154	4.00
15	1.4	124	4.32	126	4.07

Using these values as a basis, the output Conservation Management Rating density grid is overlaid onto the satellite image in Figure 32.

When interpreting the image, it is important to note that unclassified areas of reef do not have low value, but instead have not yet been surveyed and therefore cannot be included in the classification system.

A number of areas rated as of higher Conservation Management Value have be identified and numbered in the image. The northern section of the Malolo patch reef (Lau-1) appears to have, overall in the image, both the greatest density of high Conservation Management Value as well as covering a large area. Just to the West of this area, Mociu or Honeymoon Island (2) is also identified as being of higher Conservation value. Two sections of the Inner Barrier, both at the North tip (Yalo Drivi- 3) and the South (Nuku-4) are identified as being amongst the areas of highest Conservation Value on the Inner Barrier. Sunflower patch reef (5) is identified as being of high value as is Malolo Patch (8). To the northern area of the study area, both the Southeast tip of Mana Island (6) as well as the entire patch reef system of Motuse and Jaluk (7) is outlined as being of high management value.

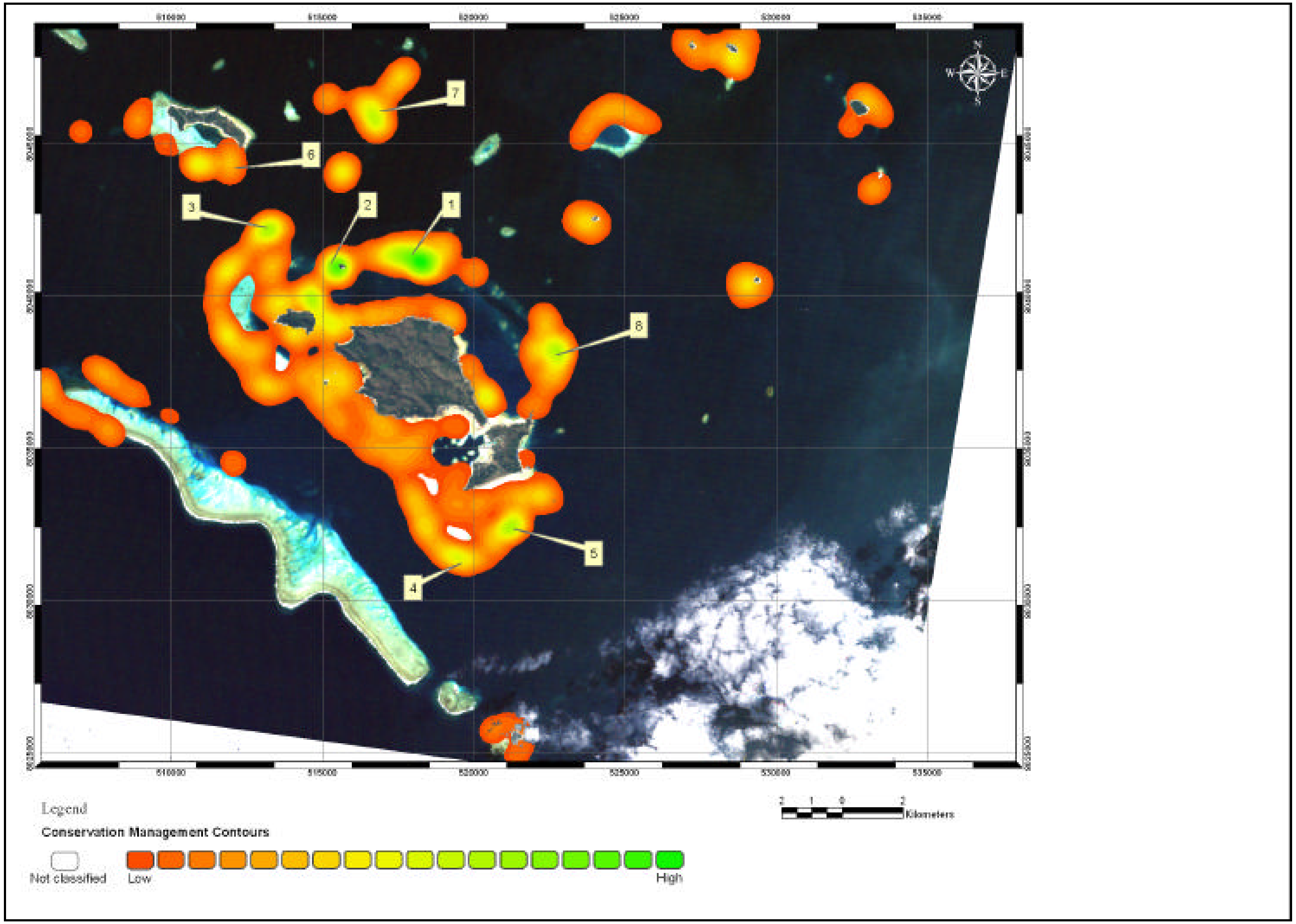

Figure 32. Conservation Management Rating contours as calculated from data collected by CCC in years one and two of the FCRCP Contours have been overlaid onto a Landsat 7ETM+ image acquired on 11th April, 2001.

5. DISCUSSION

5.1 Training

The training programme used during both the first and second years of the FCRCP proved to be appropriate for volunteer survey work in Fiji. For example, the results in the tests and in water validation exercise were, on the whole, excellent and, therefore, the data collected during survey work are likely to be accurate and consistent. The training schedule has been deemed appropriate for novice divers as well as relatively experienced divers. Further details of the training results are available upon request from the CCC-UK office

5.2 Environmental Awareness and Community Work

Arising from the Pilot Phase of the FCRCP was a recommendation that an independent coastal zone management organisation be established to oversee all management and education initiatives in the Mamanucas. As a result of this, the Mamanuca Environment Society was established in March 2003. Since its instigation, the Society has taken huge steps forward in the development of environmental education initiatives in the Mamanucas. The resources that the Society has bought to the program have been instrumental in many of the successful education initiatives that CCC has been involved in during year two of the FCRCP. However, the MES should be considered as far more than an education and capacity building organisation. CCCs main work plan in the Mamanucas terminates in approximately one year and the MES are now ideally suited to continue conservation and management initiatives and to implement the Marine Protected Area recommendations made by CCC.

5.3 Survey progress

Much of the area in the southern Mamanucas has now been completely surveyed. The satellite site established at Kadavu Lailai Island between June and October 2003 allowed the eastern islands of Beachcomber, Treasure, Vunivandra and Malamala to be surveyed. With this progress having been made, the next location that needs to worked on is the northern islands of the Mamanucas. Although 27 of the initially proposed 30 survey areas have now been completely surveyed, these initial survey areas did not include any of the Northern Mamanuca Islands. For a successful and comprehensive network of Marine Protected Areas to be established, it is however essential that these areas are surveyed so they may, if appropriate form part of the protected area network. Figure 33 indicates the locations of both completed and planned surveys.

