MAMANUCA CORAL REEF CONSERVATION PROJECT - FIJI 2001

PILOT PROJECT FINAL REPORT

- Prepared by -

Alastair Harborne, Marine Science Co-ordinator
Jean-Luc Solandt, Indo-Pacific Marine Scientist
Daniel Afzal, Project Scientist
Mark Andrews, Science Officer
Peter Raines, Managing Director

September 2001

Ministry of Tourism and Transport

Coral Cay Conservation Ltd
13th Floor, The Tower
125 High Street, Colliers Wood
London, SW19 2JG, UK
Tel: +44 (0)870-750-0668
Fax: +44 (0)870-750-0667
Email: marine@coralcay.org
www: www.coralcay.org

CORAL CAY CONSERVATION
Expeditions

Project supported by:

AIR NEW ZEALAND
A STAR ALLIANCE MEMBER
BRITISH AIRWAYS
Subsurface Fiji
The University of the South Pacific
fiji VISITORS BUREAU
CASTAWAY
Beachcomber Fiji Resort
Musket Cove Island Resort
TOKORIKI ISLAND RESORT FIJI
AQUA-TREK

CONTENTS

ACKNOWLEDGEMENTS

The success of the *Mamanuca Coral Reef Conservation Project – Fiji 2001* would not have been possible without: the vision and leadership provided by the Government of Fiji, and in particular the Ministry of Tourism and Transport and the Fiji Visitors Bureau; the generous hospitality of Ratu Sevanaia Vatunitu Nabola and Solevu village; and the guidance, encouragement and generous support provided by the following project partners (listed in alphabetical order):

Air New Zealand: Francis Mortimer, Simon Bean and colleagues.
Aqua-Trek: Andrew Redfern, Yoshi Kyakuno and colleagues.
Beachcomber Island Resort: Dan Costello and colleagues.
Biological Consultants Fiji: Edward Lovell.
British Airways.
British High Commission, Fiji.
Castaway Island Resort: Geoff Shaw, Garry Snodgrass, Craig and Karen Flannery, Geof and Trudy Loe, Veresa Naiqara, Tevita Layasewa, Joape Waqairawai and colleagues.
Dive Pacific Magazine.
Dive Tropex: Alex and Will Wragg.
Fiji Institute of Technology: Winifereti U. Nainoca.
International Secondary School, Suva: Litiana Temol and colleagues.
Live & Learn: Christian Nielsen.
Musket Cove Resort: Dick Smith and colleagues.
PADI: Colin Melrose.
Resort Support: Helen Sykes.
SOPAC: Robert Smith and colleagues.
South Seas Cruises: Mark Fifield and colleagues.
Subsurface Fiji: Tony Cottrell, John Brown and colleagues.
Tokoriki Island Resort: Andrew Turnbull and colleagues.
UNDP: Jenny Bryant-Tokalau and colleagues.
University of Newcastle: Peter Mumby, William White (SeaMap Research Group) and colleagues.
University of the South Pacific: Robin South, Robyn Cumming, Johnson Seeto, Shirley Mohammed and colleagues.
West Side Water Sports: Lance and Lily Millar, John Purves and colleagues.
WWF: Dermot O'Gorman, Lisette Wilson, Etika Rupeni and colleagues.

Finally, we would like to thank the following Coral Cay Conservation team members:

PROJECT STAFF	
Daniel Afzal, Project Scientist	Mike McCrohan, Project Manager
Mark Andrews, Science Officer	Api Nawaqa, Driver
Anna Hilton, Medical Officer	Selita Ratu, Cook
Jane Marshall, SCUBA Instructor	Amani Sorokoverata, Boat Driver

VOLUNTEERS		
Richard Adams	Peter Fry	Simon Pickles
Alexandria Aston	James Gibb	Ben Pilbrow
Matt Bird	Ruth Harris	Fionn Pilbrow
Bill Bradley	Lorna Jones	Paul Steedman
Rebecca Bruer	Jeremy Kashnow	Junichi Tomonari
Jo Davies	Catherine Kelly	Edward Trump
Heather Dugmore	Alexandra Kent	Emma Viner
Kate Dyer	Lucie McNeil	Gary Wallis
Freddie Fackelmayer	Steve Melville	Sharon Wallis
Alexandria Fisk	Jenny Morrell	Joanne Wilson
Monifa Fiu	Guy Negretti	Olivia Wilson
Nick French	Ellie Perkins	

EXECUTIVE SUMMARY

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

- Stakeholders in the Mamanuca Islands are aware of the value of conserving coral reefs and in 2001 invited Coral Cay Conservation (CCC) to assist in the implementation of a pilot project entitled '*Mamanuca Coral Reef Conservation Project – Fiji 2001*' (MCRCP).

- Fieldwork during the pilot phase of the MCRCP focused on gathering data from a wide range of geographical locations and habitat types using: baseline transects for habitat mapping; Reef Check surveys to assess reef health; and size-frequency surveys to assess the population status of five target coral taxa.

- The pilot project of the MCRCP showed a range of detrimental anthropogenic influences to be present in the Mamanuca Islands. Perhaps the most obvious of these impacts was the mass coral bleaching event which occurred in early 2000. There was evidence that these impacts reduce the attractiveness of the reefs to divers.

- A preliminary habitat map was produced and the area occupied by each of the habitats within the project area (1826 km^2) was calculated. This showed that there is only approximately 70 km^2 (3.9%) of reefal habitats. Similarly, the area supporting the most coral-rich benthic class is only approximately 20 km^2 (1.1%), showing the damage caused by bleaching and local anthropogenic impacts and the urgent need to conserve remaining coral rich areas.

- Reef Check data showed that benthic communities within the project area have been significantly impacted and most of the sites are currently in 'poor' condition using criteria based on coral cover. Coral is the basis of any reef community and, for example, in the Mamanuca Islands there was a clear pattern of a greater abundance and diversity of fish in coral rich areas.

- The support by many stakeholders for mitigating measures in the Mamanuca Islands represents a clear desire to address the threats to reef health and work towards sustainable use. Such a goal could be addressed by both reducing the threats to reef health and establishing a chain of marine reserves.

- Marine reserves are important since they: conserve biodiversity; increase fish abundances within the reserve and provide 'spill-over' into surrounding areas; facilitate reef recovery; separate conflicting uses; serve as a centre for public education and attract sustainable tourist revenue.

- 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 g*iven that the reefs delineated on the habitat map cover approximately 70 km^2, the eventual aim should be to protect 14 km^2 of shallow (<30 m) benthic habitat within the Mamanuca Islands from fishing.*

- A series of 10 recommendations have been made relating to the conservation and sustainable management of the reefs in the Mamanuca Islands. Many of these recommendations could be achieved by extending the pilot phase of the MCRCP to a long-term commitment by CCC, in conjunction with Fijian partners, to the area.

SUMMARY

Introduction

- Much of Fiji's wealth is generated by its extensive marine resources, which provide, for example, protein from fishing and income from tourism.
- A suite of factors currently threatens the ecological balance and health of Fiji's reef ecosystems.
- 'Volunteer' divers, who are able to provide useful, cost-efficient data for coastal zone management, can assist the conservation of coral reefs. This technique has been pioneered and successfully applied by Coral Cay Conservation (CCC).
- Stakeholders in the Mamanuca Islands are aware of the value of conserving coral reefs and in 2001 invited CCC to assist in the implementation of a pilot project entitled '*Mamanuca Coral Reef Conservation Project – Fiji 2001*' (MCRCP).

Project background

- The coastal zone of Fiji (which includes seagrass beds, mangroves and coral reefs) is threatened by a number of factors, for example pollution following land-use conversion and over-fishing.
- Localised anthropogenic threats have been exacerbated by storm damage, outbreaks of the coral eating crown-of-thorns starfish and coral bleaching events. For example, most areas of Fiji, including the reefs of the Mamanuca Islands, suffered from a mass coral bleaching event in early 2000.
- Marine reserves are currently limited and expansion of this network requires additional data and conservation education.
- The aim of the pilot project of the MCRCP was to initiate a programme of surveys, training and conservation education to assess the status of local reefs and improve environmental awareness amongst neighbouring communities.

Methods

Survey strategy

- Fieldwork during the pilot phase of the MCRCP focused on gathering data from a wide range of geographical locations and habitat types.
- Data were summarised for both the whole project area and five 'reef complexes' to examine spatial patterns at a range of scales (Mana Island, Namotu Group, Inner Malolo Group, Outer Malolo Group and Navini Island).
- The survey techniques used were: baseline transects for habitat mapping; Reef Check surveys to assess reef health; and size-frequency surveys to assess the population status of five target coral taxa. Data were collected at similar sites to facilitate comparisons between data sets.

Volunteer training

- During the MCRCP, CCC volunteers underwent an intensive twelve-day training programme to provide them with the skills necessary to accurately and consistently collect the requisite data.

Baseline transect technique

- Habitat mapping was achieved using a standard baseline survey technique developed by CCC that uses a series of transects perpendicular to the reef.
- Transects, or parts of transects, were surveyed by a team of four trained divers, each assessing either the physical characteristics of the site or the abundance of a specific group of organisms (e.g. fish or hard corals).
- Certain oceanographic data and observations on obvious anthropogenic impacts and activities were also recorded at depth by the divers and from the surface support vessel.

Habitat mapping

- In order to produce a preliminary habitat map for the project area, a 'Landsat 7' satellite image was purchased.
- This image was geometrically corrected and the land, deepwater and clouds were masked.
- Following an 'unsupervised classification' of the image, the use of field data from the baseline transects facilitated the assignment of a benthic class to every point on the map.

Reef Check

- The widely used 'Reef Check' protocol was used to assess reef health. The protocol utilises a 100 m transect, split into four 20 m sections, along a given depth contour.
- Five types of data were recorded: a site description sheet; abundance of commercially important fish; abundance of target invertebrate taxa; obvious anthropogenic impacts and the percentage cover of substratum types and components of the benthic community.

Coral size-frequencies

- At each site, coral size-frequency surveys combined the sizing of colonies of five target taxa with an assessment of the percentage of living tissue in a series of 49 m^2 quadrats along a notional 100 m transect.
- Target taxa were 'massive' life forms of the genus *Porites*, *Pocillopora verrucosa* / *meandrina* / *elegans*, *Ctenactis echinata*, *Diploastrea heliopora* and *Seriatopora hystrix*.

Observations of megafauna

- Observations of 'megafauna' were recorded throughout the pilot phase of the MCRCP.

Data analysis

- Data generated by each survey technique were analysed via a suite of univariate and multivariate statistics either for the whole project area or for each reef complex.
- In addition, Reef Check data were used to plot a 'ternary diagram' of coral morphology in order to assign conservation values to each site.

Community work

- As part of the pilot phase of the MCRCP, a marine ecology workshop designed for the diving professional working in the Mamanuca Islands was conducted.
- Students from the International Secondary School, Suva, visited the pilot phase as part of their course on analysing marine ecosystems.

Meetings during the course of the pilot phase of the MCRCP

- Daniel Afzal participated in a workshop to discuss the 'WWF Community Based Marine Protected Area Management Plan Development for Waisomo and Narikoso, Ono District, Kandavu' and a meeting of the Global Coral Reef Monioring Network for the Southwest Pacific 'Node'.
- Project staff attended several other meetings to introduce the project to local stakeholders, including Ratu Sevanaia Vatunitu Nabola, Luilui Ni Yavusa (Chief of Solevu village).

Results

Volunteer training

- The results of the various tests and validation exercises that concluded the science training weeks showed that the volunteers achieved a high standard of identification and surveying proficiency.

Baseline transects

- A total of 74 dives were completed (37 full baseline transects) in the project area.
- Mean surface water temperature was 26.4^{o}C, mean surface water salinity was 34.6‰ and winds were predominantly from the south-east.
- Water visibility (a measure of sedimentation) varied significantly between the five reef complexes: turbidity increased from the Namotu Group (lowest sediment load) to the Inner Malolo Group and Navini Island (joint highest).
- Algae was the most abundant surface impacts but litter was also relatively common.
- Litter, coral damage and bleaching (only occasional colonies) were common underwater impacts. There was some variation between reef complexes e.g. sedimentation was more common in the Inner Malolo Group complex.
- The highest density of boats was in the Namotu Group and the Inner Malolo Group.
- Aesthetic and biological ratings of dive quality were typically between average to good, with the exception of the Inner Malolo Group complex where ratings were poor to average. The highest ratings were assigned at Mana Island and in the Namotu Group.
- Analysis of the biological survey data discriminated seven major benthic classes: Sand with sparse algae and seagrass; Sand and algae; Sand with small coral patches; Bedrock, dead coral and sparse corals; Mixed substratum, green algae and coral; Sand with large coral patches; Bedrock and mixed corals.
- Damselfish were the most common fish in the project area.
- There was evidence of different fish communities in each benthic class with generally lower abundances in sand classes compared with coral classes.

- After restricting analysis to the most coral-rich benthic class there was evidence of variations of target fish species between reef complexes e.g. unicornfish, triggerfish and flagtail groupers were most abundant in the Namotu Group.
- Across all survey sites there was a correlation between coral and fish species richness.
- There was evidence of different invertebrate communities in each benthic class with generally lower abundances in sand classes compared with coral classes.
- After restricting analysis to the most coral-rich benthic class there was evidence of variations of target invertebrate species between reef complexes e.g. *Diadema* urchins were most abundant in the Inner Malolo group.

Habitat mapping
- A preliminary habitat map was produced.
- The area occupied by each of the habitats within the project area was calculated from the preliminary habitat map.

Reef Check
- A total of 22 Reef Check surveys were completed, generally at depths of less than 6 m.
- Linking data from Reef Check surveys with those from baseline transects showed that, for example, mean percentage coral cover in the most coral-rich benthic class was 18.6%.
- A summary of the benthic community for all sites combined shows the community generally had a low total coral cover (mean 13.7%) and was dominated by algae (mean 28.4%).
- The most abundant fish were surgeonfish and fusiliers. Commercially important families such as groupers and sweetlips had mean abundances of <1 per 500 m^3.
- Most of the invertebrate taxa, with the exception of *Diadema* urchins, were rarely seen. Coral recruits (juvenile colonies 1-5 cm in size) were also relatively common.
- Of the 45 parameters measured during Reef Check surveys, only eight (17.8%) varied significantly between reef complexes.
- Regression analysis between each fish and invertebrate taxa and coral cover highlighted significant correlations for snappers, groupers, parrotfish and surgeonfish.
- The 'ternary diagram' plotting the conservation value of each Reef Check site, showed that 12 of the sites (54.5%) had conservation values of four, nine sites (40.9%) had conservation values of one and a single site had a conservation value of three.

Coral size-frequency
- Coral size-frequency surveys were conducted at six sites (838 colonies).
- Colonies of each species were generally healthy (percentage of live tissue > 78%).
- Graphs of the frequency of each size class of each target coral taxa provided demographic information such as *Porites* 'massive' being most commonly 16-20 cm in size.
- There was evidence that colonies of *Porites* 'massive' in the Inner Malolo Group complex had less living tissue but were larger than those in the Outer Malolo Group.

Observations of megafauna

- Several observations of sharks were recorded, along with sightings of a humpback whale and pods of spinner dolphin.

Community work

- All participants in the 'Marine Ecology Workshop for the Professional Diver' strongly agreed that the information was applicable to their work and that such workshops should continue.

Discussion

Training

- The training programme used by CCC for the pilot phase of the MCRCP proved to be appropriate for volunteer-based survey work in Fiji.

Baseline data

- Climate data showed that the environmental conditions were seasonally typical during the fieldwork.
- Modelling water movement patterns more accurately than was possible in this study will be vital to assess entrainment of fish and coral larvae between 'source' and 'sink' areas.
- There was evidence of a number of anthropogenic impacts affecting the area. For example, there was relatively high sedimentation in the Inner Malolo Group because of the development of a series of major resorts and felling natural forests. Generic coral damage, possibly from diver or anchor damage, was common in the Mana Island, Namotu Group and Inner Malolo Group reef complexes.
- Overall, the indication is that all the reefs of the project area have been subjected to some degradation but the reefs of the Inner Malolo Group seem most heavily impacted and this was reflected in the aesthetic and biological ratings assigned by the survey teams.
- The seven benthic classes derived from the biological data are likely to cover all the major classes present on the reefs surveyed.
- The benthic classes were all relatively coral poor and this is evidence of the major effect that the 2000 coral bleaching had on the Mamanuca Islands. Coral mortality seems to have led to increased algal growth.
- There was a recurring pattern of a greater abundance and diversity of fish in coral rich classes because of the increased spatial complexity of these habitats.
- The commercially important flagtail grouper was most abundant in the Namotu Group complex, possibly because of a lower fishing pressure, the presence of a privately owned marine reserve and / or the high abundance of prey species.
- Invertebrates were generally uncommon but the particularly low abundance of commercially important invertebrates was noticeable (e.g. no tritons were seen).
- The low abundances of the corallivorous *Drupella* snails and crown-of-thorns starfish indicated that the threat from these species is currently minimal.

Habitat mapping

- Further data are required to improve the classification of the satellite image and more sophisticated processing will result in a more accurate map. However, the current version of the map is appropriate for the preliminary assessment of, for example, the locations of coral rich areas.

- The estimates of areal extents of each benthic class are instructive e.g. there is only approximately 70 km^2 of reefal habitats (3.9% of the project area). Similarly, the area supporting the most coral-rich benthic class is only approximately 20 km^2 (1.1%) showing the damage caused by bleaching and local anthropogenic impacts and the urgent need to conserve remaining coral rich areas.

Reef Check

- Reef Check data showed that benthic communities within the project area have been significantly impacted, much of which can be attributed to the 2000 coral bleaching event e.g. most of the sites are currently in 'poor' condition using the coral cover criteria of the ASEAN-Australia Living Coastal Resources project.
- The fish and invertebrate data also indicated significant human impacts, especially over-fishing e.g. some valuable species, such as the bumphead parrotfish, were absent.
- The number of coral 'recruits' (colonies sized from 1-5 cm) provided some evidence of reef recovery.
- Reef Check data provided further evidence of fish and invertebrate abundances increasing with increasing coral cover e.g. all other things being equal, the abundance of snappers increases by 1.4 fish per 500 m^3 with an increase of coral cover of 10%.
- Analysis of 'conservation values' showed that, despite the impacts to the area, a large proportion of the sites had a high conservation value (>50%) but further data are needed and these results must be combined with other information such as live coral cover.

Coral size-frequencies

- Size-frequency graphs showed that, despite recent mortality, population structures were typical. These data can be used, for example, to assess the impacts of the aquarium trade by comparing the demographics of the natural and harvested colonies.
- Statistics indicate that colonies are healthy and are likely to be able to reproduce sexually, providing larvae for regenerating areas damaged by bleaching.
- The lower percentage of living tissue on 'massive' *Porites* in the Inner Malolo Group complex may be linked to factors such as sedimentation.

Observations of megafauna

- A relatively large number of megafaunal species were seen during the pilot phase of the MCRCP, which is encouraging for the tourist industry.

Community work

- All coastal zone management initiatives must take into account the needs and concerns of local communities.
- Although the community work completed during the pilot phase of the MCRCP was inevitably limited, it is clear that such work can be successful and represented a first step that will be subject to evaluation.

Conclusions

- The pilot project of the MCRCP has shown that a suite of detrimental anthropogenic influences is present in the Mamanuca Islands. Perhaps the most obvious of these impacts was the mass coral bleaching event which occurred in early 2000.
- The link between coral cover and the abundance of commercially important fish was clearly demonstrated by data collected during the pilot phase.
- Although the coral bleaching event was severe, its impacts appear to be acting synergistically with more localised impacts including: sedimentation; over-fishing; increased nutrient loads; collection of aquarium species; mechanical damage (from dredging, anchors and diving); coral diseases; crown-of-thorns starfish; and litter.
- The results of this work also show, for example, that some parameters indicate lower reef health and greater threats in the 'Inner Malolo Group' reef complex.
- The support by many stakeholders for mitigating measures in the Mamanuca Islands represents a clear desire to address the threats to reef health and work towards sustainable use. Such a goal could be addressed by both reducing the threats to reef health (e.g. improving water quality) and establishing a chain of marine reserves.
- Further research is required to ensure new reserves are placed in optimal positions.
- Theoretical models indicate that 20% of the reefs of an area should be 'no-take' in order to maximise the chances of sustaining the fisheries and g*iven that the reefs delineated on the habitat map cover approximately 70 km^2, the eventual aim should be to protect 14 km^2 of shallow (<30 m) benthic habitat in the Mamanuca Islands from fishing.*
- 'Conservation values' used for each Reef Check site in this study represent a good protocol for highlighting priority areas within the project area.

Recommendations

Given the nascent status of the MCRCP, the following recommendations are intended as guidance to stimulate discussion rather than as a blueprint for coastal zone management in the Mamanuca Islands.

- Aim to establish one or more multiple use marine protected areas in the Mamanuca Islands with regulations limiting deleterious effects (i.e. integrated coastal zone management). These protected areas should aim to eventually contain approximately 14 km^2 of 'no-take' zones.
- No-take zones in the Mamanuca Islands should integrate a range of factors including the preference of many fish species for coral rich habitats, protecting a range of habitat types, including mangroves and seagrass beds, and 'conservation values' provided by ternary diagrams and other techniques.
- Consider the establishment of a 'Mamanuca Coastal Zone Management Group', including representatives from local communities, the tourist industry, Fijian NGOs, government agencies, the University of the South Pacific and other stakeholders.

- Establish conservation education programmes, including the rationale for marine protected areas, for all stakeholders at the local and national level but particularly targeted at local communities and the tourist industry.
- Establish an integrated programme to monitor reef health in the Mamanuca Islands. Reef Check has been shown to provide a good basis for reef health monitoring and non-professional divers can collect these data accurately and rapidly. The sites surveyed during the pilot phase of the MCRCP could form the basis of this monitoring programme and could be re-surveyed by local people (such as resort staff) following appropriate training programmes. All data collected by this monitoring programme should feed into both the Southwest Pacific nodes for Reef Check and GCRMN.
- Establish a programme to monitor fisherfolk and their activities in the Mamanuca Islands. Such a programme should focus on species caught, weights landed, sites used and ideally catch per unit effort. Such a programme should incorporate both artisanal and commercial operations.
- Use the data already recorded by resorts on the number of dives undertaken at sites in the Mamanuca Islands. These data could be used to help interpret monitoring programmes and assist any future 'carrying capacity' calculations.
- Establish a standard environmental awareness briefing for all divers that can be used by dive resorts in the Mamanuca Islands. Such a briefing could be developed using the PADI AWARE programme. Mechanical damage to dive sites could also be reduced by extending and improving the system of permanent mooring buoys.
- Establish an integrated GIS and associated meta-database for the Mamanuca Islands, including data from the pilot phase of the MCRCP. Such a system could also be combined with any future national database and information held by the Southwest Pacific node of GCRMN.
- Examine the potential of using data collected by the pilot phase of the MCRCP as the basis of national habitat classification scheme and subsequent national habitat map.