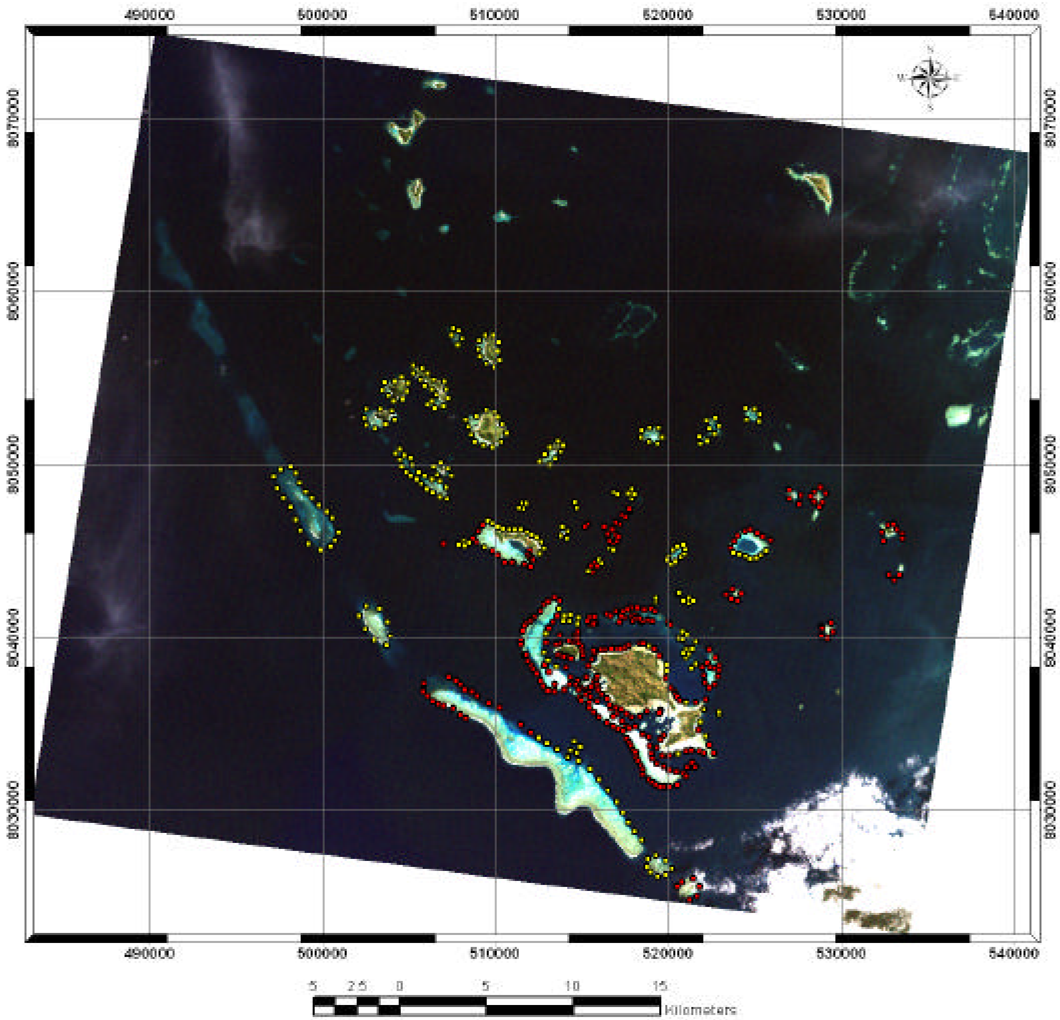

Figure 33. Completed (red) and planned (yellow) CCC Baseline transects in the Mamanucas.

5.4 Oceanographic observations

The Mamanucas displays stratification in the water column typical of tropical water bodies where the upper surface layer of water is warmer than the deeper water column. In the observations made during years one and two of the FCRCP, the boundary between these water bodies occurs between 10 and 20 meters, below which water temperatures become more stable at around 27.5°C.

Water temperature monitoring is an essential part of an early warning system for the likely occurrence of bleaching as seen in the Mamanucas in 2000-2001. Whilst the causes of bleaching are slowly becoming understood, treating the likely cause, global warming, using localised management of reef resources is not practical. Bleaching does however present a good example of what can be done at the local scale. There is increasing evidence to suggest that proper management of reef resources and the mitigation of synergistic anthropogenic impacts can firstly reduce the scale and severity of bleaching events as well as aiding the rapid and thorough recovery of coral reefs following such an event (Westmacott *et al.*, 2000).

Perhaps surprisingly, water salinity measurements recorded do not display the same stratification pattern as seen in temperature changes in the water body. Instead, variation is greatest in the top 5 meters of the water column. This is likely as a result of the tendency for heavy rainfall to cause the formation of a lens of fresh water, which being less dense than seawater, floats on the surface of the sea.

As outlined with the use of river flow data and secchi disc readings representing water column turbidity in the year one report of the FCRCP (Comley *et al.,* 2003), it is likely in the Mamanucas that a major source of sediment is the Nadi river. Data from this year appears to support this finding where surveys conducted around the eastern Mamanuca Islands such as Kadavu Lailai, which are geographically closest to the mouth of the Nadi River had the lowest overall secchi disc readings. In addition to the observations of turbid water made in this area, it also had the highest recorded incidence of sedimentation on corals; a sign of high sediment loads affecting the ecosystem health and function. Navini, by contrast, furthest away from the Nadi River had far lower water column turbidity and suspended solids. It is interesting to note that within the analysis areas, Wadigi and the Outer barrier had greatest variation in secchi disc readings. This perhaps suggests that in these areas there is re-suspension of sediments confined both spatially and temporally as a result of water movement induced by wave and tide generated current.

The most commonly observed surface impact in all survey areas are large floating mats of unattached macroalgae, most commonly of the genus *Sargassum sp.* and *Gracillaria sp*. Both of these genera have the ability to rapidly increase in biomass given conditions of increased nutrient levels present in the environment. These observations do indicate therefore that nutrient levels in the Mamanucas may be artificially elevated, perhaps as a result of sewage discharge from development on the islands (Mosely *et al.*, 2002).

Additional signs of development induced impact on the coral reef comes in the form of litter pollution which was observed in all analysis sectors and was particularly abundant around the eastern Islands surveyed from Kadavu Lailai. Coral damage was also seen extensively in the Mamanucas, though this damage could not be attributed to either natural or anthropogenic impact. Whilst evidence of dynamite fishing was observed, it is most likely that this is a misidentification, as dynamite fishing is not believed to occur in the Mamanucas.

Areas of highest boat activity are isolated to the areas where development is found; be it of native communities or resorts. Malolo Lailai and the areas around Kadavu Lailai Island have greatest boat activity where over 40% of the boats observed in the areas were conducting pleasure-based activities.

5.5 Multivariate Analysis and Benthic Habitat Definitions

Using the data recorded from year one of the FCRCP as a training set to which year two data can be compared has resulted in a comprehensive set of habitats for the Mamanuca region. It is interesting to note that despite the discriminant analysis technique employed being capable of identifying data sets that do not statistically 'fit' into one of the habitats defined previously, this did not occur during the analysis. With the inclusion of data from barrier and fringing reef systems across the Mamanucas into this analysis protocol, it is therefore likely that the set of habitat definitions presented in this report is approaching completeness. Additional data to be collected during the third and final year of the FCRCP will again provide an opportunity to test this classification scheme.

5.6 Reef Fish Populations

As in the data collected in the first year of the FCRCP, by far the most commonly observed reef fish family this year has been the Damselfish. Damselfish display territorial behaviour and are closely related to the benthic community, being found in high densities around bare substrate. There is a close correspondence between the coverage of hard corals and the abundance of bare hard substrata within Malolo Lailai and Namoa with respectively high and low bare substrate to live coral cover ratios and the high and low abundance of Damselfish respectively in these survey areas.

Commercially fished coral reef fish families were observed with very low abundance, which may indicate fishing pressure in operation.

The most biodiverse fish populations are found associated with habitats dominated by live hard coral (Benthic Classes 6, 7 and 10). This supports the theory that these two reef habitats are biodiverse not just in terms of the benthic communities they contain, but also in terms of the fish assemblages found associated with them. Interestingly, these fish assemblages are not just biodiverse; the results of the pairwise multivariate analysis procedure performed on the data indicates that these assemblages are found specifically associated with the habitat in which they area found. This has important management implications in that by protecting areas found to be comprised of these three habitats, one is also protecting three unique fish assemblages.

5.7 Habitat Mapping

The habitat map produced for this report allows the spatial coverage habitats that comprise the Mamanucas to be evaluated. The map is intended to be supplementary to that produced during the Pilot Phase of the FCRCP (Harborne *et al.,* 2001). The map produced for this report resulted from more complex pre-processing stages being carried out on the satellite image prior to its use in classification. The use of a radiative transfer model removes much of the affect of light passing through the atmosphere and its aim is to allow more accurate mapping. Perhaps of greater consequence however, was the employment of the water column correction technique. The map produced for the Pilot Phase report included reefal areas covering 70km^2; in this report this coverage has increased to 90km^2. This is obviously not as a result of the area of reef increasing by 20km^2 over the past three years; but instead is due to the ability of a water column corrected image to be able to discern between habitats in deeper water. This has important implications and allows more deep-water habitats to be mapped and assessed.

Finally, the large quantity of field data present and usable for the production of the habitat map in this report allowed for the assessment of accuracy of the map. One hundred and fifty points were not used in the classification and interpretation to produce the map; instead they could be used to assess the accuracy of the output product. It was found that the overall accuracy was 67%; a figure comparable with other studies utilising Landsat 7ETM+ imagery as summarised in Green *et al.,* 2000.

Attempt was made to map all of the fifteen discreet habitat classes identified by multivariate cluster and discriminant analysis, however, despite no accuracy assessment having been undertaken, it was clear from the output map that its accuracy was so low that it would be of little if any use. Instead, by using the nine grouped habitats for mapping purposes has allowed the production of a more accurate and therefore useful habitat map.

Many studies have been undertaken to assess the relative merits of different remote sensing data sources; excellent reviews are provided in Green *et al.,* 2000. These studies acknowledge two key factors that determine the useful application of remote sensors to coral reef habitat mapping; spectral and spatial resolution. Spectral resolution refers to both the number of bands in the electromagnetic spectrum that are imaged as well as the location of these bands in the spectrum. Spatial resolution by contrast refers to the size of individual picture elements on the ground. Landsat 7ETM+ imagery is accepted as being perhaps the best widely available and economically viable source of data. It has suitable spectral resolution with seven bands; three of which have application in coral reef remote sensing. The major disadvantage with Landsat as a data source for this genre of study is that it has very low spatial resolution with the smallest discernable features on the ground measuring 30 x 30 meters. The ideal sensor platform for coral reef mapping surveys are the multispectral airborne scanners. However, in most instances the costs associated with the acquisition of this type of data is so high and can rarely be justified when mapping at the generic habitat level necessary for management purposes.

5.8 Conservation Management Rating and Geographic Information System

The Conservation Management Rating methodology developed for this report is a culmination of many of the other advanced analysis techniques used. Based on the habitats defined from the data set by multivariate cluster analysis, the technique allows all of the data to be compared in a simple manner. Using univariate reef diversity and function statistics then allows each of these habitats to be assessed for management importance.

This method of analysis was developed during and included in the year one report of the FCRCP; however, at this stage, it only allowed for the assessment of discreet points representative of start locations of CCC Baseline transects. By developing a system of density gradients in this report, the Conservation Management Ratings scheme is now able to clearly identify areas of high management importance. It is these areas that have been recommended for the establishment of Marine Protected Areas.

However, one of the main advantages of the presenting the analysed data in this format is that it is graphical and therefore easily to interpret by all stakeholders. The ideal process for Marine Protected Area delineation is that a number of biologically and ecologically suitable sites are proposed and then, following socio-economic analysis and study, sites are chosen that have greatest chance of being successfully and sustainably established. Once involved directly in the formulation of management initiatives in this manner, the process becomes one owned not by legislators, but by the stakeholders themselves. Managements schemes established in this manner are far more likely to achieve their stated aims. It is hoped therefore that the GIS presented in this report can form an important part of the integrated decision framework involving all stakeholders to establish Marine Protected Areas.

Once created, a GIS can be developed both in complexity and function. Many parameters including not just information on biological and ecological patterns can be stored as spatial data in the GIS. What has been achieved thus far therefore is the creation of a basic system, but one that is capable of storing an increasing quantity of data from different data sets.

5.9 Management Findings and Recommendations

One of the key recommendations that came from the Pilot Phase project of CCC's involvement in the Mamanuca Islands was the establishment of an integrated approach to marine resource conservation. The recommendation was made that, based upon theoretical spatial models of Marine Protected Area population dynamics, 20% of the shallow reef areas of the Mamanuca Islands should be decreed a no-take zone. With 90 km^2 of such area found in the Mamanucas, this equates to a spatial coverage of 14 km^2.