Many of the recommendations listed here could be achieved by extending the pilot phase of the MCRCP to a long-term commitment by CCC, in conjunction with Fijian partners, to the Mamanuca Islands.

LIST OF FIGURES AND TABLES

LIST OF ABBREVIATIONS

ANOSIM	-	Analysis of Similarity
AVOVA	-	Analysis of Variance
CCC	-	Coral Cay Conservation
GCP	-	Ground Control Points
GCRMN	-	Global Coral Reef Monitoring Network
GIS	-	Geographic Information System
GPS	-	Global Positioning System
ISS	-	International Secondary School
KS	-	Kruskal-Wallis
MCRCP	-	Mamanuca Coral Reef Conservation Project – Fiji 2001
p	-	Probability value of a statistical test
PRIMER	-	Plymouth Routines in Multivariate Ecological Research
PS	-	Project Scientist
R^2	-	Regression correlation coefficient
SCUBA	-	Self-contained underwater breathing apparatus
SIMPER	-	Similarity percentage
SMB	-	Surface Marker Buoy
SO	-	Science Officer
SOPAC	-	South Pacific Applied Geoscience Commission
USGS	-	U.S. Geological Survey
WWF	-	Worldwide Fund for Nature

> *"The essence of coral-reef management is in many ways to find the means of making man's demands upon the ecosystem compatible with the reef's ecology. To the extent that man has become a major, if not the dominant, influence upon the biological communities of coral reefs, understanding the impact of human influence is probably the most critical question in reef ecology."*
>
> Craik *et al*., 1990

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. 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 has 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-sectorial 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; Harborne *et al*., In press). This technique has been pioneered and successfully applied by Coral Cay Conservation (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 Coral Cay Conservation Trust (the only British-based charity dedicated to protecting coral reefs) and the USA-based Coral Cay Conservation Foundation.

The Mamanuca Islands in western Fiji (Figure 1) 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).

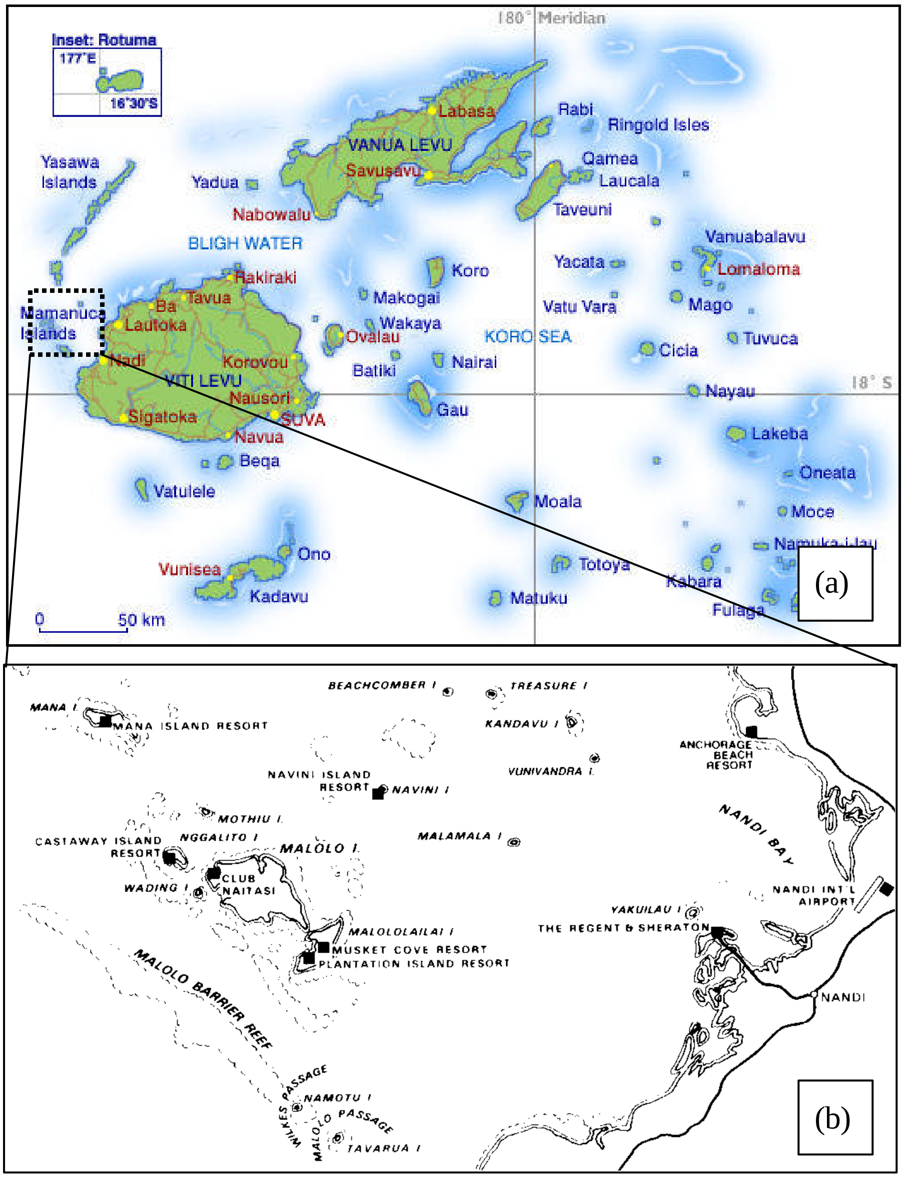


Figure 1. (a) The Fiji islands, showing the project area (dashed line) for the MCRCP. *Source*: Fiji Visitors Bureau. (b) Major islands with the Mamanucas.

This pilot project, which ran from June 8th to August 30th 2001[1], 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. The pilot project was comprised of two, six weeks phases (Phase 1 : June 8th to July 20th; Phase 2: July 20th to August 30th) and was based at 'Raviniyake' on Castaway Island, which was kindly provided as in-kind support. CCC volunteers were given the opportunity to participate on either Phase 1 or Phase 2 or to be present for the whole 12 week project. Subject to evaluation of the outputs from this pilot project by Government and other stakeholders, the objective is for CCC to establish a long-term presence in the Mamanuca Islands in order to provide detailed biological assessment and monitoring data, along with training, capacity building and environmental education work.

This report documents the results and conclusions of the pilot phase of the MCRCP and offers recommendations for both conservation initiatives and future work in the project area.

[1] The Memorandum of Understanding with the Ministry of Tourism for the pilot project of the MCRCP is shown in Appendix 1.

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 north-eastern 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.

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).

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. For example, South and Skelton (2000) and Cumming *et al*. (In press) report bleaching of up to 90% of coral colonies, although there was significant spatial variation in its severity throughout the country. 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. Fiji is also affected by a severe cyclone every 3-4 years (Vuki *et al*., 2000), causing significant coral damage in shallow water, and population explosions of crown-of-thorns starfish have 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 are, therefore, currently 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. However, a preferable approach is conservation education that highlights the advantages 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. This latter 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). 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. Similarly to other island groups in Fiji, coastal zone management in the Mamanuca Islands is relatively nascent. However, the oldest private sanctuaries in Fiji, established by "Beachcomber Cruises" in the 1970s, are found around Tai (Beachcomber) and Lovuka (Treasure) Islands.

2.3 Aims and objectives

For the pilot phase of the MCRCP, CCC and their Fijian partners developed a programme of surveys, training and conservation education aimed at assessing the status of local reefs and improving environmental awareness amongst neighbouring communities. The primary aims of the project were to harness the skills and resources of the participating organisations to provide baseline and reef health data, training opportunities for local counter-parts and environmental awareness programmes, as a basis for an integrated approach to coral reef conservation in the Mamanuca Islands (Table 1).

Table 1. Main aims, objectives and anticipated outputs of the pilot phase of the MCRCP.

AIM	OBJECTIVE	ANTICIPATED OUTPUTS
➲ Resource assessment.	❶ Undertake an initial scientific survey of target coral reefs. ❷ Conduct preliminary human impact assessment studies. ❸ Establish a baseline database. ❹ Provide preliminary management tools and recommendations.	🗎 Initial baseline database. 🗎 Description of reef habitat types. 🗎 Documentation of gross anthropogenic impacts. 🗎 Preliminary habitat map using satellite imagery. 🗎 Preliminary management recommendations.
➲ Reef health assessment.	❶ Undertake 'Reef Check' surveys within the project area to quantitatively assess benthic and fish communities and anthropogenic impacts. ❷ Establish a Reef Check database for the Mamanuca Islands. ❸ Provide data for the national and global Reef Check databases. ❹ Provide preliminary management tools and recommendations.	🗎 Quantitative assessment of reef health. 🗎 Data set for comparison with future surveys. 🗎 Preliminary management recommendations.
➲ Coral size-frequency surveys.	❶ Generate a preliminary data set on the sizes of colonies of five target coral species ❷ Provide data to assist monitoring of the aquarium trade, which collects coral species.	🗎 Size-frequency statistics for five coral species. 🗎 Data set for comparison with future surveys.
➲ Training and conservation education.	❶ Provide scientific and SCUBA training for CCC volunteers and local counterparts. ❷ Heighten awareness of marine resources, their use and protection. ❸ Begin to develop a sense of community stewardship in managing the coastal zone.	🗎 Trained project members. 🗎 Increased awareness amongst local communities.

One of the major planned outputs of the pilot phase of the MCRCP was a preliminary marine habitat map. 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.

3. METHODS

3.1 Survey strategy

Since the area encompassed by the MCRCP is extensive and the fieldwork during the pilot phase was limited to 12 weeks, the survey strategy focused on gathering data from a wide range of geographical locations. The aim was to generate data from a broad range of habitat types that represent most reef types of the area and hence provide preliminary comparisons and guidance for future research. Surveys in a series of areas also aimed to create standardised data that would allow comparisons at a range of scales, i.e. between areas within the Mamanuca Islands or between areas in the Mamanuca Islands and other areas of the South Pacific region. Areas to be surveyed were chosen based on local knowledge, popular dive sites, reconnaissance dives and an aerial survey.

The most easterly planned survey site was Navini Island. Sites were also planned for the 'Malolo' group where the reefs abut relatively large islands (dominated by Malolo Island itself) and also form submerged platfroms. The most northerly surveys were planned around Mana Island and finally the most western surveys were to be on the 'Malolo Outer Barrier Reef'. Along with summary data for the whole project area, these survey sites allowed the data to be split into five 'reef complexes' to examine more detailed spatial patterns of ecological processes or anthropogenic impacts. These reef complexes are detailed in Table 2 and Figure 2.

Table 2. A description of the five reef complexes delineated during the pilot phase of the MCRCP.

Reef complex	Description of extent
Mana Island	Fringing and platform reefs around Mana Island
Namotu Group	Fringing reefs around Namotu (Magic) Island, Tavarua Island and the Malolo Outer Barrier (Ro Ro) Reef
Inner Malolo Group	Fringing reefs around Qalito (Castaway) Island, Malolo Island, Mothiu (Honeymoon) Island, Wadingi Island and Malololailai Island
Outer Malolo Group	Platform reefs around the Inner Malolo Group
Navini Island	Fringing reefs around Navini Island

Three survey techniques were used during the pilot phase of the MCRCP: baseline transects for habitat mapping; Reef Check surveys to assess reef health; and size-frequency surveys to assess the population status of five target coral taxa. Baseline transects were completed during Phase 1 of the pilot project to allow time for subsequent analysis in conjunction with remotely sensed imagery. Phase 2 focused on Reef Check surveys close to the paths of the baseline transects so that the data sets would be complimentary and could be analysed in conjunction. Size-frequency surveys, measuring the height and diameter of colonies of given target taxa, were completed during the final week of Phase 2. Although limited time was available for size-frequency work, this technique collected important data since the population ecology and demographic structure of coral communities have received relatively little global research attention.

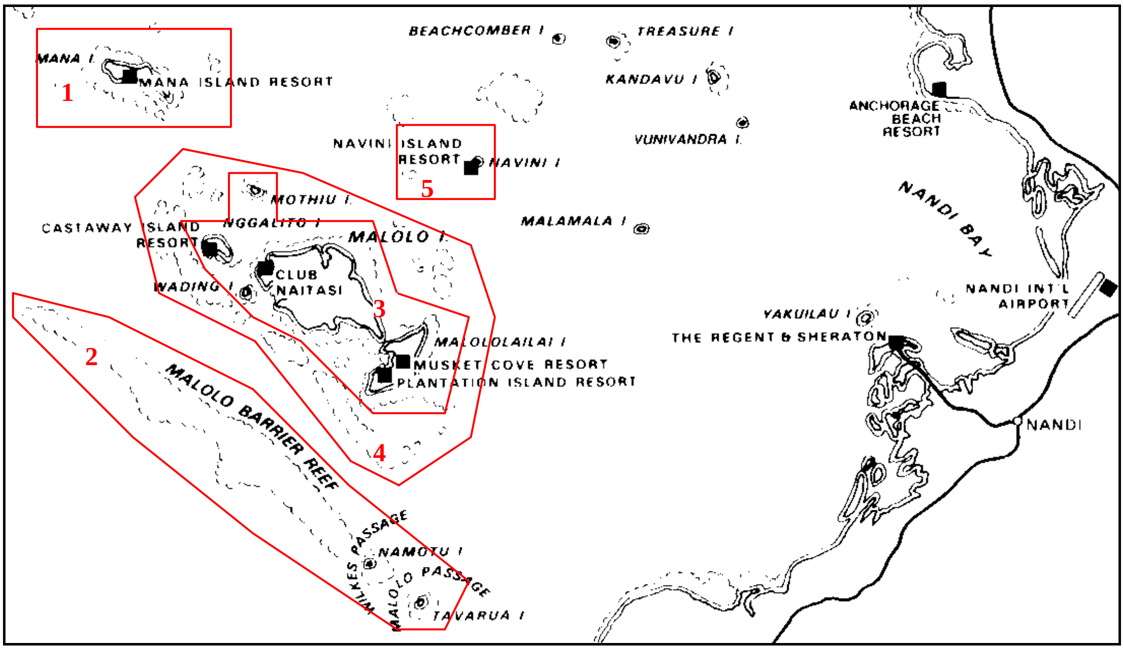


Figure 2. Diagrammatic representation of the five reef complexes (red boxes) delineated for the pilot phase of the MCRCP. 1 = Mana Island; 2 = Namotu Group; 3 = Inner Malolo Group; 4 = Outer Malolo Group; 5 = Navini Island.

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 MCRCP, CCC used an intensive 12-day training programme, plus one day of validation, which is outlined in Tables 3 and 4. Note that the only variation between these schedules is the teaching of the CCC baseline transect technique during Phase 1 and the Reef Check protocol in Phase 2. 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 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' 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 1993 to test the accuracy of volunteer divers conducting baseline transect surveys (Mumby *et al*., 1995).

Table 3. Science training week timetable for CCC volunteers during Phase 1 of the MCRCP. ID = identification.

	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7 *NO DIVING*	DAY 8	DAY 9	DAY 10	DAY 11
⇩ AM		**Lecture 3** Intro to coral reef ecology **Practical** Reef orientation	**Lecture 6** Hard coral ID **Practical** Hard coral ID	**Lecture 8** Hard coral ID Substratum **Practical** Hard coral ID	**Lecture 12** Intro to fish ID - Families **Practical** Fish ID – Families **Review** Fish ID – Families	**Lecture 15** Fish ID – target species **Practical** Fish ID – target species **Review** Fish ID – target species		**Lecture 17** Invert. ID Sponge ID **Practical** Invert. ID **Review** Invert. ID	**Lecture 19** Intro to CCC survey methods **Practical** CCC survey methods **Review** CCC survey methods	**Review** ID – coral, fish, inverts & algae **Skills validation** Benthic validation **Examination** Inverts & algae	**Review** ID – hard & soft corals **Skills validation** Corals (re-take) **Lecture 22** Other survey methods
⇩ PM	**Lecture 1** Fiji: Local culture & customs	**Lecture 4** Intro to hard coral biology & life forms **Practical** ID - coral life forms **Review** Coral life forms	**Lecture 7** Hard coral ID **Practical** Hard coral ID	**Lecture 9** Soft coral ID & other Cnidaria **Practical** Hard/soft coral ID **Review** Hard/soft coral ID	**Lecture 13** Fish ID – target species **Practical** Fish ID – target species **Review** Fish ID – target species		**Lecture 16** Marine plants & algae **Practical** Marine plants & algae ID (snorkel) Specimen ID – reference collections	**Review** ID – inverts & algae **Practical** ID – inverts & algae	**Lecture 20** Intro to CCC survey forms, habitat classifications, use of Abundance Scales **Practical** Practice survey	**Skills validation** Coral trail	**Review** ID – fish **Skills validation** Fish **Review** Validation assessments
EVE	**Lecture 2** Dangerous animals	**Lecture 5** Hard & soft corals with basic Cnidaria taxon.	**Review** Hard/soft coral ID	**Lecture 10** Intro to fish ecology & behaviour **Lecture 11** Intro to GPS	**Review** Fish ID **Lecture 14** Ropes & knots	**Review** Coral, fish and algae ID (pictionary) **Review** GPS & knots	**Examination** Corals	**Lecture 18** CCC data: analysis & use	**Review** Data entry onto CCC forms (group w/shop)	**Examination** Fish **Lecture 21** CCC data validation	**Examination** Re-takes (if required) **Lecture 23** Data entry to CCC database

Table 4. Science training week timetable for CCC volunteers during Phase 2 of the MCRCP. ID = identification.

	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7 *NO DIVING*	DAY 8	DAY 9	DAY 10	DAY 11
⇩ AM		**Lecture 3** Intro to coral reef ecology **Practical** Reef orientation	**Lecture 6** Hard coral ID **Practical** Hard coral ID	**Lecture 8** Hard coral ID Substratum **Practical** Hard coral ID	**Lecture 12** Intro to fish ID - Families **Practical** Fish ID – Families **Review** Fish ID – Families	**Lecture 15** Fish ID – target species **Practical** Fish ID – target species **Review** Fish ID – target species		**Lecture 17** Invert. ID Sponge ID **Practical** Invert. ID **Review** Invert. ID	**Lecture 19** Intro to Reef Check survey methods **Practical** Reef Check survey methods **Review** Reef Check survey methods	**Review** ID – coral, fish, inverts & algae **Skills validation** Benthic validation **Examination** Inverts & algae	**Review** ID – hard & soft corals **Skills validation** Corals (re-take) **Lecture 22** Other survey methods
⇩ PM	**Lecture 1** Fiji: Local culture & customs	**Lecture 4** Intro to hard coral biology & life forms **Practical** ID - coral life forms **Review** Coral life forms	**Lecture 7** Hard coral ID **Practical** Hard coral ID	**Lecture 9** Soft coral ID & other Cnidaria **Practical** Hard/soft coral ID **Review** Hard/soft coral ID	**Lecture 13** Fish ID – target species **Practical** Fish ID – target species **Review** Fish ID – target species		**Lecture 16** Marine plants & algae **Practical** Marine plants & algae ID (snorkel) Specimen ID – reference collections	**Review** ID – inverts & algae **Practical** ID – inverts & algae	**Lecture 20** Intro to Reef Check survey forms **Practical** Practice survey	**Skills validation** Coral trail	**Review** ID – fish **Skills validation** Fish **Review** Validation assessments
EVE	**Lecture 2** Dangerous animals	**Lecture 5** Hard & soft corals with basic Cnidaria taxon.	**Review** Hard/soft coral ID	**Lecture 10** Intro to fish ecology & behaviour **Lecture 11** Intro to GPS	**Review** Fish ID **Lecture 14** Ropes & knots	**Review** Coral, fish and algae ID (pictionary) **Review** GPS & knots	**Examination** Corals	**Lecture 18** CCC data: analysis & use	**Review** Data entry onto Reef Check forms (group w/shop)	**Examination** Fish **Lecture 21** CCC data validation	**Examination** Re-takes (if required) **Lecture 23** Data entry to CCC database

3.3 Baseline transect technique

Phase 1 of the MCRCP 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.

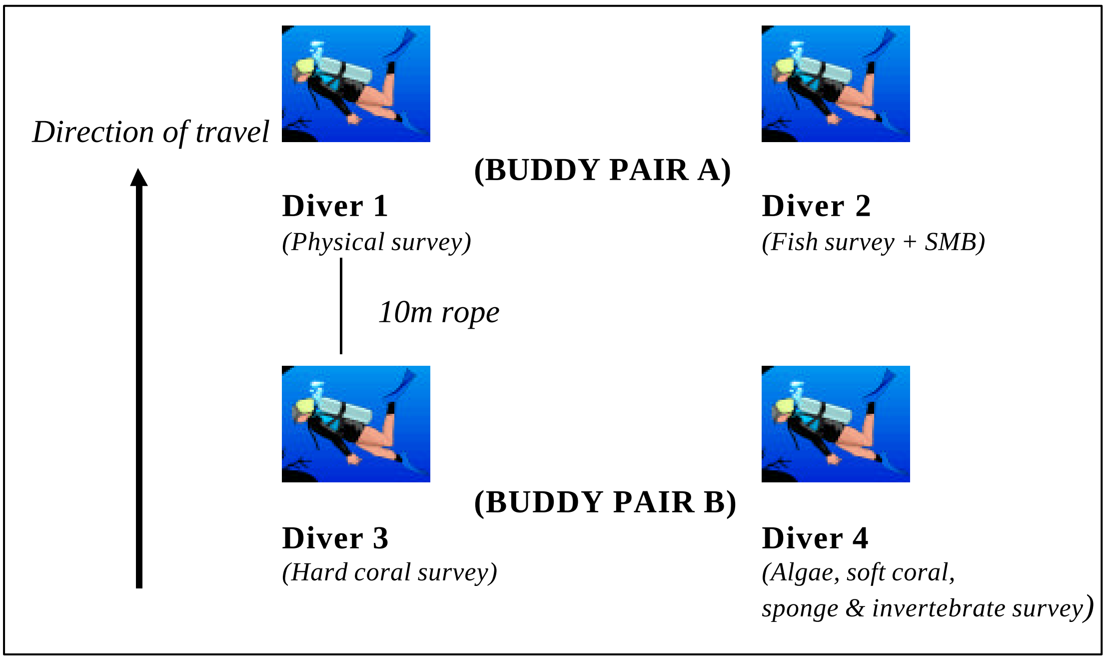


Figure 3. Schematic diagram of a baseline survey dive team showing the positions and data gathering responsibilities of all four divers. Details of the role of each diver are given in the text.

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.