Using the variety of analysis methodologies employed in the analysis of the data presented in this report, it has been possible to identify areas of coral reefs of key management importance. The basis behind Marine Protected Areas is that if healthy coral reef systems that are diverse, productive and representative of the entire region are protected, then they will aid in the sustainability of the surrounding reef areas. To this end, in the end of year one report for the FCRP, five areas of a total 3.75 km^2 were identified and recommended for protection.

In addition to these areas from year one, Figure 34 indicates an additional six areas that are recommended areas for protection as a result of the data collected in year two of the FCRCP.

Spatial statistics of both the year one and new, year two MPA recommendation areas are give in Table 21.

Table 21. Spatial statistics of Marine Protected Area recommendations from both years one and two of the FCRCP

MPA Recommendation	Area (Km^2)	Perimeter (Km)	Boundaries			
			Lower Left	Lower Right	Upper Left	Upper Right
Year 1						
1- Malolo Patch	1.25	5.82	8036980, 522090	8036980, 522917	8039243, 522090	8039243, 522917
2- Mociu	0.08	1.12	8040796, 515469	8040796, 515838	8041106, 515469	8041106, 515838
3- Yalodrivi	0.89	3.87	8040785, 512431	8040785, 513650	8040785, 512431	8040785, 513650
4- Mana	1.31	5.43	8,044,149, 510,157	8,044,149, 512,242	8,045,593, 510,157	8,045,593, 512,242
5- Navini	0.22	1.85	8042271, 523652	8042271, 524271	8042733, 523652	8042733, 524271
Year 1 recommendations total	3.75	18.09				
Year 2						
6- Sunflower	0.12	1.30	8032520, 521172	8032520, 521628	8032866, 521172	8032866, 521628
7- Nuku	1.79	6.02	8031475, 518542	8031475, 520937	8032777, 518542	8032777, 520937
8- Lau	1.51	9.79	8040141, 516622	8040141, 520066	8041597, 516622	8041597, 520066
9- Motuse	1.38	7.06	8043642, 515329	8043642, 516966	8046303, 515329	8046303, 516966
10- Namoa	2.66	6.46	8044503, 5233376	8044503, 525780	8046279, 5233376	8046279, 525780
11- Nukuwasiga	0.17	1.78	8046752, 528288	8046752, 528675	8047481, 528288	8047481, 528675
Year 2 recommendations total	7.63	32.41				
Years 1&2 recommendations total	11.38	50.5				

The recommendations from both years one and two cover 11.38km^2 or 65% of the 18km^2 area that would ensure the declaration of protected status of 20% of the entire reef area of the Mamanucas.

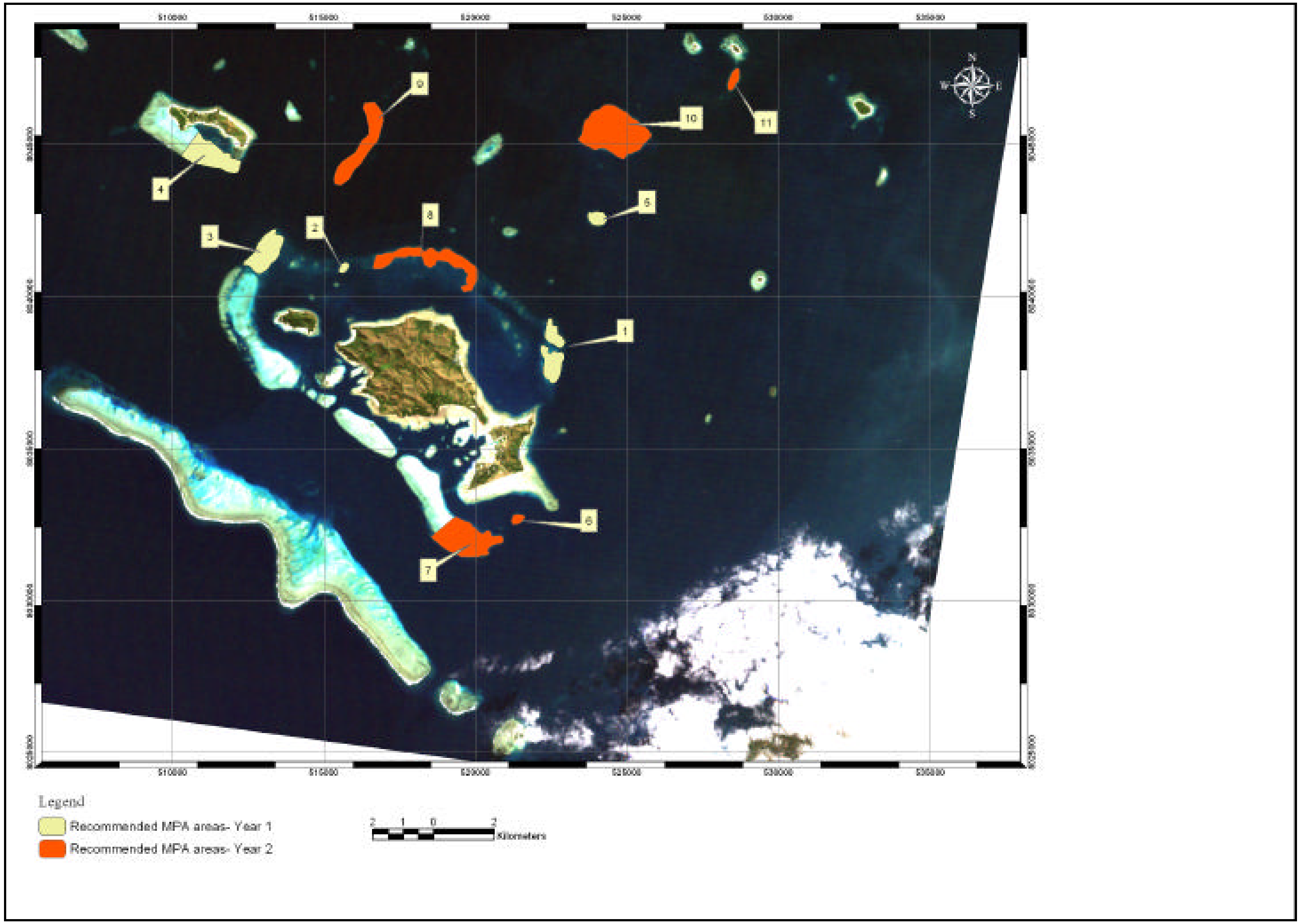

Figure 34. Year one and year two Marine Protected Area Recommendations in the Mamanuca Islands

6. RECOMMENDATIONS

The following section of recommendations is divided in two; firstly recommendations and aims for the continuation of CCCs work in the Mamanuca Islands and secondly recommendations towards the implementation of Marine Protected Areas in an integrated conservation program for the Mamanucas.