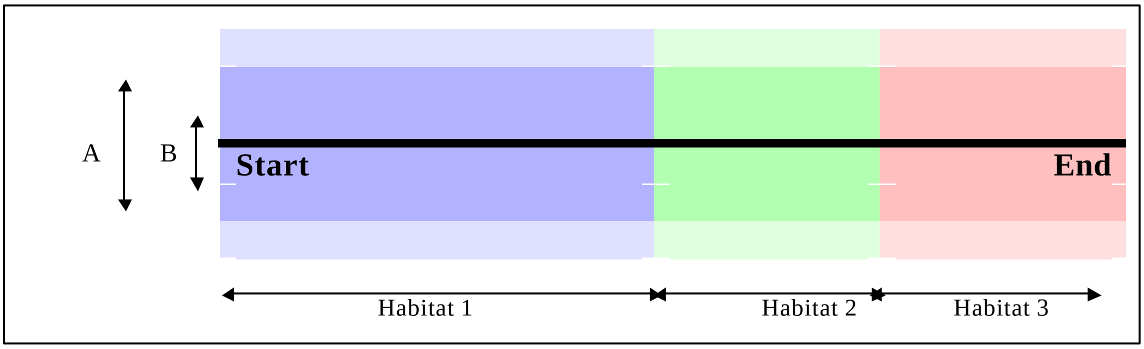


Figure 4. Schematic diagram (aerial aspect) of an example of a reef area mapped by divers during a sub-transect survey. Solid line represents imaginary sub-transect line. Dashed lines and shaded areas represent areas surveyed (A = 5m wide swathe surveyed by Divers 1, 2 and 4; B = 2 m wide swathe surveyed 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 5.

Table 5. 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.

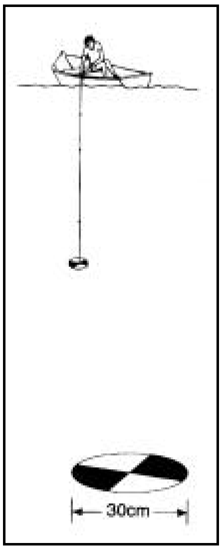


Figure 5. The use of a secchi disc to assesses vertical water clarity. The secchi disc is lowered into the water until the black and white quarters are no longer distinguishable. The length of rope from the surveyor to the disc is then recorded. *Source*: English *et al.* (1997).

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).

Data collected from each sub-transect survey were transferred to recording forms prior to incorporation into CCC's database, which is compatible with a range of Geographic Information System (GIS) software used for spatial analysis. The recording forms are shown in Appendix 2 and consist of a 'Boat Form', 'Physical Form' and 'Biological Form'. Each form is completed for each individual dive, although there may be more than one biological form depending on the number of habitats observed. The Boat Form holds data on the GPS co-ordinates of the dive along with oceanographic and climate data such as winds, currents, temperatures and salinities. The Physical Form holds data on the maximum and minimum depths of the dive, the aesthetic and biological ratings and also a reef profile drawn from the depths collected every 10 m. Finally the Biological Form(s) contain data on the reef zone, the major biotic and substratum features of the habitat and the ordinal ratings of each life form and target species.

3.4 Habitat mapping

In order to produce a preliminary habitat map for the project area, a 'Landsat 7' satellite image produced by the U.S. Geological Survey (USGS) was purchased. 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 taken on 18th May 2001, close to the initiation of the pilot project and hence should accurately represent the reefs surveyed by the CCC volunteers.

Image processing was carried out in conjunction with the University of Newcastle. Firstly the image was subseted to remove data from outside the project area and improve subsequent computer processing times. Following subseting, the image was geometrically corrected to remove positional errors. Any satellite image will inevitably be warped because of factors such as the shape and rotation of the Earth. Geometric correction is achieved using a series of Ground Control Points (GCPs) which are the correct co-ordinates, collected either via GPS in the field or from an accurate chart, of obvious features such as island headlines. These GCPs are located on the image and the computer is then able to correct the whole image so that every

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

pixel has the correct co-ordinates. Following geometric correction the land, deepwater and clouds were masked out to improve the contrast between marine habitats. Within a satellite image, pixels can only take a value from 0-255 and since land, clouds and deepwater are so different from reefal areas they use a large proportion of the scale and marine habitats are restricted to a relatively small range of values. By masking out land, cloud and deepwater, marine habitats can occupy values throughout the scale and hence the contrast and subsequent classification accuracy is increased significantly.

The final step of image processing was assigning each pixel to a benthic class to produce a habitat map. Since the baseline transect data available from the pilot project were limited, an 'unsupervised classification' of the image was used. During the unsupervised classification the computer placed each pixel into one of 30 classes based on their spectral signatures. By comparing the location of each of the thirty classes with the distribution of benthic classes delineated by the field data, each class was assigned a label. For example, if an area had been classified as class 27 and this area was known to be dominated by habitat B, class 27 was labelled as habitat B. Thirty classes were used since this was approximately three times the number of benthic classes expected in the area and hence allowed for the same benthic class to be found at different depths or in water of different turbidity. Hence if class 27 represents habitat B at a medium depth, class 26 might represent habitat B in the shallows and class 28 might represent habitat B in deeper water. By using a lower number of classes within the unsupervised classification, these spectral differences cannot be discriminated and the resulting map is consequently less accurate.

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. It is intended that if the MCRCP continues and generates further data, future habitat maps will be produced using a supervised classification.

3.5 Reef Check

Reef Check[3] was designed to be used by non-professional divers to assess reef health and hence generates relatively simple, but quantitative, information. During the MCRCP 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 on the pilot phase of the MCRCP 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 MCRCP, deeper transects (e.g. 17 and

[3] Further details at http://www.reefcheck.org

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.

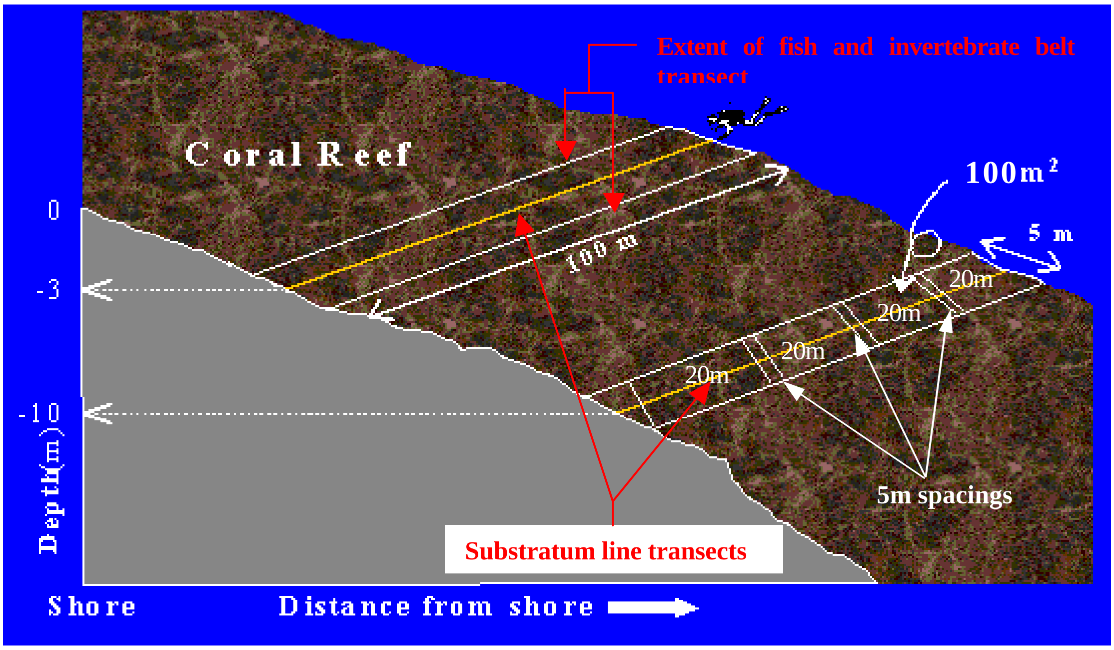


Figure 6. Schematic diagram showing the position of the transect lines during a Reef Check survey. 100 m transect is divided into four 20 m replicates so area of each belt transect is 20 x 5 m = 100 m^2. In addition to the standard 3 and / or 10 m transects, CCC used one or more deeper transects when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

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 5 m 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.

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 3).

Following the completion of the pilot phase of the MCRCP, data from the Reef Check surveys will be made available to the global and national databases, hence increasing the impact of the project.

3.6 Coral size-frequencies

The technique used to collect coral size-frequency data was a pilot methodology since no standardised protocol is currently available. The methodology used during the MCRCP combined the sizing of colonies of five target coral taxa with an assessment of the percentage of living tissue. Size-frequency surveys were conducted in the reef complexes that had already been surveyed by baseline transects and the Reef Check methodology in order to integrate the data sets.

At each site twelve 49 m^2 quadrats were placed along a notional 100 m transect, established on a reef contour using a compass bearing (Figure 7). Each quadrat was defined by a pair of 7 m polypropylene lines, laid at right angles to each other on the surface of the reef, and weighted at the intercept with a large lead weight and at the extremities with small steel washers. For the size-frequency surveys, five target coral species or assemblages of species were selected as common and easily identified representatives of the diversity of coral life-forms prevalent in the Mamanuca Islands ('massive' life forms of the genus *Porites*, *Pocillopora verrucosa* / *meandrina* / *elegans*, *Ctenactis echinata*, *Diploastrea heliopora* and *Seriatopora hystrix*). These species were chosen since they were thought to be easily identifiable, relatively abundant and also because for 'massive' *Porites* there is a body of literature on its population dynamics. All the species are also affected by collection for the 'live rock' trade.

Within each quadrat divers recorded the depth, maximum height, maximum and minimum diameter of each target colony. Heights and diameters were measured using the following size classes (cm): 1=1-5; 2=6-10; 3=11-15; 4=16-20; 5=21-25; 6=26-30; 7=31-35; 8=36-40; 9=41-45; 10=46-50; 11=>50. In addition, the percentage of living tissue visible on each colony, when viewed from directly above, was estimated. Finally, each quadrat was assigned a coral cover from the following size classes: > 100%; 100-90%; 90-75%; 75-50%; 50-25%; 25-10% (corals < 2 coral diameters apart); 10-1% (corals < 3 coral diameters apart); 1-0.1 % (corals < 10 coral diameters apart) and < 0.1 % (corals < 30 coral diameters apart). The process for assigning these classes is presented in Appendix 4.

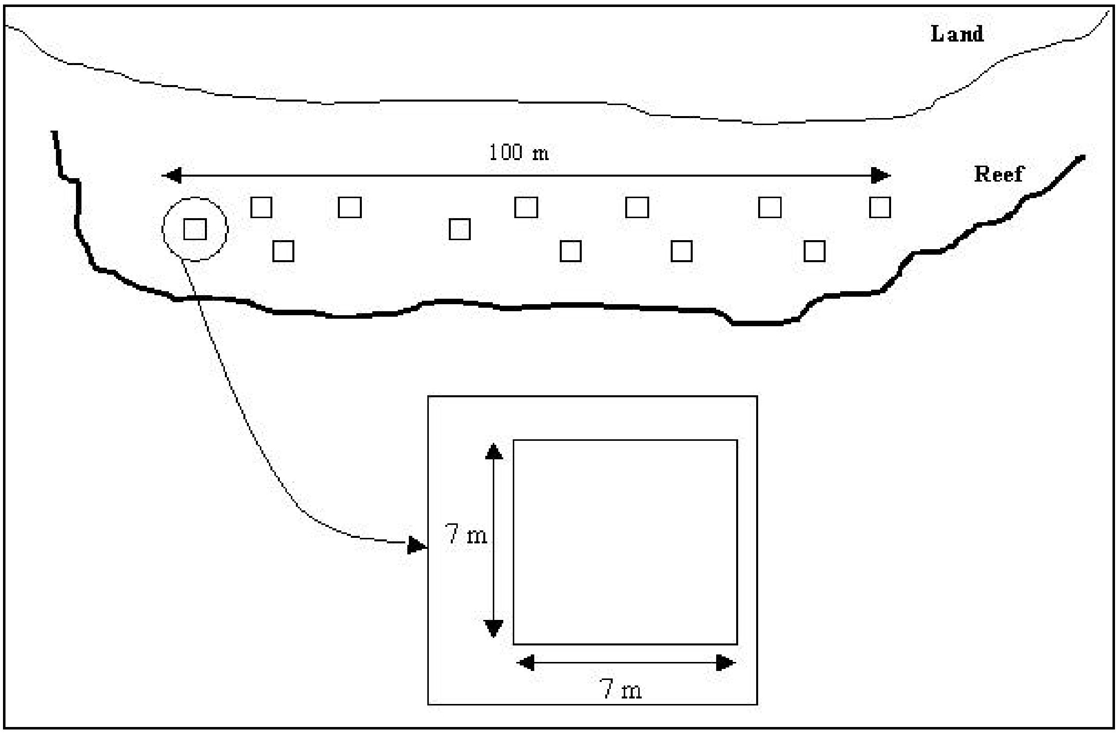


Figure 7. Placement of quadrats along a notional 100m transect during MCRCP coral size-frequency surveys.

3.7 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'.

3.7.1 Baseline data

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.

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 gemorphological class and benthic class to produce a habitat label follows the format described by Mumby and Harborne (1999).

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 or for each of the five reef complexes as appropriate. Note that the ordinal scores for fish and invertebrates cannot be standardised for transect length.

3.7.2 Reef Check

Reef Check data were summarised graphically and via univariate statistics, along with more detailed examination of the data using Analysis of Variance (ANOVA) and regression analysis to test for correlations. Percentage data were Arcsin transformed to ensure normality where appropriate. Data were either summarised by site, for the whole project area or for each of the five reef complexes as appropriate. Note that coral cover is generally divided into '*Acropora*' and 'non-*Acropora*'. Such a division is often used in coral reef ecology since *Acropora* is the largest genus of coral within the Indo-Pacific region, with over 160 species (Veron, 2000), and may have distinct ecological properties. For example, it is known to be particularly susceptible to coral bleaching (e.g. Marshall and Baird, 2000). Total coral cover is a sum of these two parameters.

Assessment of site conservation values

Assigning conservation values to areas of the MCRCP project area is important in order to select priority areas for marine protected areas. 'Conservation value' is a complex term that can be related to biodiversity, fisheries potential, aesthetic value, naturalness, representativeness, uniqueness and tourist potential. One method that has been proposed as a summary of conservation value is the use of 'ternary diagrams' of coral morphology (Edinger and Risk, 2000). Using techniques originating in botany, Edinger and Risk (2000) assign conservation values to sites based on the proportion of disturbance-adapted (ruderal) *Acropora* corals, competitively dominant branching and foliose non-*Acropora* corals and stress-tolerant massive and submassive non-*Acropora* corals that are present.

By plotting the proportion of each coral type present on the ternary diagram, each site can be assigned a conservation value as shown in Figure 8. Note that reefs dominated (>60%) by stress-tolerators have a low (1) conservation value, reefs dominated (>50%) by competitively dominated or disturbance-adapted corals are assigned medium (2 and 3 respectively) conservation value and reefs with a mixed community have a high (4) conservation value. Edinger and Risk (2000) assigned these conservation values because they showed them to be correlated with coral species richness, number of rare coral species and habitat complexity (which is likely to be linked to fish diversity and abundance).

The use of ternary diagrams was applied to the quantitative data on coral morphologies generated by Reef Check surveys during the MCRCP in order to investigate their applicability for highlighting areas of high conservation value.

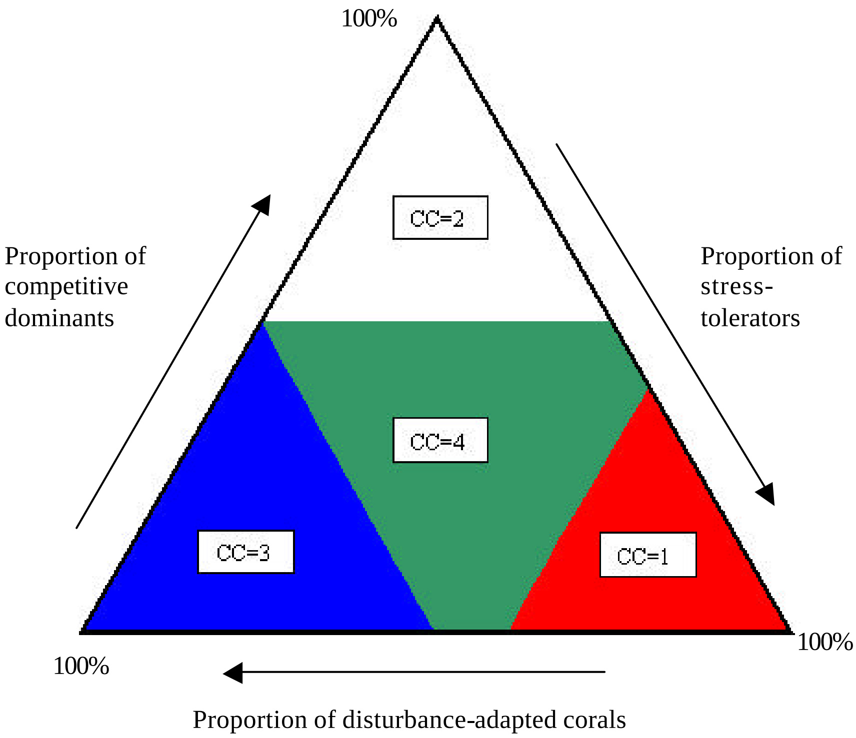


Figure 8. Schematic representation of a ternary diagram of coral morphology and the assignment of conservation values. CC = conservation value from 1 (low) to 4 (high). CC=1 represents poor reefs dominated by massive and submassive corals; CC=2 represents reefs dominated by stands of foliose and branching non-*Acropora* corals; CC=3 represents reefs dominated by branching and tabular Acropora; CC=4 represents mixed coral morphology reefs.

3.7.3 Coral size-frequencies

Data on the size-frequencies of each coral taxa measured were summarised graphically and via univariate statistics, along with more detailed examination of the data using Analysis of Variance (ANOVA) and Kruskal-Wallis tests. Percentage data were Arcsin transformed to ensure normality where appropriate. Data were either summarised for the whole project area or for each of the reef complexes as appropriate.

3.8 Observations of megafauna

Throughout the surveys undertaken during the pilot phase of the MCRCP qualitative observations of megafauna were recorded. The abundance of megafauna is important because, for example, they are attractive to tourists and are often the first species to be reduced or extirpated by over-fishing.

3.9 Community work

3.9.1 Marine Ecology Workshop for the Professional Diver

As part of the pilot phase of the MCRCP, a marine ecology workshop designed for the diving professional working in the Mamanuca Islands was conducted during Phase 1 (Figure 9). The workshop was carried out on three separate days in the first three weeks of July. Each workshop was held at the CCC base on Qalito (Castaway) Island from 10am to 4pm. The objectives of the 'Marine Ecology Workshop for the Professional Diver' were to:

- Provide participants with a general background in the ecology of coral reefs;
- Emphasize conservation issues and ethics in a fun and practical manner;
- Give participants information in a format that can be easily passed on to their students and clients;
- Provide a forum for the exchange of information between CCC and the Fijian dive community.

Figure 9. Lecture during the 'Marine Ecology Workshop for the Professional Diver' at CCC's expedition base.

The content of the workshop is summarised in Table 6.

Table 6. Summary of topics covered during the 'Marine Ecology Workshop for the Professional Diver'.

Workshop 1
An overview of the interactions between upland forests, mangroves, seagrass beds, coral reefs and the importance in conserving them. A broad introduction to coral reefs with a general picture of coral reefs at a global level.
Workshop 2
An introduction to the features, morphology and behaviour of reef organisms and the importance of conserving them. Focus on biology of corals and fish ecology/behaviour.
Workshop 3
To focus on how to apply what has been learned during workshops 1 and 2 to the professional diving industry. Focus on communicating ideas and information learned in workshop 1 and 2 to customers and marketing value of reef knowledge as well as marketing the unique features of Fiji's coral reefs and organisms.

3.9.2 International Secondary School, Suva

Five students and two staff from the International Secondary School (ISS), Suva joined the expedition for three days as part of their course on analysing marine ecosystems. The mini-course consisted of three lectures each day followed by snorkeling sessions on local reefs. Lectures focused on general coral reef ecology, coral biology, fish behaviour and coastal zone management issues and strategies.

3.10 Meetings during the course of the pilot phase of the MCRCP.

3.10.1 Worldwide Fund for Nature (WWF)

From 6th-8th August, Daniel Afzal (PS) participated in a workshop to discuss the 'WWF Community Based Marine Protected Area Management Plan Development for Waisomo and Narikoso, Ono District, Kandavu'. Following this workshop, which included a briefing on CCC's work in the Mamanuca Islands, there was a workshop for participants to look at long-term strategy for Fiji and the South Pacific. WWF has identified a list of priority ecoregions known as the global 200, covering the major terrestrial and marine habitats to prioritise efforts. Ecoregions are not defined by political boundaries and WWF hopes that the global 200 will provide a foundation for a unified strategy to conserve representative ecosystem types. However, data are needed to support ecoregion scale analysis and establishment of a network of marine protected areas and it was suggested that CCC's expertise with mapping and analysis could fill this gap both in Fiji and in the other South Pacific priority areas.

3.10.2 Global Coral Reef Monitoring Network

From 26th – 31st August Daniel Afzal participated in a Global Coral Reef Monitoring Network (GCRMN) workshop for the Southwest Pacific 'Node'. The workshop focused on developing partner country monitoring plans and CCC were involved in the planning sessions for the Fiji node. CCC were given the opportunity to present an overview of the pilot phase of the MCRCP and a number of training and monitoring collaborations were discussed with South Pacific countries. Several countries expressed an interest in training links with CCC and the use of the MCRCP expedition base as a regional training centre for their monitoring personnel.

3.10.3 Other meetings

CCC project staff attended several other meetings to introduce the project to various stakeholders:

- Project staff met for discussions with Ratu Sevanaia Vatunitu Nabola, Luilui Ni Yavusa (Chief of Solevu village) at the initiation and conclusion of the project;
- Science staff were invited to Solevu village, Malolo Island, to meet with community elders and discuss the project;
- Science staff held a presentation for Castaway Island Resort staff to inform them of the project;
- During Phase 1, project staff were invited to the Mamanucas Hoteliers Association meeting to present a project update and outline Phase 2 activities.

4. RESULTS

4.1 Volunteer training

The results of the tests and validation exercises that concluded the science training weeks in Phase 1 and 2 are shown in Table 7. Table 7 shows that the volunteers achieved a high standard in the tests and validation exercises.

Table 7. Summary of test and validation results for Phase 1 and 2 volunteers. Thirteen volunteers and staff members undertook science training in Phase 1 and 24 in Phase 2. Figures in parentheses show standard deviation.