CCC

Recommendation 1- To continue Baseline and Reefcheck data collection in the Mamanucas

Recommendation 2- Expand the area of survey to the reefs and islands that comprise the Northern Mamanucas that are, at present un-surveyed. It is an expectation that once surveyed, these areas will form an important and integral role in the Marine Protected Area network for the Mamanucas

Recommendation 3-To continue community capacity building activities in close collaboration with the Mamanuca Environment Society. These activities include school workshops, dive operator networks, resort and guest education initiatives and best practice guidelines. Of key importance here is the inclusion of all stakeholder groups in the Mamanucas.

Recommendation 4-Continue to develop and refine habitat definitions for the Mamanucas to derive a comprehensive breakdown of all reef types found in the area.

Recommendation 5-Develop more advanced Geographic Information Systems and habitat mapping techniques to aid in the efficient dissemination of data to all stakeholders

Recommendation 6- To act, if invited, in an advisory capacity to support the lead role agency in the process of Marine Protected Area implementation. To provide assistance in areas such as the development of a monitoring scheme and educational workshops aimed at the integration of MPAs.

Marine Protected Area Implementation

Recommendation 1- CCC recommends that the Mamanuca Environment Society be invited to take lead role in the implementation of Marine Protected Areas

Recommendation 2- To act, if invited, in an advisory capacity to support the appointed lead agency in the process of Marine Protected Area implementation. To provide assistance in areas such as the development of a monitoring scheme and educational workshops aimed at the integration of MPAs.

Recommendation 3- Without delay, application be made to acquire a UN-GEF Medium Sized Grant with which to progress the implementation process

Recommendation 4- Support be sought from all levels of administration to forward the development of a legislative framework upon which to base MPA implementation

Recommendation 5- Sources of infrastructure support for MPAs be evaluated. Infrastructure needs to include patrol bases, offices and community education and environmental interpretation facilities

Recommendation 6- Specific and targeted workshops be conducted to inform all stakeholders of the importance of Marine Protected Areas and conservation

Recommendation 7- Data derived from CCC s work and the recommendations are not definitive. Using techniques such as the GIS developed for this report, all stakeholders be invited to a consultation process to refine MPA location and function. Without consensus from all stakeholders, any Marine Protected Areas will fail to be successfully implemented

Recommendation 8- Studies be undertaken on the socio-economic and demographic factors that may affect successful MPA implementation. The findings of these studies enter both early on in defining suitable MPA sites as well as providing a feedback monitoring program to detail the success of implemented MPA programs

Recommendation 9- A monitoring program be established to identify changes in the coral reef communities of the Mamanucas as a result of the implementation of Marine Protected Areas

Recommendation 10- Any MPAs and management planning be dynamic enough to respond to feedback from both socio-economic and biological monitoring programs

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APPENDIX 1

Recording forms used for data collected during CCC standard baseline surveys.

BOAT FORM

DATE: ____________________ **COX:** ____________________

STUDY: ____________________ **BM:** ____________________

TRANSECT: ____________________ **BUOY:** ____________________

SUBZONE: ____________________

COORDINATES

START:

GPS Unit: ____________________

Datum: ____________________

	Latitude (UTM)	Longitude (UTM)	Time	Est. error	Waypoint
1.					
2.					
3.					

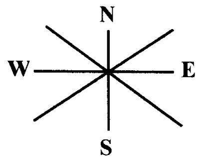
END:

	Latitude (UTM)	Longitude (UTM)	Time	Est. error	Waypoint
1.					
2.					
3.					

CURRENT STRENGTH

none
weak
medium
strong

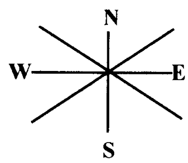
CURRENT DIRECTION (towards)



WIND STRENGTH (1-12)

1 5
2 6
3 7
4 8

WIND DIRECTION (from)



Temperature: °C at depth of: m **Surface temperature:** °C **Secchi disc:** m

Salinity: at depth of: m **Surface salinity:**

SURFACE ACTIVITY

BOAT	No. OCCUPANTS	PROXIMITY (m)	ACTIVITY eg. diving/fishing/pleasure/commercial
1.	________	________	________
2.	________	________	________
3.	________	________	________
4.	________	________	________

SURFACE IMPACTS

	LITTER	SEWAGE	DRIFTWOOD	ALGAE	NETS / POTS
(please tick)	☐	☐	☐	☐	☐

Other Impacts/Details..

OTHER COMMENTS:..

PHYSICAL RECORDING FORM

Study. Transect No. Zone Code.

Date: ____/____/____

Start Time: ____________End Time: ____________

Recorder's Name: ____________Phys.

____________Fish

____________Corals

____________Algae/Inverts.

Depth Limits - Min: __________m

- Max: __________m

Underwater visibility __________m

Repeat visit? Y/N

TYPE OF SURVEY

- Spot dive ☐
- Transect ☐
- General ☐
- Mapping ☐
- Photography ☐
- Sounding ☐
- Other ☐

ZONE (Tick all that apply)

- Backreef ☐
- Reef crest ☐
- Spur & groove ☐
- *Low spur & groove* ☐
- *High spur & groove* ☐
- Forereef ☐
- Escarpment ☐
- Patch reef ☐
- *Dense patch reef* ☐
- *Diffuse patch reef* ☐
- Lagoon floor ☐
- *Shallow lagoon* ☐
- *Deep lagoon* ☐

Italics indicate a sub-class of a main class

IMPACTS

- Litter ☐
- Sewage ☐
- Coral damage ☐
- Lines / nets ☐
- Fish traps ☐
- Sedimentation ☐
- Coral disease ☐
- Bleaching ☐
- Dynamite ☐
- Other: ____________

YOUR IMPRESSION OF THE SITE

	AESTHETIC	BIOLOGICAL
Excellent		
Very good		
Good		
Average		
Poor		

Other comments:

Navigation bearing: _____°

Depth buoy tied: _______m

Buoy colour/I.D.: _______

SITE DESCRIPTION (Describe general location of the site, topography and main habitats - coral, sand, etc.)

General Location ____

____

Topography ____

____

Main Habitats ____

____

SITE PROFILE /PLAN DRAWING (Note depths, distances and habitats)

SIDE VIEW: Orientation: degrees

DEPTH (m)

/ / / / / / / / / / / / / / /

Distance (m) / Depth (m)

AERIAL VIEW:

WIDTH (m)

Line of Transect

Distance (m)

BIOLOGICAL RECORDING FORM

Study: Transect No: Zone Code:

Habitat No: ________ of ______ Date: ____________

Database Code:

Percentage of Dive: ________ % Start time:____________ End time: __________

	First:	Last:	No. dives/snorkels in Fji		Depth Limits:		
Recorder's Name	______________________	Phys	____________		Min:	______________	m
	______________________	Fish	____________		Max:	______________	m
	______________________	Coral	____________	Underwater Visibility:		______________	m
	______________________	Algae	____________	Cox:		______________	

GEOMORPHOLOGICAL CLASS - TICK ONE ONLY.