Test	Phase 1	Phase 2
Coral Test - % passed	63.6	69.2
Coral Test - mean score (%)	80.2 (10.1)	82.1 (7.4)
Coral Re-test - % passed	100.0	100.0
Coral Re-test – mean score (%)	89.3 (8.3)	93.8 (5.3)
Coral Trail - % passed	100	100
Coral Trail - mean score (%)	91.6 (5.0)	80.2 (9.0)
Mean similarity coefficient for benthic validation exercise (%)	79.0 (4.1)	80.0 (8.8)
Fish Test - % passed	75.0	91.3
Fish Test – mean score (%)	82.9 (20.2)	91.3 (6.5)
Fish Re-test - % passed	66.7	100.0
Fish Re-test – mean score (%)	77.0 (16.4)	92.5 (6.5)
Mean similarity co-efficient for fish validation exercise (%)	71.6 (7.9)	83.9 (12.5)

4.2 Baseline transects

4.2.1 Surveys completed

During Phase 1 of the MCRCP a total of 74 dives were completed which resulted in 37 baseline transects (Table 8). These dives generated 123 Biological Forms including over 7,000 individual records of species or life form abundance and location. Surveys were carried out on four general reef types: fringing; shallow reef platform; inner barrier reef and outer barrier reef. The transect locations are shown in Figure 10. Note that surveys in most of the eastern islands of the project area, for example Tai (Beachcomber) and Lovuka (Treasure), were out of range for survey teams. However, one survey was completed at Navini Island.

Table 8. Baseline transects completed during the MCRCP. Refer to Figure 10 for specific locations of transect codes.

Transect code	Transects completed	Description of location	No. of dives	Reef type
CA	4	On the shallow fringing reefs around Qalito (Castaway) Island	5	Fringing
RA	3	The shallow fringing reefs around Qalito (Castaway) Island, in front of CCC base camp (Raviniyake)	3	Fringing
WA	2	The fringing and inner barrier reef close to Waidigi Island	2	Fringing
HM	2	The fringing reef around Mothiu (Honeymoon) Island	4	Fringing
NI	1	The fringing reefs around Navini Island	3	Fringing
ML	5	The fringing reefs around Malolo Island	9	Fringing
NA	1	Namavulevu channel near the fringing reefs of Malolo Island	2	Fringing
SS	3	Shallow reef platform called Seven Sisters, a popular dive site	3	Platform
SF	2	Shallow reef platform called Sunflower	5	Platform
SM	2	Shallow reef platform called Supermarket, a popular dive site	6	Platform
IB	6	The inner barrier reef that runs between Qalito (Castaway) Island and the Outer Malolo Barrier Reef	14	Inner Barrier
MI	3	Namotu (Magic) Island, two surveys on the inside of the barrier and one on the outside. These surveys are just south of Wilkes Passage, a popular dive site.	10	Outer Barrier
OB	2	On the inside of the outer barrier	6	Outer Barrier
BW[4]	1	The edge of the 'W' formation on the Outer Malolo Barrier Reef	2	Outer Barrier
TOTAL	**37**		**74**	

As discussed in Section 3.1, the survey strategy was designed to allow the data to be analysed within five reef complexes. The reef complex to which each transect was assigned is shown in Table 9.

Table 9. The assignment of each baseline transect to the five 'reef complexes' delineated during the pilot phase of the MCRCP.

Reef complex	Transects	Number of surveys
Mana Island	All SS and SM transects	9
Namotu Group	All MI, BW and OB transects	18
Inner Malolo Group	All CA, RA, HM and ML transect plus transect WA1	22
Outer Malolo Group	All IB, SF and NA transects plus transect WA2	22
Navini Island	All NI transects	3

[4] Weather conditions prevented detailed surveys of the seaward side of the outer barrier for most of Phase 1.

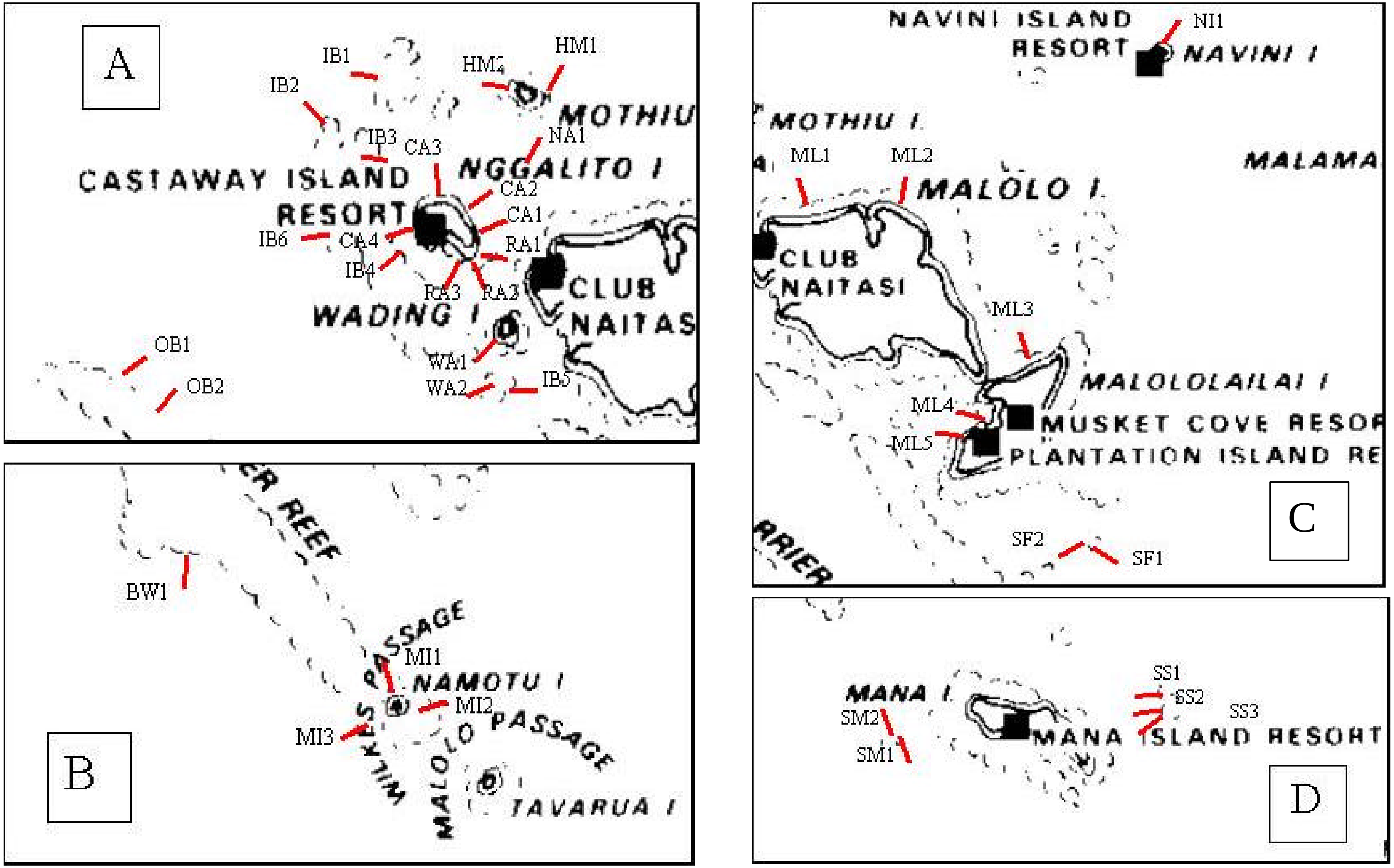


Figure 10 (a-d). Locations of baseline transects (red lines) completed during the pilot phase of the MCRCP. Key to codes in Table 8.

4.2.2 Oceanography, climate and anthropogenic impacts

Temperature

Mean surface water temperature during the pilot phase of the MCRCP was 26.4°C (standard deviation 0.6°C; n = 72). Water temperatures collected by the survey teams at the maximum survey depths were summarised in 5 m 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) and the results are shown in Figure 11. Figure 11 shows that there was some evidence of temperature variation throughout the water column, with the lowest temperatures found between 10.1 and 15 m. However, the decrease in temperature was less than 0.5°C and the variation was not statistically significant (ANOVA, p>0.05). Data from more accurate metres are required to check if the variation is significant.

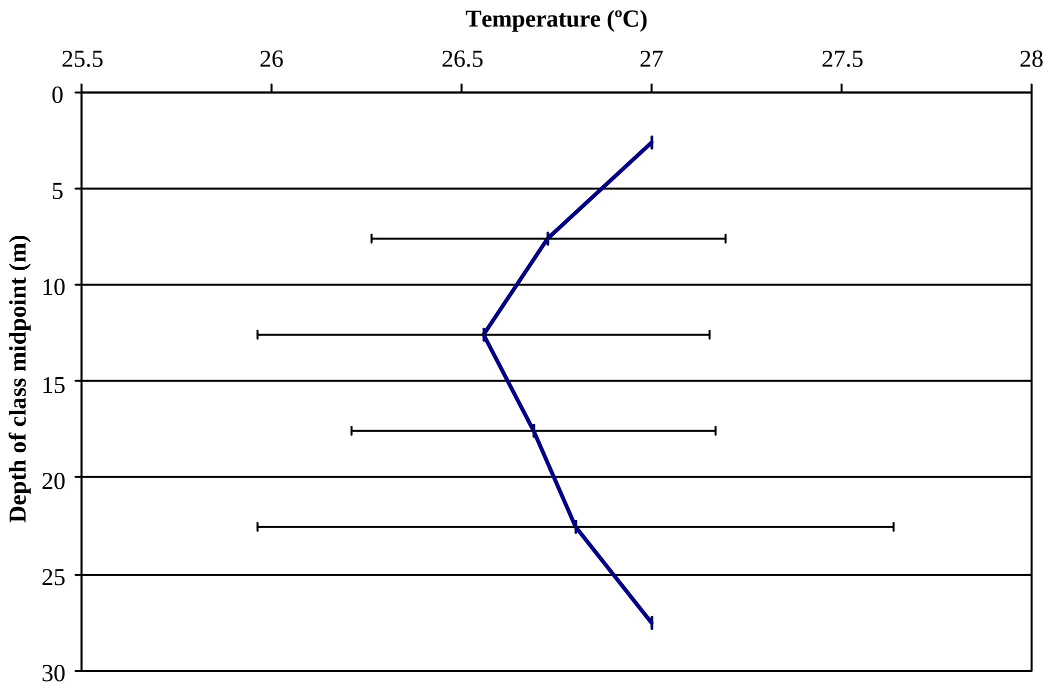


Figure 11. Mean water temperatures for all surveys in the project area in 5m depth classes throughout the water column. Bars represent standard deviation. Sample sizes: 0.1-5 m = 5; 5.1-10 m = 11; 10.1-15 m = 27; 15.1-20 m = 16; 20.1-25 m = 5; 25.1-30 m = 4.

Salinity

Mean surface water salinity during the pilot phase of the MCRCP was 34.6‰ (standard deviation 2.4‰; n = 59). However, these values varied significantly between the five reef complexes (ANOVA, p<0.01) with Mana Island having the highest salinity (37.0‰), followed by the Namotu Group (35.6‰), the Outer Malolo Group (34.3‰), the Inner Malolo Group (33.4‰) and finally Navini Island which had the lowest salinity (32.9‰). Water temperatures collected by the survey teams at the maximum survey depths were summarised in 5 m 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) and the results are shown in Figure 12. Figure 12 shows that there was no consistent pattern of salinity variation throughout the water column. Furthermore, the variation in salinity was less than 3‰. Data from more accurate metres are required to check if there are haloclines in the project area.

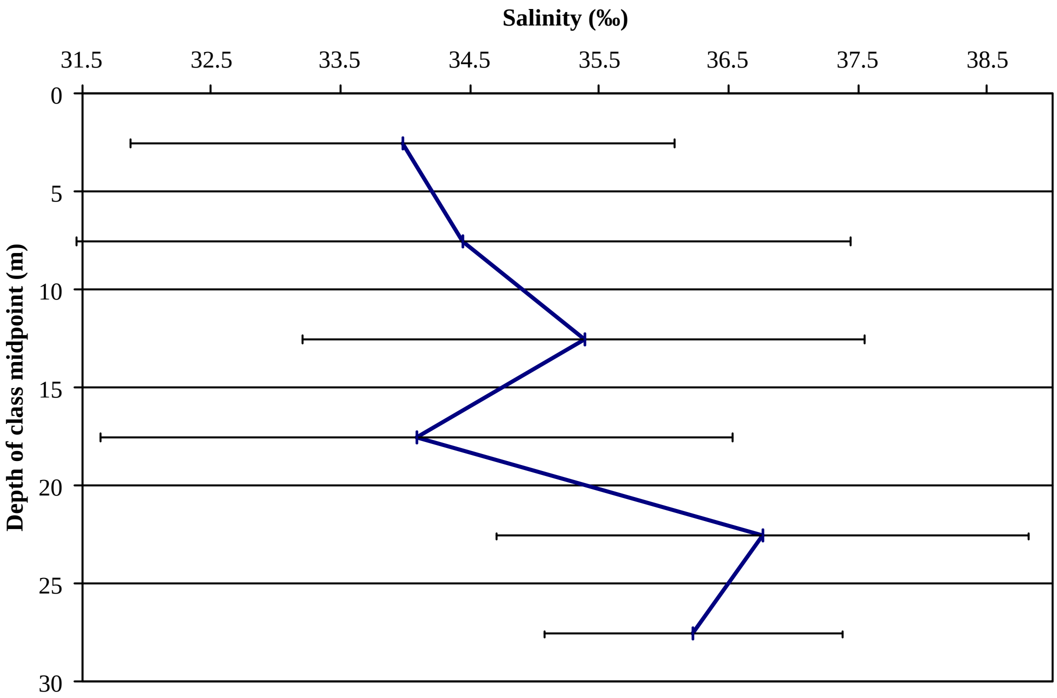


Figure 12. Mean water salinity for all surveys in the project area in 5m depth classes throughout the water column. Bars represent standard deviation. Sample sizes: 0.1-5 m = 5; 5.1-10 m = 11; 10.1-15 m = 27; 15.1-20 m = 16; 20.1-25 m = 5; 25.1-30 m = 4.

Water visibility

Water visibility is a surrogate of turbidity (the amount of suspended material), which is a key influence on coral health. For example, corals can be smothered and killed in areas with high turbidity caused by changes in land use and subsequent increased erosion. During the pilot phase of the MCRCP both vertical and horizontal visibility were measured and the results are shown in Figure 13. Note that in this bar chart, high values represent high visibility and hence low turbidity. Figure 13 shows that there is an obvious and expected correlation between horizontal and vertical visibility and further analysis of both data sets shows that there is significant variation between the five reef complexes (ANOVA, $p<0.0005$). The values show that turbidity in each reef complex increased in the following order: Namotu Group (lowest); Mana Island; Outer Malolo Group; Inner Malolo Group and Navini Island (joint highest turbidities). Multiple range tests show that turbidity in the Namotu group is significantly higher than the other four reef complexes ($p<0.05$).

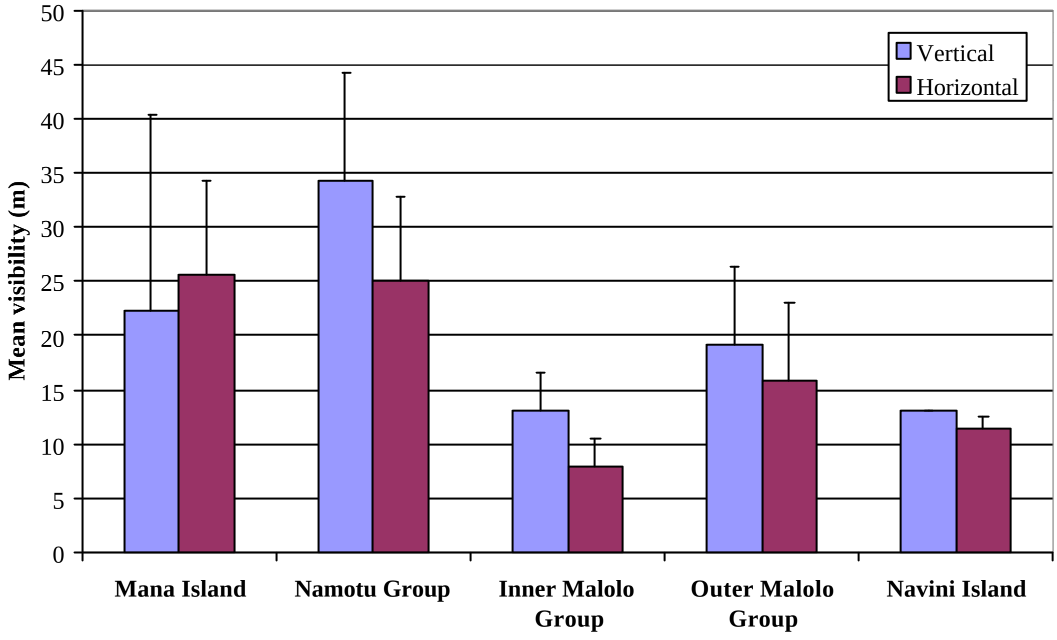


Figure 13. Vertical (via secchi disc readings) and horizontal (via diver estimations) water visibilities in each of the five reef complexes. Bars represent standard deviation. Sample sizes: Mana Island = 4 vertical, 9 horizontal; Namotu Group = 8, 25; Inner Malolo Group = 11, 50; Outer Malolo Group = 13, 35; Navini Island = 2, 4.

Currents

Forty-seven surveys (63.5%) recorded no perceptible currents. The directions and strengths of currents that were recorded are shown diagrammatically in Figure 14. Figure 14 shows that insufficient surveys were completed to provide a clear impression of the currents within the project area and more detailed spatial and temporal (i.e. throughout the tidal regime) data are required from more accurate meters. However, there was some evidence of water movement along the Malolo Barrier Reef, south-easterly away from Malololailai Island and complex patterns between the islands in the Malolo group and around platform reefs.

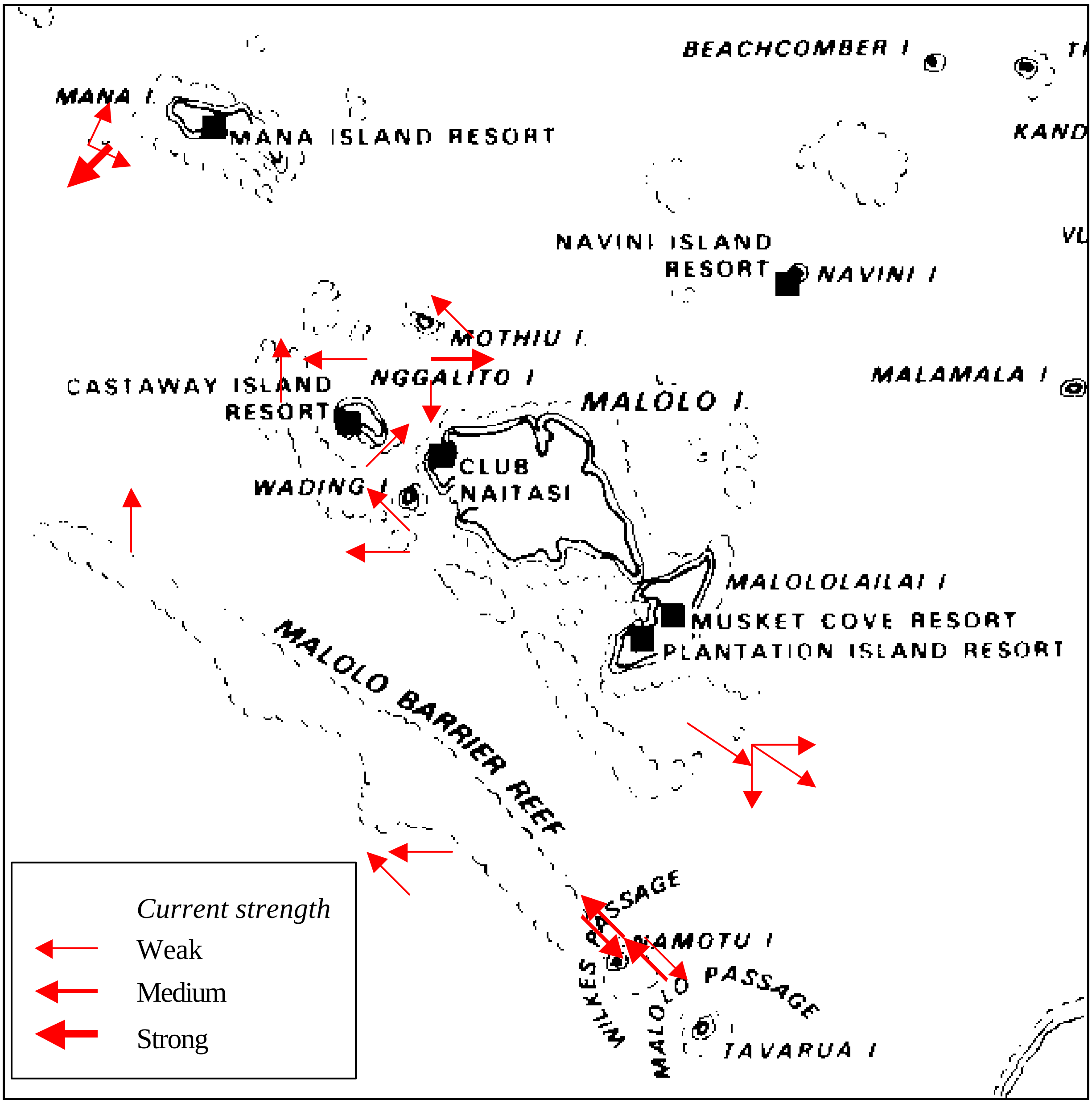


Figure 14. Schematic representation of the current directions and strengths recorded during the MCRCP.

Wind

The prevailing winds during the pilot phase of the MCRCP are summarised as a 'radar diagram' in Figure 15. Wind was recorded for 93.2% of surveys and it was calm on 6.8% of surveys. Figure 15 shows that the prevailing winds were from the east or south-east with occasional occurrences from the south-west. Winds were generally light (1 or 2 on the Beaufort Scale).

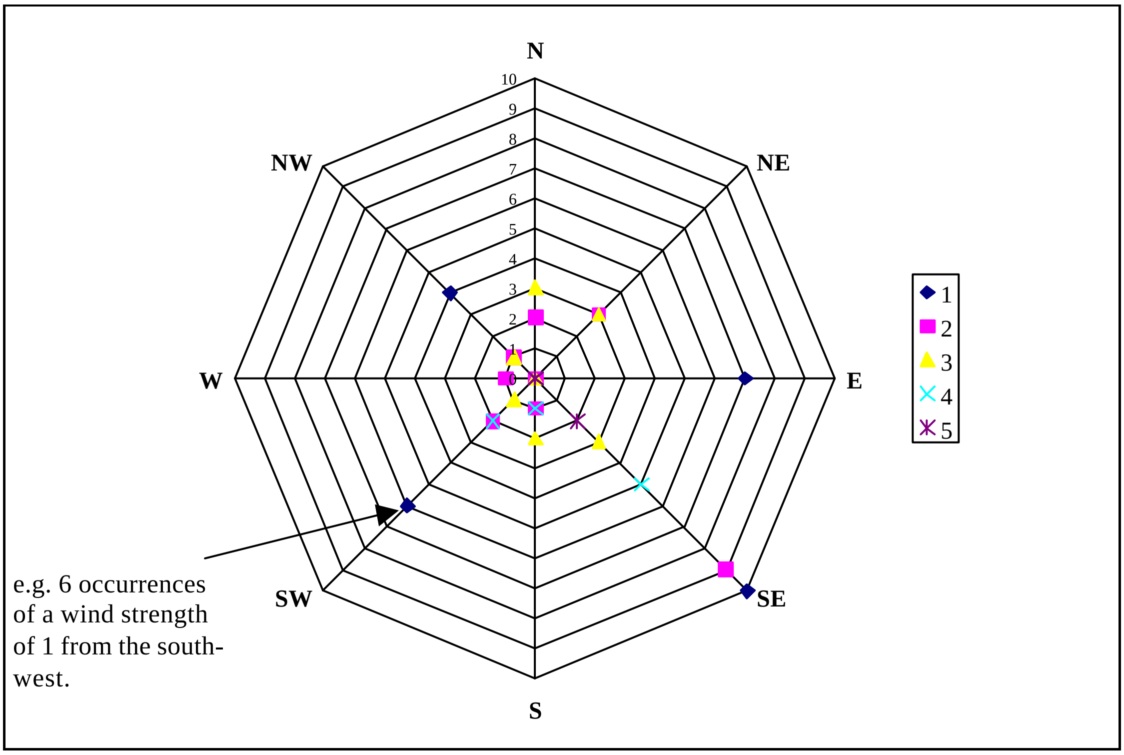


Figure 15. A radar diagram showing the prevailing winds recorded during the MCRCP. Points represent the frequency of occurrence of combinations of wind direction and strength. Colours represent wind strength on the Beaufort scale.

Surface impacts

Surface impacts for the whole survey area are summarised in Table 10 and shown by reef complex in Figure 16. Table 10 and Figure 16 show that algae was the most common category seen at the surface. Litter was also relatively common, particularly around Navini Island (33.3% of surveys). Driftwood was infrequent (only seen in the Namotu Group reef complex) and no surface sewage or fishing nets were seen. No surface impacts were recorded around Mana Island.

Table 10. Percentage of surveys across the whole project area affected by each category of surface impact. n = 74.

	Litter	Sewage	Driftwood	Algae	Fishing nets	Other
Surveys affected (%)	6.8	0.0	2.7	14.9	0.0	4.1

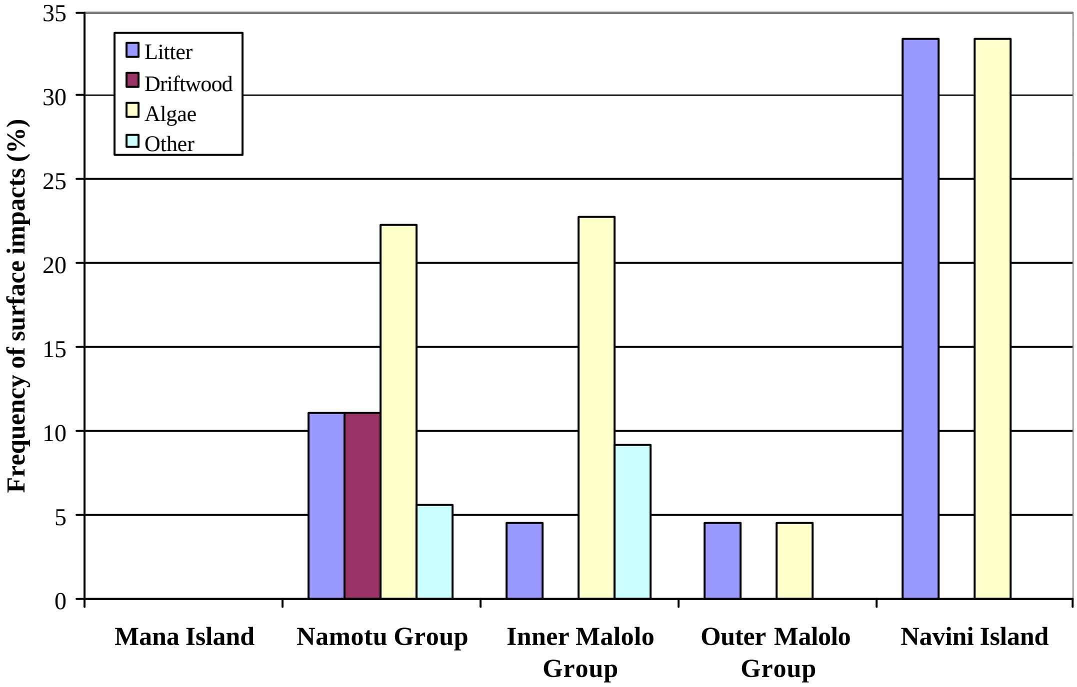


Figure 16. Frequency of occurrence within each reef complex of each surface impact category. Sample sizes: Mana Island = 9; Namotu Group = 18; Inner Malolo Group = 22; Outer Malolo Group = 22; Navini Island = 3.

Underwater impacts

Underwater impacts for the whole survey area are summarised in Table 11 and shown by reef complex in Figure 17. Table 11 and Figure 17 show that litter, generic coral damage and bleaching were common in the project area (>=23%). It is important to note that these data indicate that one or more coral colonies were damaged or bleached on 31.1% and 23.0% dives respectively, *not* that 31.1% of all corals were damaged or that 23.0% of corals were bleached. Litter was particularly common in the Inner Malolo Group, Outer Malolo Group and Navini Island reef complexes (>30%). In contrast, generic coral damage was most common in the Mana Island, Namotu Group and Inner Malolo Group complexes (>30%). Coral bleaching was relatively similar in all reef complexes but was highest at Mana Island (44.4%). Sedimentation was generally absent but was common in the Inner Malolo Group complex (45.5%). No signs of sewage, fish traps, dynamite fishing or cyanide fishing were seen in the project area.

Table 11. Percentage of surveys across the whole project area affected by each category of underwater impact. n = 74.

	Litter	Sewage	Coral damage	Lines and nets	Fish traps	Dynamite fishing	Cyanide fishing	Sediment	Coral disease	Coral bleaching	Other
Surveys affected (%)	26.0	0.0	31.1	8.1	0.0	0.0	0.0	14.9	1.4	23.0	13.5

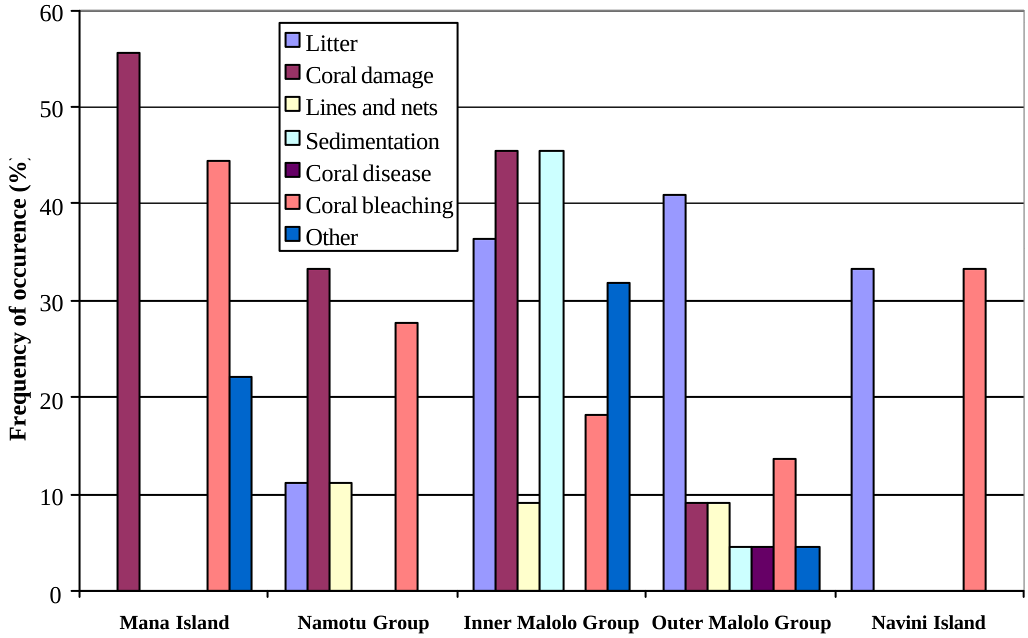


Figure 17. Frequency of occurrence within each reef complex of each underwater impact category. Sample sizes: Mana Island = 9; Namotu Group = 18; Inner Malolo Group = 22; Outer Malolo Group = 22; Navini Island = 3.

Boats

A total of 82 boats were seen during the 74 surveys (24 diving, 9 fishing, 30 pleasure and 19 commercial). A summary of the number of boats per survey (Figure 18) shows that the highest density of boats was in the Namotu Group (1.56) and the Inner Malolo Group (1.18). Figure 19 shows the activities of these boats and highlights that the highest proportion of dive boats was at Navini Island and Mana Island (>77%). The highest proportion of commercial and pleasure boats was in the Inner Malolo Group. Finally, the highest proportion of fishing boats were seen in the Mana Island and Outer Malolo Group reef complexes (>22%).

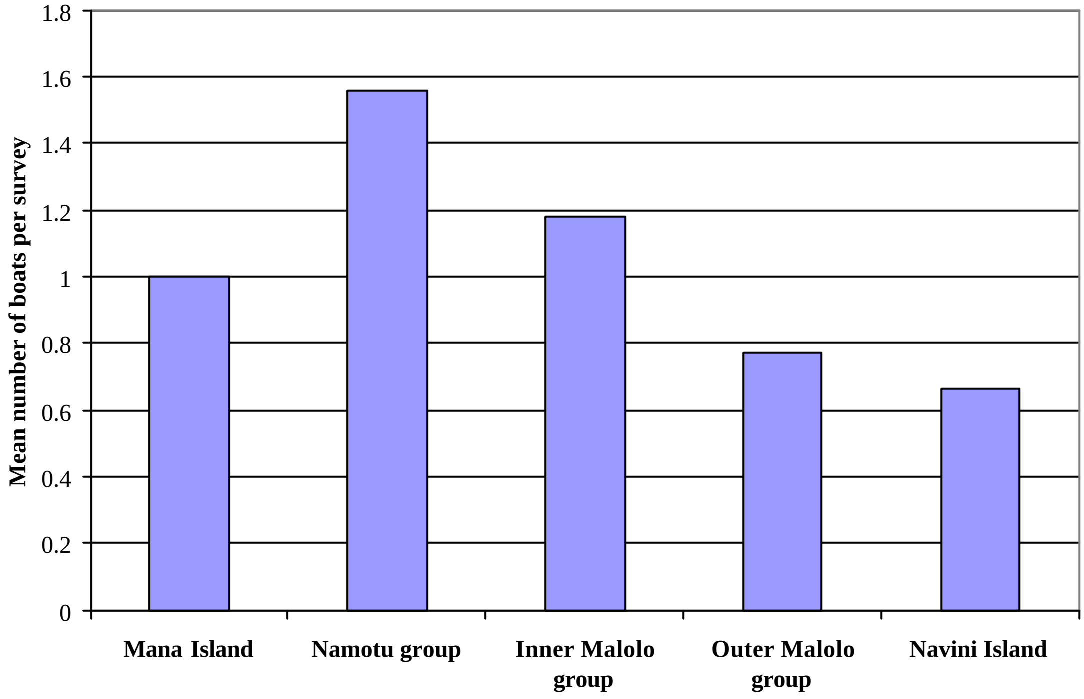


Figure 18. Comparative density of boats in each reef complex. Sample sizes: Mana Island = 9; Namotu Group = 18; Inner Malolo Group = 22; Outer Malolo Group = 22; Navini Island = 3.

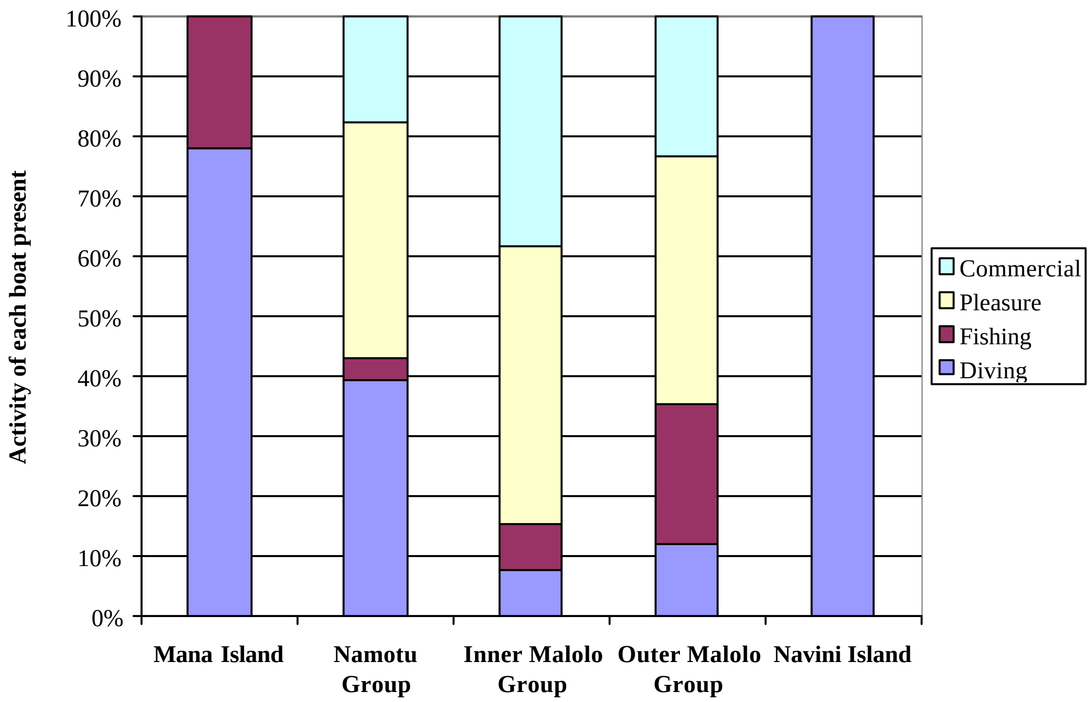


Figure 19. Summary of boat activities observed in each reef complex. Sample sizes: Mana Island = 9; Namotu Group = 18; Inner Malolo Group = 22; Outer Malolo Group = 22; Navini Island = 3.

Aesthetic and biological impressions

A summary of the median aesthetic and biological ratings across all habitat types in each reef complex are shown in Figure 20. Aesthetic values were assigned depending on, for example, an interesting reef topography and biological values reflected the abundance and diversity of the fauna and flora. Both ratings were assigned by divers using a scale from 0 (poor) to 5 (excellent). Figure 20 shows that there was an obvious correlation between aesthetic and biological ratings and the median value was typically between 2 (average) and 3 (good). The exception to this trend was the Inner Malolo Group reef complex where ratings had a median value of approximately 1.25 (poor-average). The highest ratings were assigned at Mana Island and in the Namotu Group (median values > 2.6).

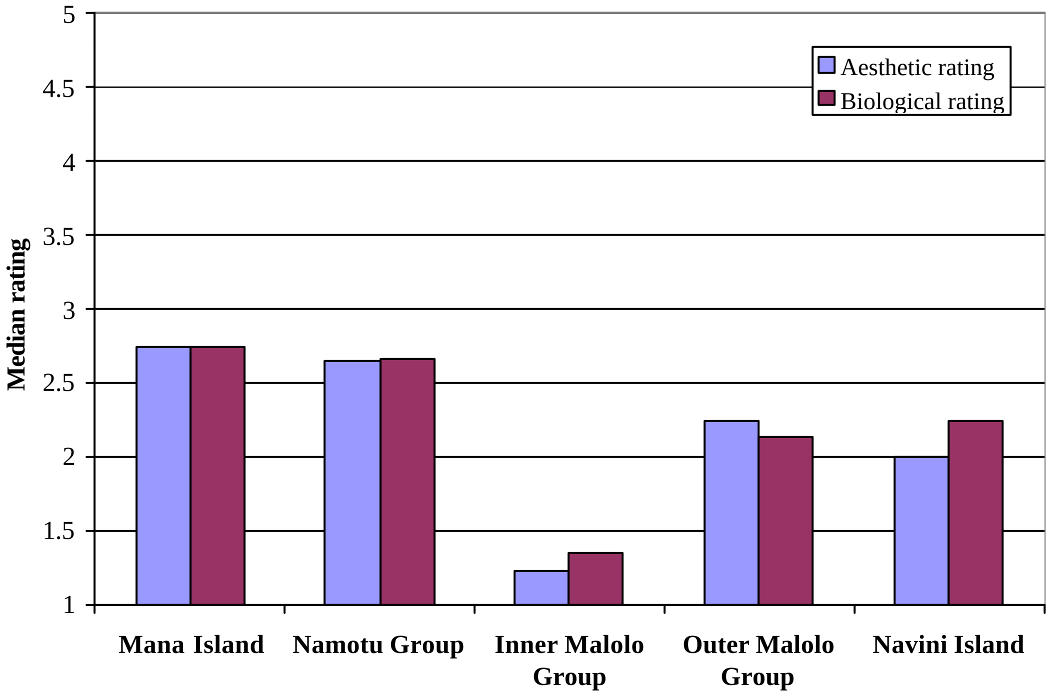


Figure 20. Summary of aesthetic and biological ratings in each reef complex. Ratings assigned via a scale from 1 (poor) to 5 (excellent). Sample sizes: Mana Island = 9; Namotu Group = 18; Inner Malolo Group = 22; Outer Malolo Group = 22; Navini Island = 3.

4.2.3 Benthic data

The dendrogram resulting from cluster analysis of the baseline survey data discriminated seven major benthic classes, each with a minimum of three Site Records. The dendrogram resulting from cluster analysis of the 123 records is shown in Figure 21. The remaining 7 records (5.7%) were discarded because the dendrogram showed that they represented either erroneous data or extremely rare habitats i.e. they did not cluster with any other site records.

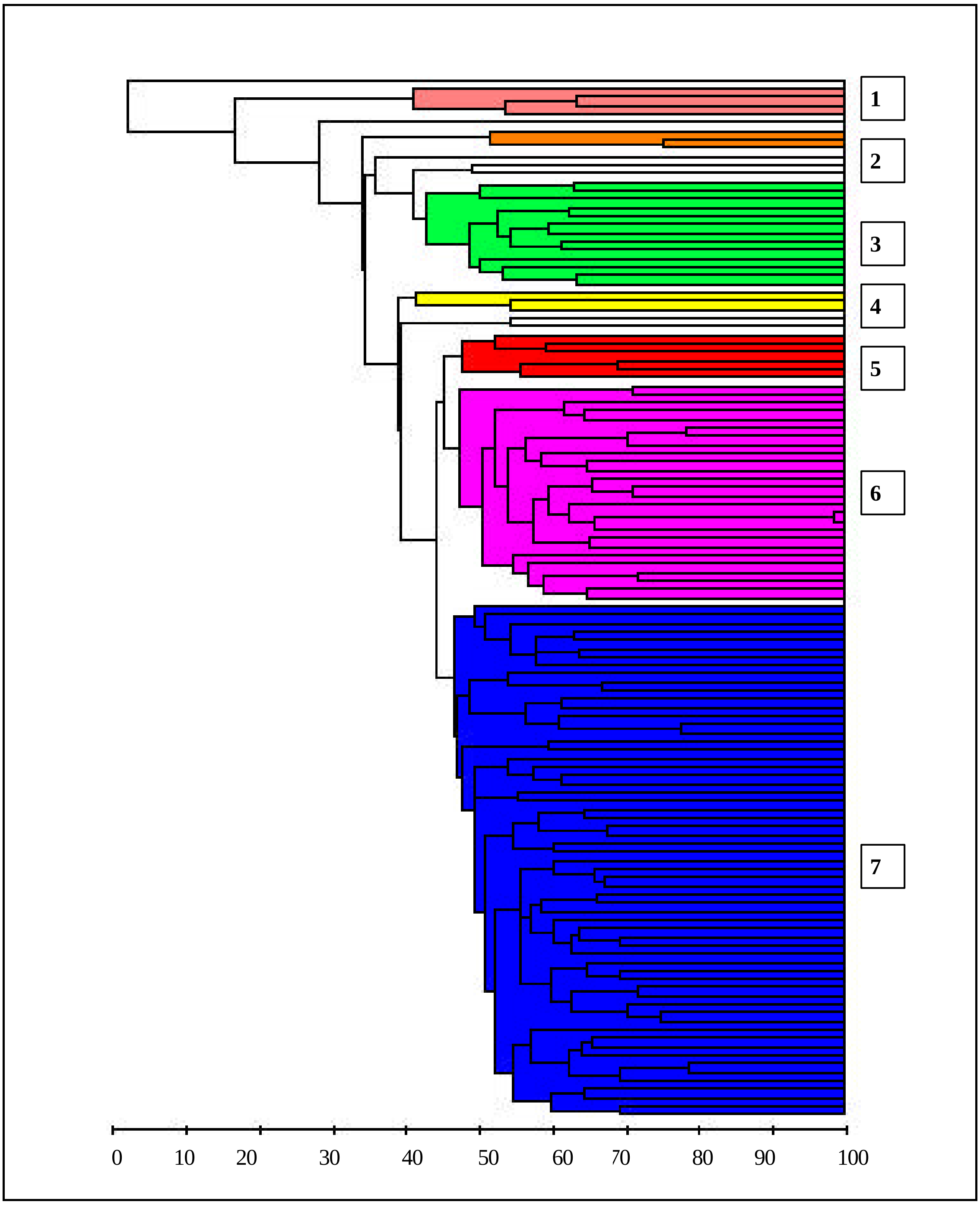


Figure 21. Dendrogram from cluster analysis of CCC baseline survey data from the pilot phase of the MCRCP. Each line represents benthic and substratum data from each Site Record (one completed Biological Form). The different colours highlight the major clusters representing the benthic classes discriminated. Horizontal axis represents similarity as calculated with the Bray-Curtis coefficient (%).

Using the characteristics of the benthic class defined by SIMPER and univariate analysis (Table 12 and Appendix 5), the seven benthic classes were labelled as shown in Table 13.