Remember that if the geomorphology changes you must start another habitat

Backreef	☐	Shallow zone between the reef crest and lagoon or land. Usually hard substratum pavement
Reef crest	☐	Shallowest and often emergent part of the reef, separating forereef from backreef / lagoon
Spur and groove	☐	Spurs of hard corals / calcified green algae with sand / bedrock grooes.
Low spur and groove	☐	Spurs less than 5m high
High spur and groove	☐	Spurs greater than 5m high
Forereef	☐	Any area of reef with an incline of between 0 and 45º
Escarpment	☐	Any area of benthos whose angle of slope exceeds 45º
Patch reef	☐	Coral formations in the lagoon which are surrounded by either seagrass, sand or algae
Dense patch reef	☐	Areas of aggregated coral colonies (living or dead) which cover > 70% of the benthos
Diffuse patch reef	☐	Areas of dispersed coral colonies where < 30% of the benthos is covered by coral colonies
Lagoon floor	☐	The lagoon floor where the angle of the slope does not exceed 45º
Shallow lagoon floor	☐	Lagoon with a depth of > 12m
Deep lagoon floor	☐	Lagoon with a depth of < 12m

Italics indicate a sub-class of a main class and if there is any uncertainty, the main class should be used.

SUBSTRATUM AND BIOLOGICAL COVER

Rating from 0-5 (figures need not add up to 5 total)

Bedrock	☐	Any exposed area of hard, bare substratum without visible coraline structures
Dead Coral with Algae	☐	Any area of hard bare substratum with visible coralite structure covered in algae
Dead Corals	☐	Any area of hard bare substratum with visible coralite structure
Rubble	☐	Any area of oose bedrock or hard substratum
Sand	☐	Coarse sediment (diameter > 1mm). "Grainy" when disturbed
Mud	☐	Fine sediment (diameter < 1mm). "Milky" when disturbed
Hard corals	☐	
Soft corals	☐	
Sponges	☐	
Green algae	☐	Non-calcerous algae forming mats or turfs
Brown fleshy algae	☐	e.g. Lobophora, Padina, Sargassum, Turbinaria
Red/brown branching algae	☐	e.g. Dictyota, Galaxaura, Amphiroa, Jania
Green calcified algae	☐	e.g. Halimeda, Tydemania
Red coralline algae	☐	e.g. Cement, crustose coralline
Seagrass	☐	

Substratum types within the habitat: (e.g. sand / bedrock) ______________________________

Other comments : ______________________________

SPECIES ABUNDANCE

N.B. ALL CORAL AND FISH TARGET SPECIES MUST <u>ALSO</u> BE COUNTED IN THE APPRORIATE FAMILY OR LIFEFORM

Rating	Meaning	Fish/Inverts
0	None	0
1	Rare	1-5
2	Occasional	6-20
3	Frequent	21-50
4	Abundant	51-250
5	Dominant	250+

MACRO-ALGAE

Cyano-Bacteria: Blue-Green	1	
Chlorophyta: Green		
Green Filamentous	39	
Ventricaria sp.	3	
Bornetella sp.	10	
Neomeris sp. (Finger)	29	
Caulerpa sp. (Grape)	12	
Calcified: - Halimeda sp.	24	
- Tydemania sp.	33	
Codium sp. (Spongy)	18	
Further Green Species:		
________		
________		
________		
________		
TOTAL GREEN ALGAE		
Phaeophyta: Brown		
Dictyota sp. (Flat-Branched)	44	
Padina sp. (Fan Blade)	50	
Lobophora sp. (Blade/Ruffle)	49	
Hydroclathrus sp.	48	
Turbinaria sp. (Pyramid)	55	
Filamentous	42	
Sargassum sp. (Bladder)	53	
Further Brown Species:		
________		
________		
________		
________		
TOTAL BROWN ALGAE		
Rhodophyta: Red		
Calcified	70	
Galaxaura	73	
Amphiroa	63	
Jania / Spikeweed	83	
Filamentous - *Ceramium* sp.	60	
Sheet - *Halymenia* sp.	80	
Further Red Species		
________		
________		
________		
________		
TOTAL RED ALGAE		

Angiospermophyta: Marine Plants		
Sea Grass	102	
Thalassia sp.	108	
Halophila sp.	105	
Other: ________		
Mangroves	114	
TOTAL PLANTS (Not Including Algae)		

TARGET INVERTEBRATES

Porifera : Sponges		
Tube	126	
Barrel	146	
Elephant Ear	128	
Branching	143	
Encrusting	130	
Lumpy	145	
Rope	144	
Vase	125	
Cnidaria: Soft Coral Forms		
Deadman's Fingers	275	
Leather	277	
Tree	278	
Pulsing	295	
Sea Fan	280	
Sea Whip	281	
Bamboo	283	
Organ Pipe	293	
Flower	294	
Black Coral	303	
Anemone	306	
Zoanthid	315	
Medusa (Jellyfish)	327	
Hydroid	333	
Corallimorph	320	
Annelida: Worms		
Segmented Worms	348	
Feather Duster	349	
Christmas Tree	350	
Anthropoda: *Crustacea*		
Shrimps	361	
Spiny Lobster	366	
Crab	381	

Mollusca:			
Gastropods:	Abalone	390	
	Murex sp.	394	
	Conch	398	
	Cowrie	402	
	Triton	406	
	Cone Shell	408	
	Drupella sp.	419	
	Limpet	445	
	Topshell	404	
	Other	389	
Bi-Valves:	Oyster	426	
	Clam	438	
	Other	425	
Chiton		442	
Nudibranch		448	
Cephalopods:	Cuttlefish	469	
	Squid	470	
	Octopus	468	
Echinoderms			
Sea Stars:			
- Crown Of Thorns		472	
- *Linkia laevigata* (Blue)		478	
- *Nardoa* sp. (Brown)		479	
- *Culcita novaeguineae*		474	
- *Protoreaster nodosus*		482	
- *Choriaster granulatus*		473	
- Other		471	
Brittle Star		483	
Feather Star		489	
Basket Star		495	
Sea Urchin:	Short Spine	502	
	Long Spine	503	
Sea Cucumber	Synaptid	515	
	Other	520	
Tunicate		529	
Bryozoan		526	
FURTHER SPECIES:			
________			
________			
________			
________			
TOTAL INVERTEBRATES			