Table 12. Major characteristics of the seven benthic classes discriminated during the MCRCP. Figures in parentheses indicate median abundances derived from 0-5 ratings assigned during surveys. A full list of all medians is provided in Appendix 5. The most characteristic species, life forms or substratum categories (greater than 5% contribution to cluster similarity as highlighted by SIMPER analysis) are in bold.

BENTHIC CLASS	SUBSTRATUM	HARD CORALS	OCTOCORALS	SPONGES	ALGAE / SEAGRASS
1	**Sand (4.8)**	-	-	-	**Algal turf (1.0)**, *Halimeda* (0.5), ***Halophilia* (0.5)**
2	**Sand (3.0)**, Rubble (2.0)	-	**Pulsing *Xenia* (3.0)**	-	***Padina* (3.0)**, ***Caulerpa* (2.8)**, ***Lobophora* (2.8)**, *Amphiroa* (2.8), **Red calcified (2.8)**, *Eucheuma* (2.8), *Galaxaura* (2.8), *Jania* (2.8), ***Halimeda* (2.3)**, *Dictyota* (2.0)
3	**Sand (4.9)**, **Dead coral with algae (1.2)**	**Non-*Acropora* massive (1.0), *Porites* massive (1.0)**	-	**Encrusting (1.0)**	***Halimeda* (1.3)**, *Caulerpa* (1.0), *Halophilia* (1.0)
4	**Bedrock (4.0)**, **Dead coral (1.0)**, Rubble (1.0)	**Non-*Acropora* encrusting (1.0)**, **Non-*Acropora* foliose (1.0)**, **Non-*Acropora* massive (1.0)**, **Non-*Acropora* sub-massive (1.0)**, *Diploastrea heliopora* (1.0), ***Favites* (1.0)**, *Porites* massive (1.0)	-	**Encrusting (1.3)**	Red calcified (1.0)
5	**Rubble (2.5)**, **Recently killed coral (2.3)**, **Sand (2.2)**, **Bedrock (1.5)**, Dead coral with algae (1.3), Dead coral (1.0)	Non-*Acropora* massive (1.0), *Porites* massive (1.0), Non-*Acropora* branching (0.9), Non-*Acropora* encrusting (0.9).	-	Lumpy (1.2)	***Tydemania* (2.5)**, Red calcified (2.0), **Algal turf (2.0)**, *Padina* (1.8), *Halimeda* (1.5), Green filamentous (1.0)
6	**Sand (2.9)**, Dead coral with algae (2.1), Recently killed coral (1.8)	*Porites rus* (1.8), Non-*Acropora* massive (1.8), Non-*Acropora* branching (1.7), *Porites* massive (1.7), *Porites cylindrica* (1.6), Non-*Acropora* sub-massive	-	**Encrusting (1.7)**	***Padina* (2.0)**, *Tydemania* (1.7), Red calcified (1.6)
7	**Bedrock (3.2)**, Dead coral with algae (1.7), Sand (1.5)	*Acropora* branching (1.7), Non-*Acropora* massive (1.7), *Favia* (1.5), Non-*Acropora* encrusting (1.5), Non-*Acropora* branching (1.4), *Porites* massive (1.4)	-	Encrusting (1.8), Lumpy (1.4)	Red calcified (2.0), Algal turf (1.8)

Table 13. The benthic classes discriminated by cluster analysis and labelled using SIMPER and univariate statistics.

Benthic class	Number of site records	Code	Label
1	4	SAS	Sand with sparse algae and seagrass
2	3	SAA	Sand and algae
3	13	SSC	Sand with small coral patches
4	3	BDC	Bedrock, dead coral and sparse corals
5	6	MGC	Mixed substratum, green algae and coral
6	26	SLC	Sand with large coral patches
7	61	BMC	Bedrock and mixed corals
Unknown	7	-	-

When combined with the geomorphological habitats, a total of 20 habitats were delineated during the pilot phase of the MCRCP. These habitats are listed in Table 14.

Table 14. Habitat types delineated by baseline transect data during the MCRCP.

Habitat type	Number of records	Percentage of records
Back Reef + Mixed substratum, green algae and coral	1	0.8
Escarpment + Bedrock and mixed corals	9	7.3
Escarpment + Bedrock, dead coral and sparse corals	1	0.8
Forereef + Bedrock and mixed corals	40	32.5
Forereef + Bedrock, dead coral and sparse corals	2	1.6
Forereef + Mixed substratum, green algae and coral	3	2.4
Forereef + Sand and algae	3	2.4
Forereef + Sand with large coral patches	22	17.9
Forereef + Sand with small coral patches	13	10.6
Forereef + Sand with sparse algae and seagrass	3	2.4
Forereef + Unknown	6	4.9
Low relief spur and groove + Bedrock and mixed corals	1	0.8
Lagoon + Bedrock and mixed corals	4	3.3
Lagoon + Mixed substratum, green algae and coral	1	0.8
Lagoon + Sand with sparse algae and seagrass	1	0.8
Lagoon + Unknown	1	0.8
Patch reef + Bedrock and mixed corals	1	0.8
Reef Crest + Bedrock and mixed corals	6	4.9
Reef Crest + Mixed substratum, green algae and coral	1	0.8
Reef Crest + Sand with large coral patches	4	3.3

4.2.4 Fish data

Fish community within the whole project area

Analysis of individual fish taxa (all surveys combined) showed that the most obvious feature of fish populations in the project area is the overall dominance of the damselfish (Pomacentridae; median abundance 2.6) (Table 15). The most abundant group of damselfish were the planktivores *Chromis* spp.. Wrasse were also frequently seen throughout the project area (median abundance 1.7) and pearlscale angelfish was the most abundant species overall (median abundance 1.1).

Table 15. The median abundance from all baseline surveys of the 10 commonest fish families, genera or species recorded in the MCRCP area.

Taxa	Median abundance
Damselfish (Pomacenthidae)	2.63
Wrasse (Labridae)	1.69
Chromis spp.	1.13
Pearlscale angelfish (*Centropyge vrolikii*)	1.09
Goatfish (Mullidae)	0.63
Humbug dascyllus (*Dascyllus aruanus*)	0.49
Vagabond butterflyfish (*Chaetodon vagabundus*)	0.47
Spinecheek (Nemipteridae)	0.46
Twoline spinecheek (*Scolopsis bilineatus*)	0.44
'Cleaner' wrasse	0.44

Population variations between habitat types

ANOSIM between the fish communities (all 131 taxa) in each benthic class showed that there was an overall significant difference (r = 0.359, p<0.01) i.e. there were different fish communities in each benthic class. Detailed ANOSIM analysis showed that the major differences were between sand classes ('Sand with sparse algae and seagrass' and 'Sand and algae') and coral classes (particularly 'Bedrock and mixed corals') (p<0.10). Similarly, the benthic class 'Sand with small coral patches' class had a significantly different fish community to the class 'Bedrock and mixed coral'.

Eleven relatively abundant ecologically and economically important fish species, genera or families from different trophic levels were then selected for more detailed analysis. These were: unicornfish (*Naso* spp.); rabbitfish (Siganidae); triggerfish (Balistidae); Kleins butterflyfish (*Chaetodon kleinii*); flagtail grouper (*Cephalopholis urodeta*); convict surgeonfish (*Acanthurus triostegus*); snappers (Lutjanidae); parrotfish (Scaridae); goatfish (Mullidae); groupers (Serranidae) and damselfish (Pomacentridae). Firstly, these species were assessed using Kruskal-Wallis analysis for variation in abundance between the seven benthic classes distinguished by the baseline transects. Five of the 11 target taxa showed significant differences in abundances between benthic classes (p<0.05): triggerfish; convict surgeonfish; snappers and parrotfish. There were also trends of differences in abundance (p<0.1) for unicornfish, Kleins butterflyfish and flagtail grouper.

Figure 22 shows the abundance of each target taxa in each benthic class. Damselfish were the dominant taxa in all reef classes (particularly in coral dominated classes e.g. median abundance of 3.3 in 'Bedrock and mixed corals'). Sandy habitats ('Sand with sparse algae and seagrass' and 'Sand and algae') generally supported low abundances of most fish taxa. However, goatfish were more evenly distributed between all benthic classes since this family includes invertivore species that use soft sediments as a food source (e.g. dash-and-dot goatfish, *Parupeneus barberinus*) and also species that are predominantly found in coral rich areas (e.g. yellowsaddle goatfish, *Parupeneus cyclostomus*).

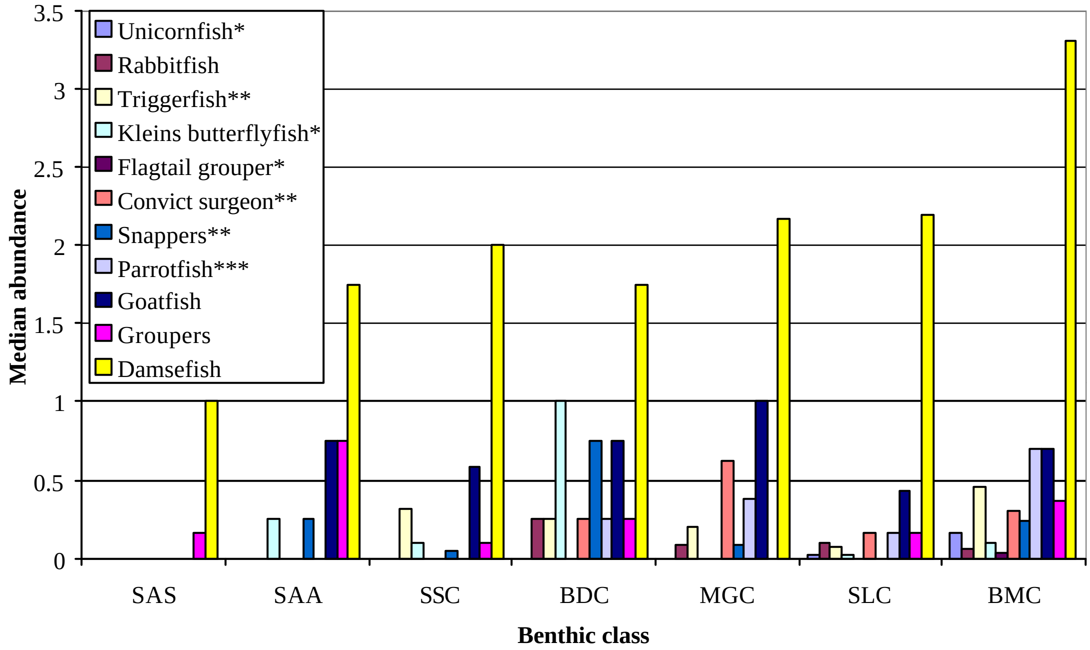


Figure 22. Abundance of each target fish taxa in each benthic class delineated during baseline surveys. Key to benthic classes: SAS = Sand with sparse algae and seagrass; SAA = Sand and algae; SSC = Sand with small coral patches; BDC = Bedrock, dead coral and sparse coral; MGC = Mixed substratum, green algae and coral; SLC = Sand with large coral patches and BMC = Bedrock and mixed coral. Asterisks in legend refer to results of Kruskal-Wallis tests: * = $p<0.1$; ** = $p<0.05$, *** = $p<0.01$. See Table 13 for sample sizes.

Population variations between reef complexes

In order to examine spatial variations in fish abundances within the project area, comparisons were made between the five reef complexes. In order to control for variations between benthic classes, this analysis was restricted to the most abundant class ('Bedrock and mixed coral' which had 61 replicates). Removing variation between benthic classes is vital because, for example, lower abundances in reef complex A compared to reef complex B may simply be caused by a higher proportion of habitat that is unattractive to many fish species (e.g. sand). By restricting the analysis to one benthic class, these differences are removed and any remaining patterns can be attributed to factors such as differential fishing pressure.

ANOSIM analysis showed that there was no overall significant difference between the fish communities in each reef complex ($r = 0.062$, $p>0.10$). However, detailed ANOSIM analysis showed that there was a trend for differences in communities between Mana Island and the Inner Malolo Group ($p<0.10$).

Kruskal-Wallis tests were then used to test for variations between reef complexes of populations of the same eleven relatively abundant ecologically and economically important fish species, genera or families that were tested for differences between habitat types. Six of the 11 target taxa showed significant variations ($p<0.05$) or trends ($p<0.1$) of abundances between reef complexes. The abundances of these species are shown in Figure 23 (non-significant taxa are omitted for clarity). Figure 23 shows that abundances were generally lower in the Inner and Outer Malolo Group. For example, unicornfish, triggerfish and flagtail groupers were most abundant in the Namotu Group (medians of 0.4, 1.6 and 0.2 respectively), rabbitfish and convict surgeonfish were most abundant at Navini Island (medians of 1.5 and 1.0 respectively) and Kleins butterflyfish were most abundant at Mana Island (median abundance 0.3).

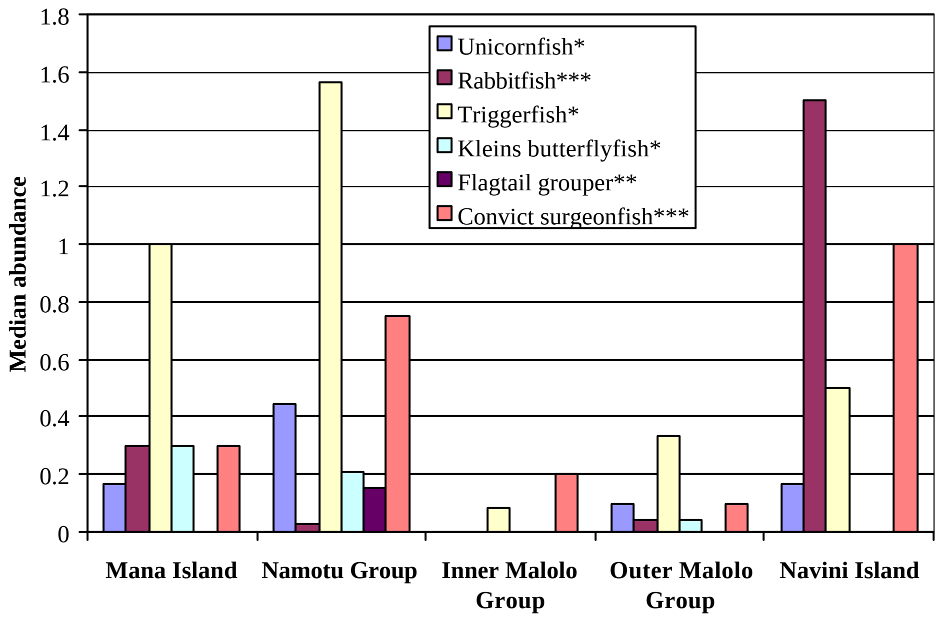


Figure 23. Fish abundances within the benthic class 'Bedrock and mixed corals' at different reef complexes within the MCRCP area. Asterisks in legend refer to results of Kruskal-Wallis tests: * = $p<0.1$; ** = $p<0.05$; *** = $p<0.01$. Sample sizes: Mana Island = 8; Namotu Group = 17; Inner Malolo Group = 7; Outer Malolo Group = 25 and Navini Island = 4.

Correlation between fish and coral species richness

The final analysis of fish data collected during the baseline transects was an investigation of the link between coral and fish species richness. This was achieved via regression analysis between the number of target coral species in each habitat ('Site Record') delineated by the survey teams (maximum 38 species) and the number of target fish species (maximum 89 species). This relationship was significantly correlated ($p<0.001$; $R^2 = 0.23$) and is shown in Figure 24. Note that R^2 is the correlation coefficient that varies from –1 (strong negative correlation) to 1 (strong positive correlation). There was also a significant positive correlation between the number of coral life forms and number of fish families, both of which are proxies of species richness ($p<0.001$; $R^2 = 0.18$).

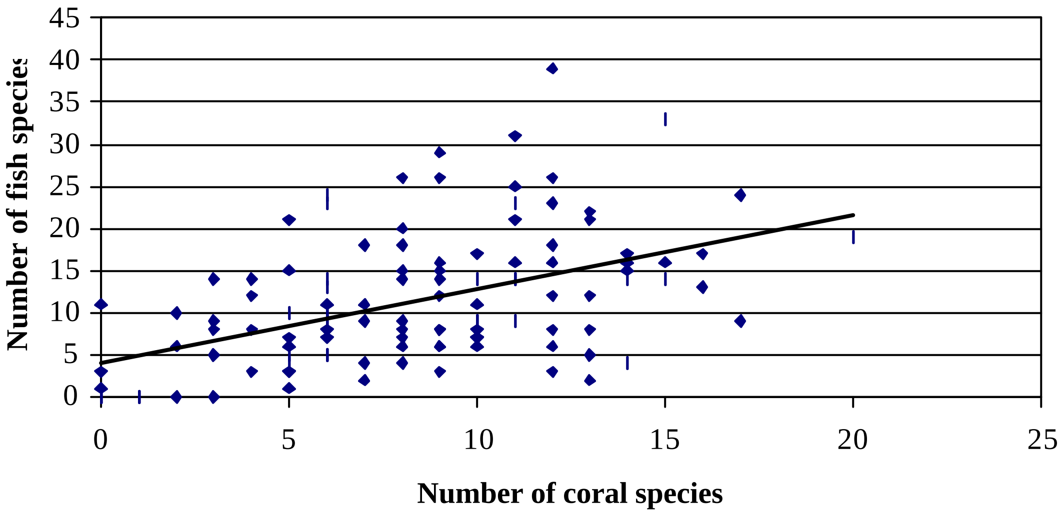


Figure 24. Relationship between the number of target coral and fish species seen during baseline transect surveys. Trendline shows linear relationship via regression analysis.

4.2.5 Invertebrate data

Invertebrate community within the whole project area

Analysis of individual invertebrate taxa[5] (all surveys combined) showed that the most obvious feature of invertebrate populations in the project area is that most are relatively infrequent with only tunicates having a median abundance >1 (Table 16). Echinodermata is the dominant phyla, with feather stars, blue sea stars and short spine and *Diadema* urchins all having median abundances > 0.25.

Table 16. The median abundance from all baseline surveys of the 10 commonest invertebrate taxa recorded in the MCRCP area.

Taxa	All surveys combined
Tunicates (Ascidiacea)	1.09
Feather stars (Crinoidea)	0.78
Synapta maculata (sea cucumber)	0.66
Nudibranchs (Nudibranchia)	0.40
Blue sea star (*Linkia laevigata*)	0.31
'Short spine' urchins	0.28
Diadema spp.	0.27
Clams (Tridacnidae)	0.25
Synaptid sea cucumbers	0.24
Periclimenes shrimps	0.16

[5] For the purposes of this report 'invertebrate' refers to invertebrates not included in the multivariate cluster analysis i.e. taxa other than hard corals, soft corals and sponges.

Population variations between habitat types

ANOSIM between the invertebrate communities (all 39 taxa; not including corals, octocorals or sponges which are analysed during cluster analysis in Section 4.2.3) in each benthic class showed that there was an overall significant difference ($r = 0.219$, $p<0.01$) i.e. there were different invertebrate communities in each benthic class. Note that this analysis excluded the benthic class 'Sand with sparse algae and seagrass' since there were no records of any of the invertebrates occurring in these areas. Detailed ANOSIM analysis showed that the major differences were between the sand class ('Sand and algae') and the coral rich classes ('Sand and large coral patches' and 'Bedrock and mixed corals') ($p<0.01$).

Nine relatively abundant ecologically and economically important invertebrate species, genera or families were then selected for more detailed analysis. These were: conch (*Strombus* spp.); cowries (Cypraeidae); *Drupella* spp.; clams (Tridacnidae); octopus (Octopodidae); squid (Loliginidae); crown-of-throns starfish (*Acanthaster planci*); *Diadema* urchins and sea cucumbers (Holothuriidae). Firstly, these species were assessed using Kruskal-Wallis analysis for variation in abundance between the seven benthic classes distinguished by the baseline transects. Only two of the nine target taxa showed significant differences in abundances between benthic classes ($p<0.05$): *Diadema* and sea cucumbers. There were also trends of differences in abundance ($p<0.1$) for cowries and clams.

Figure 25 shows the abundance of each target taxa in each benthic class. Conch and cowries were seen in low numbers in all habitats, with the exception of cowries in the 'Mixed substratum, green algae and coral' benthic class (median abundance 0.5). Clams were more abundant in coral rich classes ('Bedrock, dead coral and sparse coral', 'Mixed substratum, green algae and coral', 'Sand with large coral patches' and 'Bedrock and mixed coral'). Other molluscs such as octopi and squid were encountered very infrequently on the reef (median abundances <0.03). Crown-of-thorns starfish and *Drupella* were also rarely seen during survey work (median abundances <0.2).

The most significant differences in invertebrate populations between different benthic classes were seen in *Diadema* spp. and sea cucumbers. Sea cucumbers were abundant in the mixed substratum area of the forereef and backreef zones (benthic class 'Mixed substratum, green algae and coral'). In contrast *Diadema* spp. were particularly abundant in the patchy reef areas where sand surrounded large coral 'bommies' (benthic class 'Sand with large coral patches'). *Diadema* spp. were generally seen on these coral bommies adjacent to the sand.

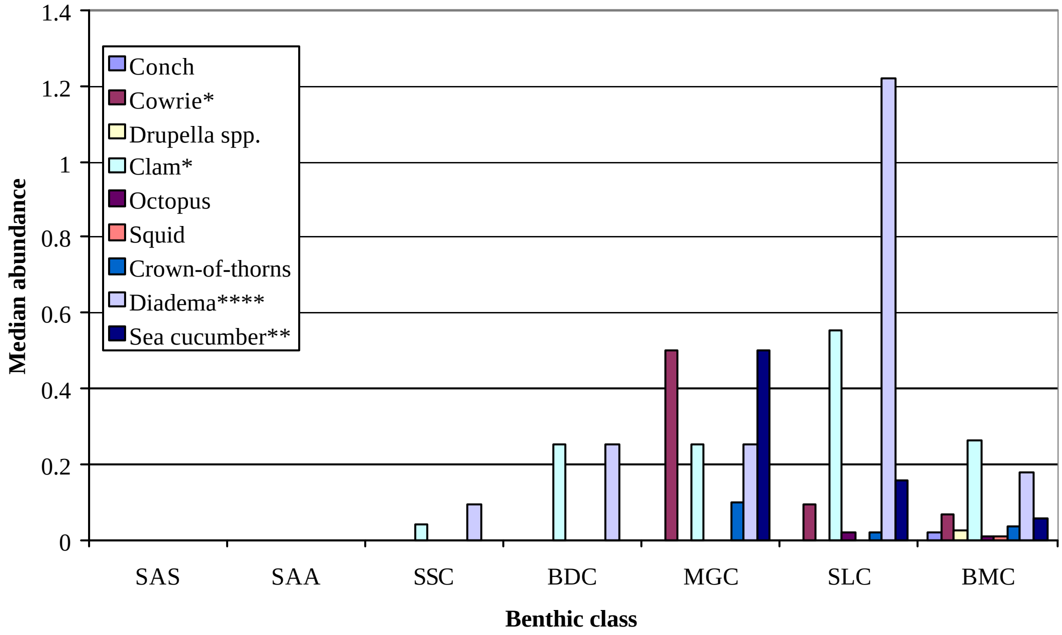


Figure 25. Abundance of each target invertebrate taxa in each benthic class delineated during baseline surveys. Key to benthic classes: SAS = Sand with sparse algae and seagrass; SAA = Sand and algae; SSC = Sand with small coral patches; BDC = Bedrock, dead coral and sparse coral; MGC = Mixed substratum, green algae and coral; SLC = Sand with large coral patches and BMC = Bedrock and mixed coral. Asterisks in legend refer to results of Kruskal-Wallis tests: * = $p<0.1$; ** = $p<0.05$, **** = $p<0.001$. See Table 14 for sample sizes.