HARD CORAL

Life Forms

DEAD CORAL	148
DEAD CORAL WITH ALGAE	149
ACROPORA:	
BRANCHING	150
ENCRUSTING	151
SUBMASSIVE	152
DIGITATE	153
TABULATE	154
NON-ACROPORA:	
BRANCHING	155
ENCRUSTING	156
FOLIOSE	157
MASSIVE	158
SUB-MASSIVE	159
MUSHROOM	160
FIRE (*Millepora*)	161
BLUE (*Heliopora*)	162
TOTAL CORAL LIFE FORMS	

Target Life forms, genera and species

Pocilloporadae	
Pocillopora: Small	164
Medium	165
Large	166
Seriatopora hystrix	834
Stylophora pistillata	833
Stylophora mordax	803
Acroporidae	
Bottlebrush *Acropora*	163
Montipora foliose spp.	167
Poritidae	
Massive *Porites*	844
Porites cylindrica	845
Porites nigrescens	846
Porites rus	848
Goniopora / Alveopora	893
Agariciidae	
Pavona clavus	855
Pachyseris speciosa	859
Pachyseris rugosa	858
Fungiidae	
Ctenactis echinata	208
Herpolitha limax	248
Polyphyllia talpina	861
Upsidedown bowl	167
Oculinidae	
Galaxea	236
Pectiniidae	
Pectinia lactuca	865
Mycedium elephantotus	815
Mussidae	
Lobophyllia	269
Faviidae	
Favia	222
Favites	227
Diploastrea heliopora	215
Echinopora lamellosa	218
Caryophylliidae	
Euphyllia	895
Plerogyra	874
Milleporidae	
Millepora platyphylla	827
Millepora intricata	826
Dendrophylliidae	
Tubastrea micrantha	877
Turbinaria reniformis	884

Merulinidae	
Hydnophora sp.	247
Merulina scabricula	895
Miscellaneous	
Brain: Small	202
Medium	273
Large	253

FURTHER SPECIES

TOTAL TARGET CORALS

N.B. ALL CORAL AND FISH TARGET SPECIES MUST ALSO BE COUNTED IN THE APPROPRIATE FAMILY OR LIFEFORM

TARGET FISH

Butterflyfish	540
(Big) Long-Nosed	752
Klein's	651
Vagabond	541
Pyramid	750
Eastern Triangle	783
Latticed	681
Redfin	760
Chevroned	677
Saddled	899
Threadfin	674
Teardrop	898
Humphead Bannerfish	669
Pennant Bannerfish	939
Longfin Bannerfish	588
Masked Bannerfish	587
Angelfish	544
Regal	663
Bicolour	673
Emperor	756
Blue-girdled	937
Dusky	561
Semicircle	576
Lemonpeel	563
Surgeonfish	546
Convict	547
"Ringtail" sp.	548
Brushtail tang	638
"Bristletooth" sp.	959
Sailfin Tang	961
Mimic	700
Unicorn sp.	550
Tunas/Mackerels	940
Narrow-banded king mackerel	558
Fusiliers	571
"Blue and yellow" sp.	929
Bluestreak	930
Damselfish	589
"Chromis" sp.	590
Blue-Green Chromis	596
Black Bar Chromis	646
Threespot *dascyllus*	671
Humbug *dascyllus*	767
Reticulated *dascyllus*	771
Talbot's demoiselle	612
Whitebelly	654
Staghorn	745
Blue Devil	657
Black	759
Lemon	713
Golden	740
"Seargent" sp.	656
"Anemone fish" sp.	871

Wrasse	598
Diana's hogfish	931
Mesothorax hogfish	611
Humhead	600
Red-banded	932
Checkerboard	725
Twotone	768
Crescent	647
Sixbar	744
Jansen's	678
Cigar	685
Bird	610
Cleaner	605
Rockmover	949
Slingjaw	620
Black-Edged Thicklip	770
Goatfish	615
Half-and-half	648
Two-barred	666
Dash-and-dot	781
Multibarred	934
Blackstriped	616
Yelowfin	897
Triggerfish	624
Redtooth	786
Orangestriped	625
clown	626
Blackbelly Picassofish	927
Pinktail	782
Scthye	692
Halfmoon	796
Picasso	628
Moustache / Titan	623
Grouper	583
Flagtail	682
Peacock	935
Humpback	936
"Honeycomb" sp.	586
Lyretail	946
Saddleback Coral	578
Leopard Coral	580
Soapfish	928
Anthias	642
Parrot Fish	613
Bumphead	933
Bicolour Parrot juv.	614
Spinecheek	581
Twoline	582
Snapper	565
Two-spot	753
Twinspot	956
Black-and-white	569
Bluelined	925
Five-lined	957
Paddletail	564

Rabbitfish	579
Foxface	757
Pencil-streaked	958
Uspi	896
Dartfish	774
Blackfin	695
Cardinalfish	621
Pyjama	917
Blackstriped	717
Toby	636
Spotted	794
Puffer	635
Blackspotted	652
Blenny	926
Yellowtail Poisonfang	705
Bicolour	687
Goby	749
Sphynx	954
Brownbarred	955

OTHER MAJOR FAMILIES

Jack / Trevally	553
Sweetlips	577
Barracuda	560
Moorish Idol	551
Emperor	924

MISCELLANEOUS FAMILIES

Spadefish / Batfish	595
Dottyback	900
Porcupine	634
Trunk / Box / Cowfish	640
Squirrelfish / Soldierfish	619
Filefish	629
Lionfish	631
Scorpionfish / Stonefish	632
Lizardfish	643
Hawkfish	902
Sandperch	675
Sharksucker	787
Needlefish	562
Pipefish	911
Shrimp fish	790
Trumpetfish	664
Moray Eel	637

FURTHER SPECIES

____

____

____

____

____

____

TOTAL FISH

APPENDIX 2

Recording forms used for data collected during Reef Check surveys. Note that these are modified from the standard forms available at http://www.ReefCheck.org/

Site name and code	
Date	
Time of day that work started	
Time of day that work ended	
Longitude of Reef Check transect	
Latitude of Reef Check transect	
Orientation of Reef Check transect	N-S NE-SW E-W SE-NW
Distance of Reef Check transect from shore	_____ m
Distance of site from nearest river	_____ km
River mouth width	<10m 11-50m 51-100m 101-500m
Weather	sunny_____ cloudy_____ raining_____
Air temperature	___ degrees Celsius
Water temperature at surface	___ degrees Celsius
Water temperature at 3 m	___ degrees Celsius
Water temperature at 10 m	___ degrees Celsius
Water temperature at 20 m	___ degrees Celsius
Water temperature at 30 m	___ degrees Celsius
Distance to nearest population centre	_____ km
Approximate population size	_____ x 1000 people
Horizontal visibility in water	_____ m
Vertical visibility in water	_____ m
Why was this site selected?	
Is this site -	sheltered_____ or exposed_____
Any major coral damaging storms in past years?	yes no unknown
How do you rate this site overall in terms of anthropogenic impact?	none____ low____ moderate____ heavy__
What types of impact do you believe occur?	
Number of fishing boats within 500m	
Number of other boats within 500m	
Dynamite fishing	none____ low____ moderate____ heavy__
Poison fishing	none____ low____ moderate____ heavy__
Aquarium fish collection	none____ low____ moderate____ heavy__
Harvest of invertebrates for food	none____ low____ moderate____ heavy__
Harvest of invertebrates for curio sales	none____ low____ moderate____ heavy__
Tourist diving	none____ low____ moderate____ heavy__
Sewage pollution	none____ low____ moderate____ heavy__
Industrial pollution	none____ low____ moderate____ heavy__
Other forms of fishing? (Specify)	none____ low____ moderate____ heavy__
Other impacts? (Specify)	none____ low____ moderate____ heavy__
Is there any form of protection (statutory or other) at this site?	yes_____ no_____
If yes, what type of protection?	
Other comments	

Site name and code:
Depth: Time: Date:

Point Codes

ACB *Acropora* branching	**SC** Soft coral	**RKC** Recently killed coral
ACE *Acropora* encrusting	**SP** Sponge	**RC** Rock
ACS *Acropora* submassive	**ZO** Zoanthids	**SI** Silt/mud
ACD *Acropora* digitate	**AA** Algal assemblage	**RB** Rubble
ACT *Acropora* tabulate	**CA** Coralline algae	**SD** Sand
CB Non-*Acropora* branching	**HA** *Halimeda*	**OT** Other
CE Non-*Acropora* encrusting	**MA** Macroalgae	**WA** Water
CF Non-*Acropora* foliose	**TA** Turf algae	
CM Non-*Acropora* massive		
CS Non-*Acropora* submassive		
CMR Non-*Acropora* mushroom		
CHL *Heliopora*		
CME *Millepora*		
CTU *Tubipora*		

Code	Sps	Code	Sps	Code	Sps	Code	Sps
PS	Pocillopora small	PN	Porites nigrescens	G	Galaxea	MII	Millepora intricata
PM	Pocillopora medium	PR	Porites rus	PLA	Pectinia lactuca	TM	Tubastrea micrantha
PL	Pocillopora large	GA	Goniopora / Alveopora	ME	Mycedium elephantotus	TR	Turbinaria reniformis
SH	Seriatopora hystrix	PCL	Pavona clavus	L	Lobophyllia	BS	Brain small
S	Stylophora	PAS	Pachyseris speciosa	FVA	Favia	BM	Brain medium
MF	Montipora foliosa	PAR	Pachyseris rugosa	FVT	Favites	BL	Brain large
MD	Montipora digitata	CEC	Ctenactis echinata	DH	Diploastrea heliopora		
BA	Bottlebrush Acropora	HL	Herpolitha limax	EU	Euphyllia		
MP	Massive Porites	PT	Polyphyllia talpina	PLE	Plerogyra		
PC	Porites cylindrica	UB	Upsidedown bowl	MIP	Millepora platyphylla		

"Sps" is for coral only - if non-coral, leave blank

(For first segment, if start point is 0 m, last point is 19.5 m)

SEGMENT 1						SEGMENT 2						SEGMENT 3						SEGMENT 4					
0 - 19.5 m						25 - 44.5 m						50 - 69.5 m						75 - 94.5 m					
	Form	Sps		Form	Sps		Form	Sps		Form	Sps		Form	Sps		Form	Sps		Form	Sps		Form	Sps
1			21			41			61			81			101			121			141		
2			22			42			62			82			102			122			142		
3			23			43			63			83			103			123			143		
4			24			44			64			84			104			124			144		
5			25			45			65			85			105			125			145		
6			26			46			66			86			106			126			146		
7			27			47			67			87			107			127			147		
8			28			48			68			88			108			128			148		
9			29			49			69			89			109			129			149		
10			30			50			70			90			110			130			150		
11			31			51			71			91			111			131			151		
12			32			52			72			92			112			132			152		
13			33			53			73			93			113			133			153		
14			34			54			74			94			114			134			154		
15			35			55			75			95			115			135			155		
16			36			56			76			96			116			136			156		
17			37			57			77			97			117			137			157		
18			38			58			78			98			118			138			158		
19			39			59			79			99			119			139			159		
20			40			60			80			100			120			140			160		

MAKE CORAL CATEGORIES BOLD IF THEY ARE RECRUITS (I.E. < 5 CM DIAMETER)

TOTAL NUMBER OF RECRUITS (ALL LIFE FORMS COMBINED)

MAKE CORAL CATEGORIES ITALICS IF THEY ARE BLEACHED

TOTAL NUMBER OF BLEACHED CORALS (ALL LIFE FORMS COMBINED)

REEF CHECK 2001- Please fill in all Black outlined boxes

Site Name:

Depth:

Date: Time:

Indo-Pacific Belt Transect : Fish

Data recorded by:

	0-20m	25-45m	50-70m	75-100m
Butterfly fish (ALL SPS)				
Sweetlips (Haemulidae) (ALL SPS)				
Snapper (Lutjanidae) (ALL SPS)				
Two-spot				
Checkered				
Black-and-white				
"Bluelined"				
Paddletail				
Barramundi Cod (*Cromileptes*)				
Grouper >30cm (Give sizes in comments) (ALL SPS)				
Flagtail				
Peacock				
"Honeycomb"				
Lyretail				
Humphead wrasse				
Bumphead parrot				
Other Parrotfish (>20cm)				
Tuna / Mackerel				
Fusiliers				
Surgeonfish				
Rabbitfish				
Barracuda				
Jacks / Trevally				
Moray eel				

"ALL SPS" means that all individuals from that family should be counted in the box and additional target species are counted a second time on subsequent line e.g. a paddletail snapper is

counted both as a snapper AND as a paddletail snapper

Indo-Pacific Belt Transect : Invertebrates

Data recorded by:

	0-20m	25-45m	50-70m	75-100m
Banded coral shrimp (*Stenopus hispidus*)				
Diadema urchins				
Pencil urchin (*Heterocentrotus mammilatus*)				
Sea cucumber (edible only)				
Crown-of-thorns star (*Acanthaster*)				
Giant clam (*Tridacna*)				
Triton shell (*Charonia tritonis*)				
Drupella sp				
Squid				
Octopus				
Lobster				

For each segment, rate the following as: None=0, Low=1, Medium=2, High=3

Coral damage : Anchor				
Coral damage:Dynamite				
Coral damage : Other				
Trash : Fish nets				
Trash : Other				

Comments:				

Grouper sizes (cm)				
Bleaching (% of coral population)				
Bleach (% of colony)				
Suspected disease (type/%):				
Rare animals sighted (type/#):				
Other:				