Population variations between reef complexes

In order to examine spatial variations in invertebrate abundances within the project area, comparisons were made between the five reef complexes. In order to control for variations between benthic classes, this analysis was restricted to the most abundant class ('Bedrock and mixed coral' which had 61 replicates). Removing variation between benthic classes is vital because, for example, lower abundances in reef complex A compared to reef complex B may simply be caused by a higher proportion of habitat that is unattractive to many fish species (e.g. sand). By restricting the analysis to one benthic class, these differences are removed and any remaining patterns can be attributed to factors such as differential fishing pressure.

ANOSIM analysis showed that there was no overall significant difference between the invertebrate communities in each reef complex ($r = 0.095$, $p>0.40$). However, detailed ANOSIM analysis showed that there was a slight trend between the communities at Mana Island and Inner Malolo Group ($p<0.20$).

Kruskal-Wallis tests were then used to test for variations between reef complexes of populations of the same nine relatively abundant ecologically and economically important invertebrate species, genera or families that were tested for differences between habitat types. Only three of the nine target taxa showed significant variations ($p<0.05$) or trends ($p<0.1$) of abundances between reef complexes. The abundances of these species are shown in Figure 26. Figure 26 shows that conch, cowrie, octopus and squid were rare at all reef complexes (median abundances <0.09). Similarly, the coralivorous *Drupella* spp. and crown-of-thorns starfish were generally seen at low abundances in all reef complexes (<0.07). However, *Drupella* spp. were significantly more abundant on dives in the Inner Malolo Group (median of 0.2) compared to other locations (KS = 10.32, p<0.04).

Diadema spp. were significantly different in their distribution between different reef complexes (KS = 18.68, p<0.001). The highest abundance was recorded in the Inner Malolo group (median of 1.3) with animals aggregating amongst the coral heads and on shallow bedrock areas of reef. For example, the largest concentrations (median value of 3 which represents >20 individuals) were rarely seen on the reef (only three times) and were always in the shallowest part of the transect. Finally, there was a trend of variation of sea cucumber abundances between reef complexes (KS = 8.50, p<0.080), with the highest populations around Navini Island (median abundance of 0.5).

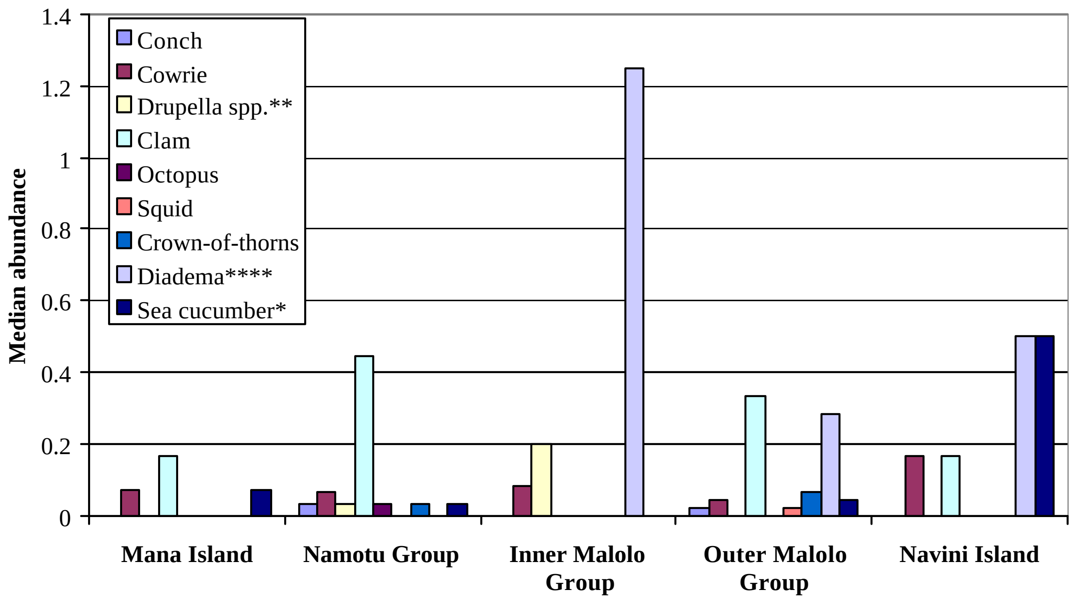


Figure 26. Invertebrate abundances within the benthic class 'Bedrock and mixed corals' at different reef complexes within the MCRCP area. Asterisks in legend refer to results of Kruskal-Wallis tests: * = p<0.1; ** = p<0.05; *** = p<0.01. Sample sizes: Mana Island = 8; Namotu Group = 17; Inner Malolo Group = 7; Outer Malolo Group = 25 and Navini Island = 4.

4.3 Habitat mapping

Figures 27 to 31 show the results of processing the Landsat 7 image purchased for the pilot phase of the MCRCP. Note that Figure 31 has 10 habitat classes comprising of the seven benthic classes delineated during the baseline survey work plus three additional classes that could not be surveyed by CCC volunteers. These three additional habitats are 'Unclassified' (deep water >20 m) and the two geomorphological classes 'Reef crest' (very shallow or emergent areas characterised by high levels of wave action) and 'Beach / Shallow sand' (effectively inter-tidal areas). Since the classified habitat map is held within a GIS, it is possible to quantify the area covered by each benthic class (Table 17).

Table 17. The areal coverage of each benthic or geomorphological class and the total project area.

Benthic / Geomorphological class	Area (km^2)	Percentage of total area of all benthic / geomorphological classes
Beach / Shallow sand	1.58	2.2
Bedrock and mixed corals	20.12	28.4
Bedrock, dead coral and sparse coral	3.88	5.5
Mixed substratum, green algae and coral	6.71	9.5
Reef crest	0.68	1.0
Sand and algae	9.01	12.7
Sand with large coral patches	7.14	10.1
Sand with small coral patches	15.19	21.5
Sand with sparse algae and seagrass	6.46	9.1
Total (all benthic classes)	**70.78**	**100**
Unclassified	1755.31	
Total (whole project area	**1826.09**	

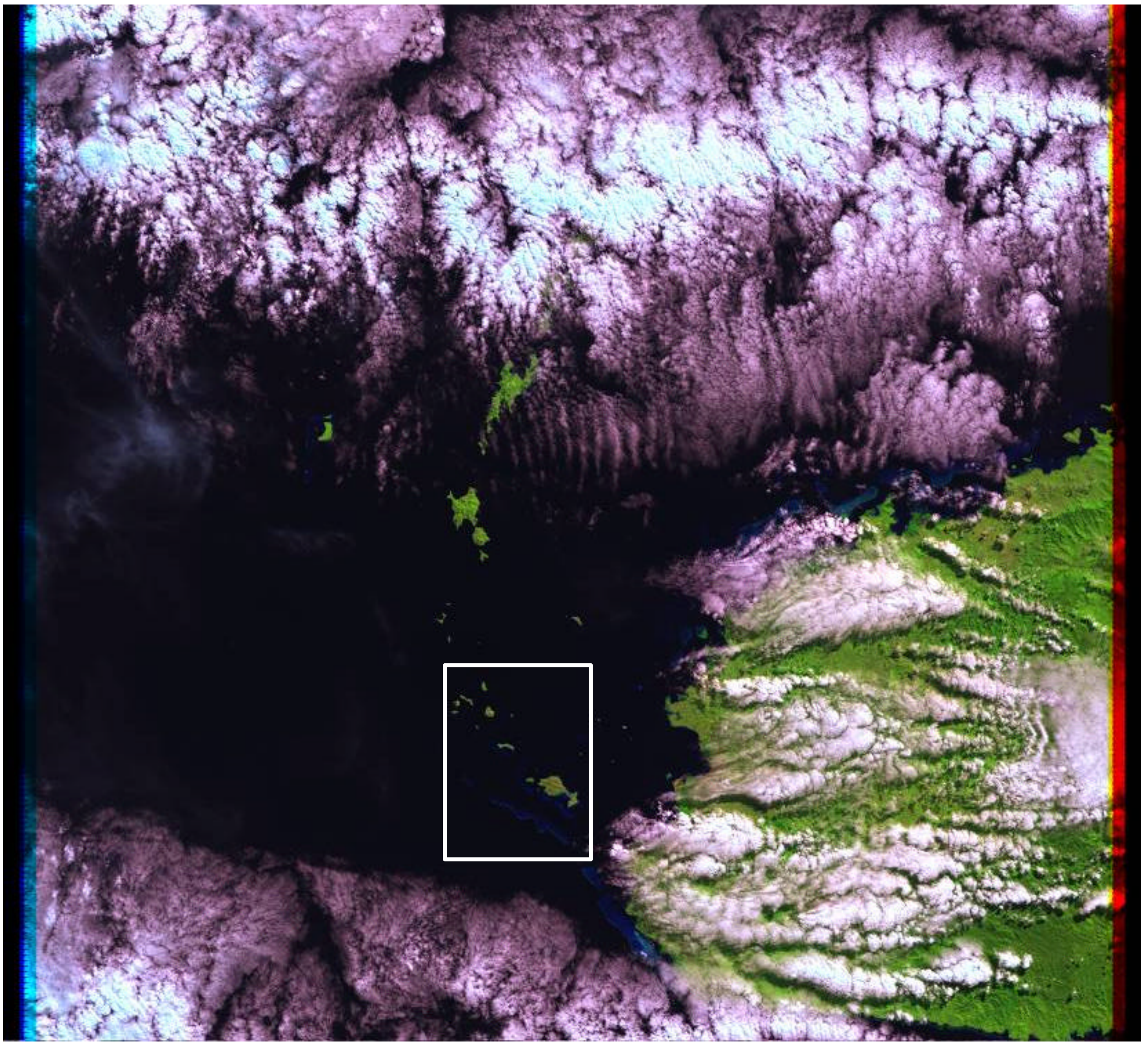


Figure 27. The full extent of the Landsat 7 satellite image purchased for the MCRCP. The white box shows the location of the project area. Note that although the whole image contains significant cloud cover, the project area is virtually cloud free and hence the reefs are clearly visible.

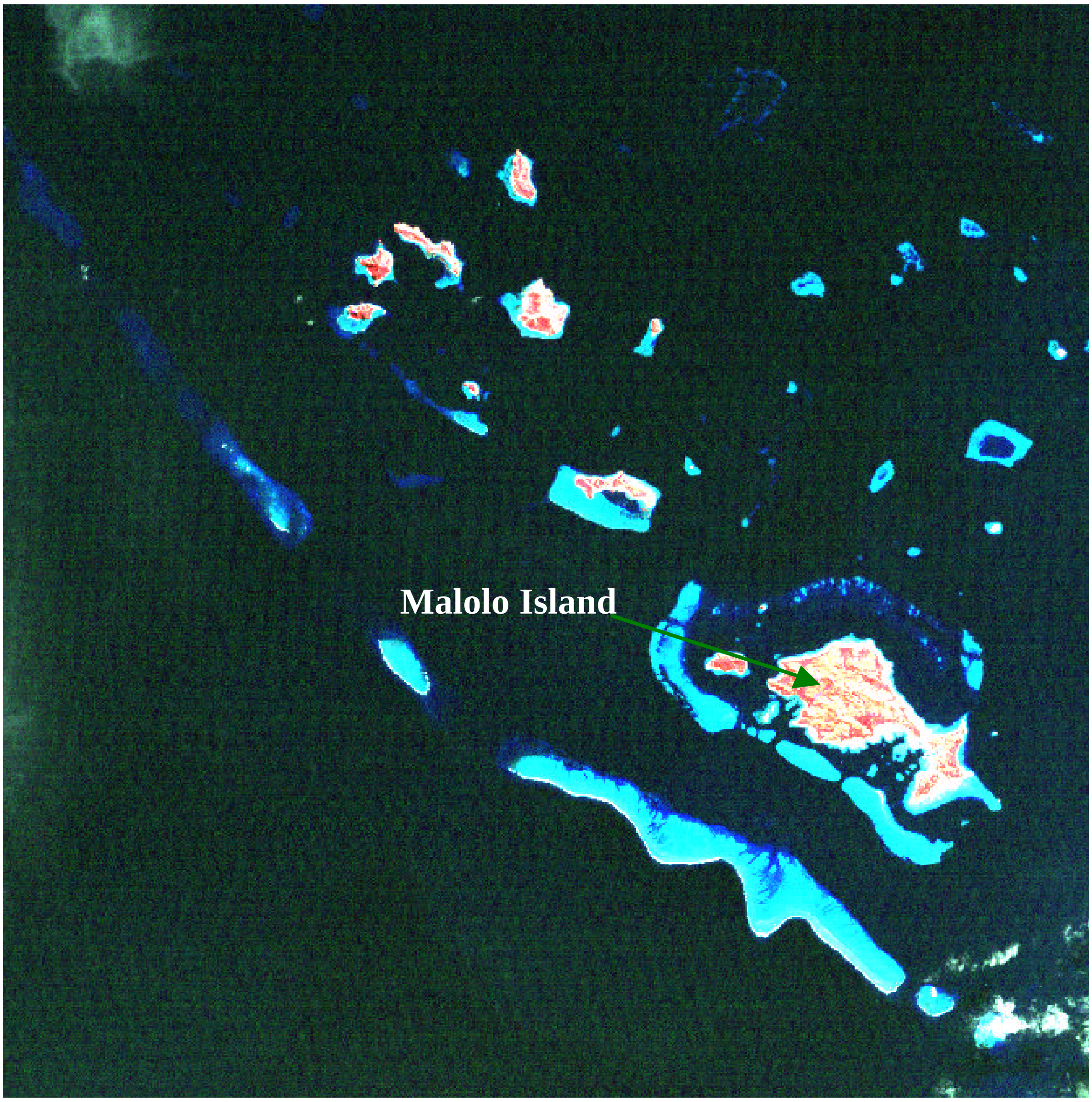


Figure 28. The raw satellite image after subseting to remove data outside the project area to improve subsequent computer processing times. Malolo Island is labelled for orientation. Land is shown in red, deepwater is black and the shallow (<20 m) marine habitats are shown in blue.

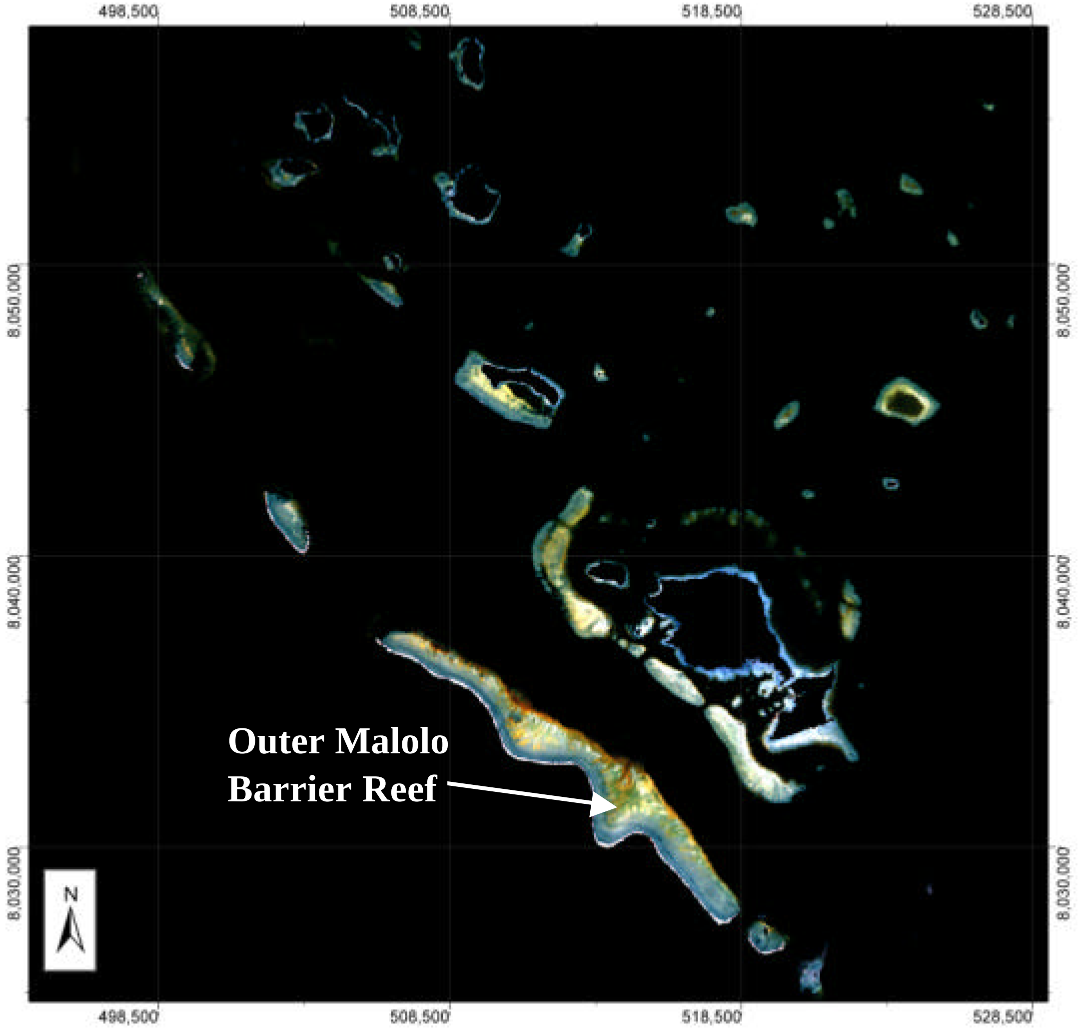


Figure 29. The subseted image following geometric correction and masking out land, deep water and clouds. Since the image is geometrically corrected so that each pixel has the correct co-ordinates, the outer scale shows the Universal Transverse Mercator co-ordinate system. Note the improved contrast between marine habitats on the Outer Malolo Barrier Reef compared to the unmasked image in Figure 28.

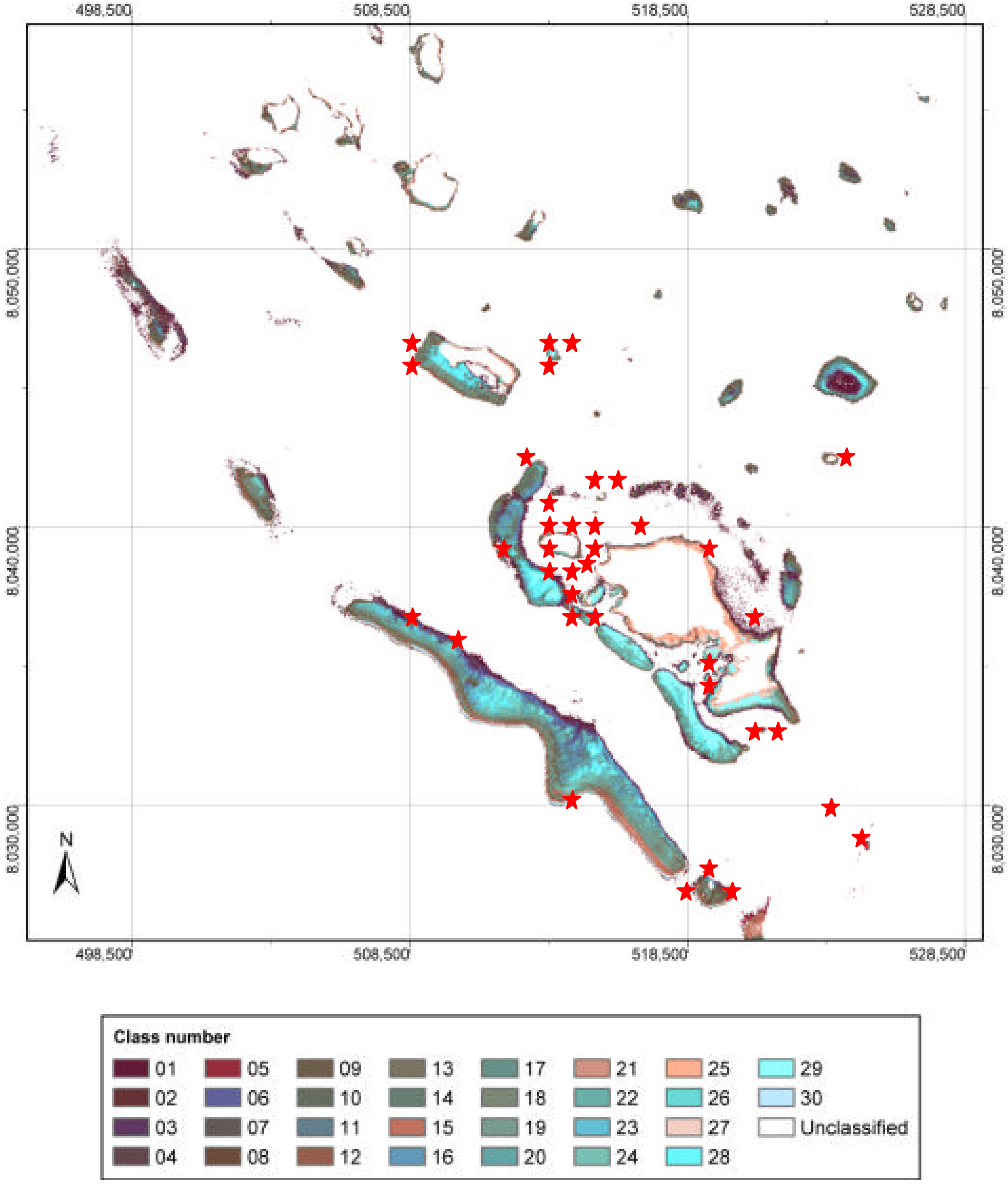


Figure 30. Results of the unsupervised classification during which the computer classified each pixel into one of 30 classifies based on their spectral signatures. The location of each CCC baseline transect is shown by a red star.

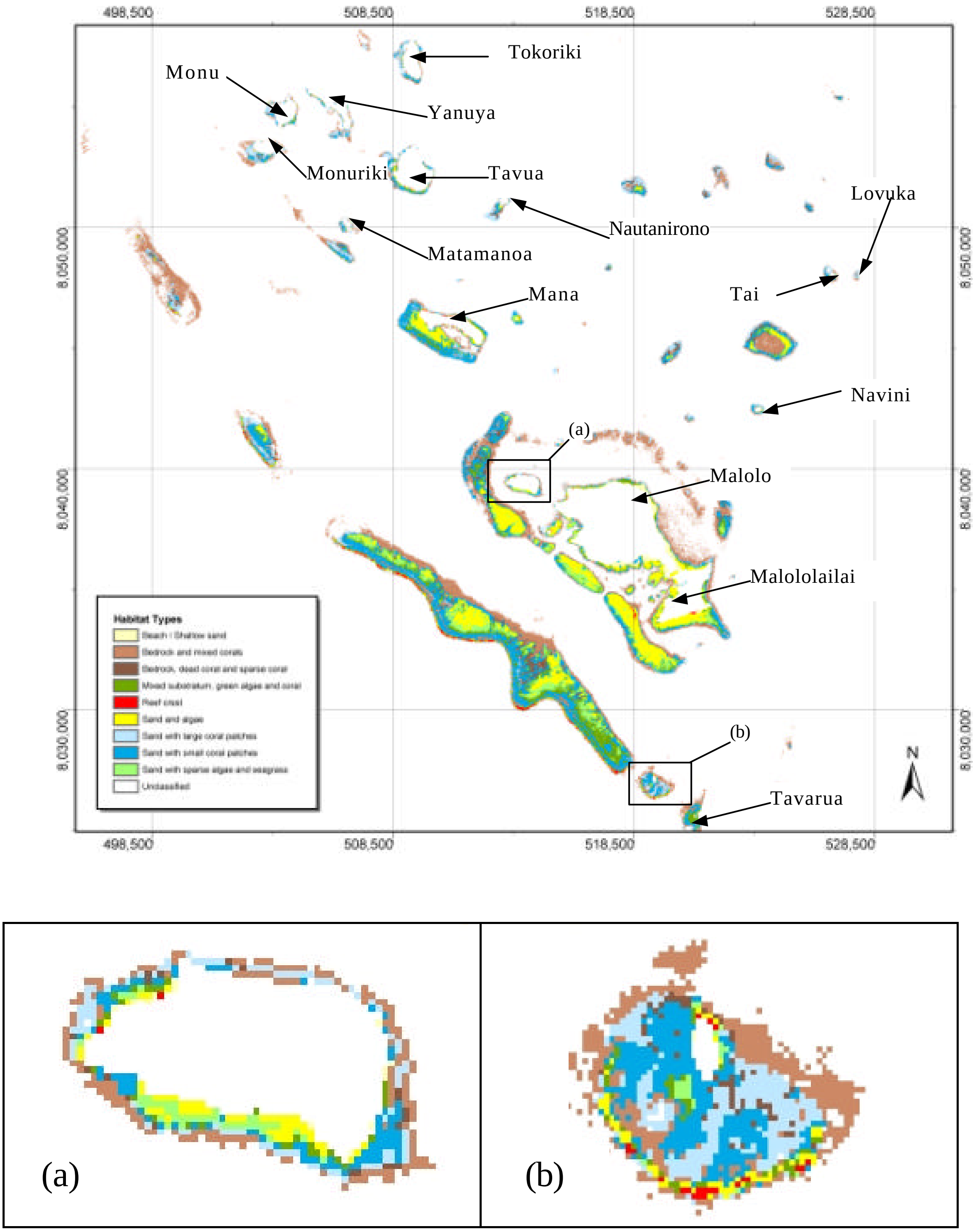


Figure 31. Habitat map produced from the data collected during the pilot phase of the MCRCP. The pixels are classified using the seven benthic classes delineated by the baseline transects plus 'Beach / Shallow sand' (inter-tidal areas), 'Reef crest' (very shallow areas with obvious wave action) and 'Unclassified' (deep water). Major islands shown for orientation. Figures 31 (a) and (b) show reef detail from Qalito (Castaway) Island and Namotu (Magic) Island respectively.

4.4 Reef Check

4.4.1 Surveys completed

During Phase 2 of the pilot project of the MCRCP, a total of 22 Reef Check surveys were completed. The locations of these transects are shown in Table 18 and Figure 32. Note that because of limited reef development below 6m, most of the transects were completed in the 'shallow' depth band (3-6 m) define by the standard Reef Check methodology. Deeper transects were generally restricted to platform reefs or the Outer Malolo Barrier Reef where reef development was more extensive.

Table 18. Sites used for Reef Check surveys during Phase 2 of the MCRCP. See Figure 32 for the exact location of each site. Reef complexes: MA = Mana Island; NO = Namotu Group; IM = Inner Malolo Group; OM = Outer Malolo Group; NA = Navini Island. 'Impacts' refers to an overall qualitative assessment of anthropogenic impacts based on the data contained within the site description form.

Site code	Site name / General location	Reef complex	Depth (m)	Impacts
RCA1	Cousteau Rock	IM	5	Medium
RCA2	Castaway house reef	IM	5	Medium
RCA3	Runners Beach	IM	3	Medium
RCA4	Castaway wall	IM	4	Medium
RHM1	Mothiu (Honeymoon) Island	IM	5	Low
RIB1	Inner barrier reef (Castaway Cut)	OM	3	High
RIB2	Outside of inner barrier reef close to Waidigi Island	OM	1	High
RIB3	Outside of inner barrier reef, south west of Qalito (Castaway) Island	OM	3	High
RMI1	Wilkes Passage	NO	20	Medium
RMI3	Outer barrier reef close to Namotu (Magic) Island	NO	6	Medium
RMI4	Outer barrier reef close to Namotu (Magic) Island	NO	13.5	Medium
RML1	Malolo Island	IM	7	High
RML2	Malolo Island	IM	4	High
RML3	Malololailai	IM	6	High
RNA1	Nayauu Levu	OM	3	Low
RNI1	Navini Island	NA	5	Low
RRA1	Raviniyake (close to CCC base)	IM	3	Medium
RRA2	Raviniyake (close to CCC base)	IM	4	Medium
RSF1	Sunflower	OM	14	Medium
RSF2	Sunflower	OM	4	Medium
RSM1	Supermarket	MA	8	Medium
RWI1	Waidigi Island	IM	6	Medium

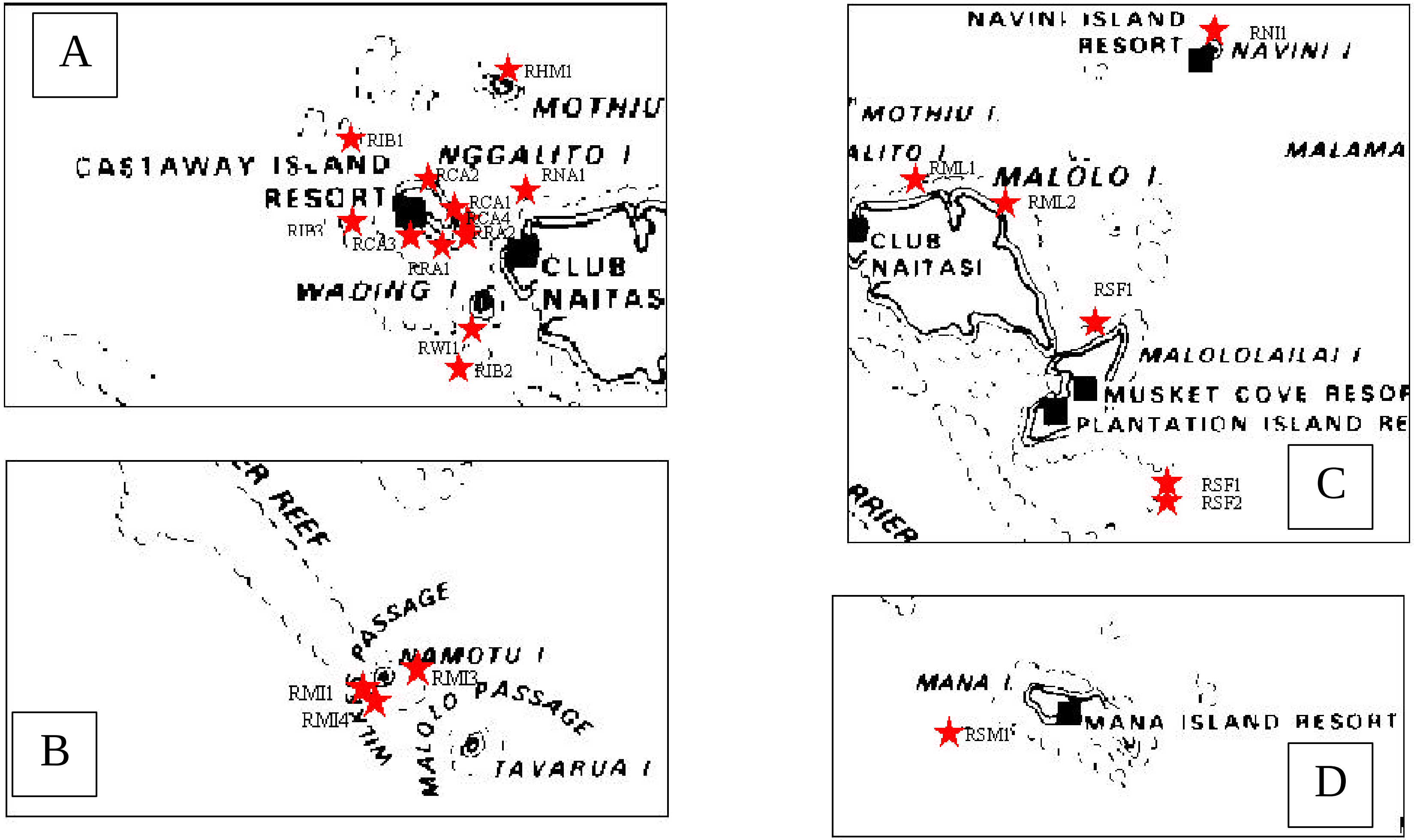


Figure 32 (a-d). Location of Reef Check sites (red stars) completed during the pilot phase of the MCRCP. Key to codes in Table 18.

4.4.2 Characterisation of benthic classes

Since the Reef Check sites were placed close to the location of selected baseline transects, the data can be used to assign quantitative percentage cover values to some of the benthic classes discriminated in Section 4.2.3. For example, f Reef Check site A was at 3m and was close to transect B, the Reef Check data from site A provide information on the benthic class discriminated at 3 m on the baseline transect. The quantitative data for each benthic class surveyed are shown in Table 19.

Table 19. Quantitative data for the benthic classes discriminated by baseline transects and re-surveyed using the Reef Check protocol. Note that the other three benthic classes were not found at any of the Reef Check sites. Figures in parentheses represent standard deviation where appropriate (n>1). Sample sizes: Sand with small coral patches = 1; Bedrock, dead coral and sparse coral = 1; Sand with large coral patches = 9; Bedrock and mixed coral = 11.

Benthic category	Sand with small coral patches	Bedrock, dead coral and sparse coral	Sand with large coral patches	Bedrock and mixed coral
Acropora	0.0	0	0.6 (0.8)	5.5 (6.1)
Non-*Acropora*	1.3	6.9	9.2 (6.8)	13.1 (9.7)
Total coral cover	*1.3*	*6.9*	*9.8*	*18.6*
Soft coral	0.0	0.0	0.4 (0.7)	1.1 (1.3)
Sponge	0.0	0.0	0.2 (0.3)	1.0 (1.6)
Zoanthid	0.0	0.0	0.0 (0.0)	0.0 (0.0)
Algae	51.3	7.5	29.2 (9.1)	27.4 (13.2)
Recently killed coral	0.6	1.3	1.9 (1.8)	3.1 (2.8)
Rock	16.3	72.5	16.9 (5.8)	27.2 (15.6)
Silt	0.0	0.0	0.0 (0.0)	0.0 (0.0)
Rubble	5.0	0.6	15.9 (5.3)	8.8 (8.8)
Sand	25.6	11.3	25.3 (13.1)	11.5 (11.5)
Other	0.0	0.0	0.3 (0.6)	1.2 (1.8)

Table 19 shows that the Reef Check data support the labels, and hence the data, assigned from the baseline transects. For example, coral cover is highest in the 'Bedrock and mixed coral' class (18.6%) and lowest in the 'Sand with small coral patches' class (1.3%). Similarly, rock was abundant in the 'Bedrock, dead coral and sparse coral' and 'Bedrock with mixed coral' classes (rock and dead coral are not distinguished during Reef Check surveys). Algae were most abundant in the 'Sand with small coral patches' class. Note that the data from the benthic classes 'Sand with small coral patches' and 'Bedrock, dead coral and sparse coral' are from only one replicate and should, therefore, be viewed with caution.

4.4.3 Quantitative assessment of reef health

A summary of the parameters recorded along each transect line during the Reef Check surveys are shown in Tables 20, 21 and 22. A graphical summary of all sites combined is shown in Figure 33. Tables 20 to 22 and Figure 33 show that the sites surveyed generally had low total coral cover (mean 13.7%, standard deviation 4.9%) and had more non-*Acropora* than *Acropora* corals (means of 10.7% and 3.0%

respectively). The highest coral cover was seen on the two Sunflower transects RSF1 and RSF2 (44.4% and 28.1% respectively). The benthic community was dominated by algae (mixed assemblage, coralline, *Halimeda* and macro-algae combined) with a mean percentage cover of 28.4% (standard deviation 12.7%). Soft corals and sponges were scarce (percentage cover <1%). The benthic community was generally growing on a rock and sand substratum (mean cover 24.5% and 17.8% respectively). Rubble was common (mean cover 11.1%) and recently killed coral was scarce (mean cover 2.4%).

The most abundant fish were surgeonfish (Acanthuridae) and fusiliers (Caesionidae) with mean abundances of 12.3 and 10.0 per 500 m^3 respectively. Surgeonfish were generally common on each transect but fusiliers were generally found in shoals and hence were abundant at some locations (mean abundance of 121.3 at Mothiu (Honeymoon) Island) and absent at others. Butterflyfish (Chaetodontidae), ‘other parrotfish’ (Scaridae; not bumphead) and snappers (Lutjanidae) were the only other taxa with mean abundances >1 per 500 m^3.

Most of the invertebrate taxa targeted by the Reef Check surveys were rarely seen. However, *Diadema* urchins were common (mean abundance 24.9 per 100 m^2; standard deviation 24.9) but were patchily distributed with abundances ranging from absent to 85.5 at RCA1 (‘Cousteau Rock’ close to Qalito Island). Coral recruits (juvenile colonies 1-5 cm in size) were also relatively common (mean abundance 8.8). All other taxa had abundances <2.2 per 100 m^2. The commercially important sea cucumbers, clams and lobsters were scarce with only 188, 101 and 3 individuals seen during all the surveys (total of 8,800 m^2). Coralivorous crown-of-thorns starfish and *Drupella* were also scarce (10 and 4 individuals in total respectively).

Table 20. Summary of percentage cover of each parameter per 20 m section of the Reef Check line transect at each site. No zoanthids or silt were recorded and have been omitted for clarity. See Table 18 and Figure 32 for location of each site.

Site	*Acropora* (%)	Non-*Acropora* (%)	Soft coral (%)	Sponge (%)	Algae (%)	Recently killed coral (%)	Rock (%)	Rubble (%)	Sand (%)	Other (%)
RCA1	0.6 (1.3)	5.6 (5.2)	0.0 (0.0)	0.0 (0.0)	33.8 (16.1)	0.0 (0.0)	17.5 (3.5)	18.8 (8.5)	23.8 (11.8)	0.0 (0.0)
RCA2	0.6 (1.3)	16.3 (11.6)	1.3 (1.4)	0.0 (0.0)	35.6 (14.8)	1.3 (1.4)	16.3 (8.8)	8.8 (8.3)	20 (10.6)	0.0 (0.0)
RCA3	0.0 (0..0)	6.3 (2.5)	0.0 (0.0)	0.0 (0.0)	37.5 (7.4)	3.1 (4.7)	11.3 (10.1)	19.4 (3.1)	22.5 (12.4)	0.0 (0.0)
RCA4	1.3 (1.4)	1.3 (2.5)	1.9 (3.8)	0.6 (1.3)	25 (9.1)	1.9 (2.4)	26.3 (7.8)	13.1 (6.3)	28.1 (13.6)	0.6 (1.3)
RHM1	3.8 (3.2)	5.6 (4.3)	1.3 (1.4)	1.3 (1.4)	36.3 (24.7)	1.3 (2.5)	40.0 (33.6)	2.5 (2.0)	6.3 (1.4)	1.9 (2.4)
RIB1	0.0 (0.0)	1.3 (1.4)	0.0 (0.0)	0.0 (0.0)	51.3 (9.5)	0.6 (1.3)	16.3 (12.3)	5.0 (3.5)	25.6 (13.3)	0.0 (0.0)
RIB2	8.1 (6.9)	15.0 (3.5)	0.6 (1.3)	0.0 (0.0)	6.3 (6.0)	7.5 (5.4)	55.0 (12.1)	6.3 (6.0)	0.6 (1.3)	0.6 (1.3)
RIB3	5.0 (2.0)	4.4 (2.4)	0.0 (0.0)	0.0 (0.0)	48.1 (17.8)	1.3 (2.5)	3.8 (3.2)	5.0 (2.0)	32.5 (17.7)	0.0 (0.0)
RMI1	0.0 (0.0)	16.9 (9.0)	3.8 (4.3)	3.8 (1.4)	39.4 (10.1)	0.0 (0.0)	22.5 (26.1)	1.9 (1.3)	5.6 (4.7)	6.3 (10.9)
RMI3	2.5 (3.5)	16.9 (5.5)	1.9 (1.3)	0.0 (0.0)	24.4 (28.2)	6.9 (5.5)	34.4 (34.2)	1.9 (2.4)	11.3 (6.6)	0.0 (0.0)
RMI4	0.0 (0.0)	20.6 (6.9)	3.1 (3.8)	4.4 (5.2)	24.4 (21.3)	2.5 (3.5)	35.6 (25.9)	5.0 (3.5)	4.4 (2.4)	0.0 (0.0)
RML1	0.0 (0.0)	6.9 (6.3)	0.0 (0.0)	0.6 (1.3)	15.0 (6.5)	0.0 (0.0)	10.6 (4.7)	11.3 (6.6)	55.6 (3.1)	0.0 (0.0)
RML2	0.0 (0.0)	11.9 (5.5)	0.0 (0.0)	0.0 (0.0)	43.8 (12.7)	1.3 (2.5)	16.9 (2.4)	11.3 (6.0)	13.1 (3.8)	1.9 (2.4)
RML3	0.6 (1.3)	22.5 (4.1)	0.0 (0.0)	0.0 (0.0)	27.5 (18.4)	3.1 (2.4)	9.4 (2.4)	25.6 (19.1)	11.3 (1.4)	0.0 (0.0)
RNA1	6.9 (5.2)	10.0 (5.8)	0.0 (0.0)	0.0 (0.0)	37.5 (8.4)	0.6 (1.3)	15.6 (5.5)	15.6 (3.8)	12.5 (2.0)	1.3 (1.4)
RNI1	3.8 (3.2)	11.3 (12.0)	0.6 (1.3)	0.0 (0.0)	21.3 (25.0)	1.9 (3.8)	43.8 (25.0)	7.5 (13.4)	8.8 (10.9)	1.3 (2.5)
RRA1	0.0 (0.0)	2.5 (3.5)	0.0 (0.0)	0.6 (1.3)	23.1 (9.7)	1.3 (1.4)	22.5 (27.4)	17.5 (12.7)	32.5 (15.4)	0.0 (0.0)
RRA2	2.5 (2.0)	9.4 (17.1)	0.6 (1.3)	0.0 (0.0)	21.9 (19.5)	5.6 (3.8)	21.3 (16.9)	17.5 (9.1)	21.3 (8.3)	0.0 (0.0)
RSF1	8.8 (1.4)	35.6 (15.5)	0.6 (1.3)	0.6 (1.3)	13.8 (8.3)	7.5 (11.9)	20.0 (7.4)	9.4 (13.0)	3.1 (6.3)	0.6 (1.3)
RSF2	21.3 (4.3)	6.9 (1.3)	0.6 (1.3)	1.3 (2.5)	37.5 (9.6)	1.9 (2.4)	13.8 (14.8)	8.8 (6.3)	6.9 (5.9)	1.3 (1.4)
RSM1	0.0 (0.0)	6.9 (4.3)	0.0 (0.0)	0.0 (0.0)	7.5 (7.9)	1.3 (1.4)	72.5 (9.8)	0.6 (1.3)	11.3 (9.2)	0.0 (0.0)
RWI1	0.6 (1.3)	0.6 (1.3)	0.0 (0.0)	0.0 (0.0)	13.1 (7.2)	3.1 (4.7)	15.0 (6.8)	32.5 (2.0)	35.0 (16.8)	0.0 (0.0)
Mean for all sites	*3.0 (4.9)*	*10.7 (8.4)*	*0.7 (1.1)*	*0.6 (1.2)*	*28.4 (12.7)*	*2.4 (2.4)*	*24.5 (16.4)*	*11.1 (8.2)*	*17.8 (13.4)*	*0.7 (1.4)*

Table 21. Summary of abundance of each fish taxa per 500 m^3 section of the Reef Check belt transect at each site. No barracuda or humphead wrasse were recorded and have been omitted for clarity, along with checkered snappers, flagtail, peacock and lyretail groupers, bumphead parrotfish, tuna / mackerel and moray eels which had an abundance of <=0.1. See Table 18 and Figure 32 for location of each site.

Site	Butterflyfish	Sweetlips	Snapper	Snappers				Groupers >30 cm	Groupers	Other Parrotfish (>20 cm)[6]	Fusiliers	Surgeonfish	Rabbitfish	Jacks / Trevally
				Two-spot	Black-and-white	'Bluelined'	Paddletail		'Honeycomb'					
RCA1	2.3 (2.1)	0.5 (0.6)	1.8 (2.9)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.5)	0.5 (1.0)	9.5 (14.2)	16.5 (4.7)	0.5 (1.0)	0.0 (0.0)
RCA2	7.8 (3.9)	1.3 (1.9)	3.0 (2.2)	1.8 (2.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.5 (3.0)	0.3 (0.5)	3.0 (3.2)	0.0 (0.0)	15.0 (10.0)	0.0 (0.0)	0.0 (0.0)
RCA3	2.8 (1.5)	0.0 (0.0)	0.8 (1.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.0 (2.7)	0.0 (0.0)	8.0 (5.0)	0.0 (0.0)	0.0 (0.0)
RCA4	5.0 (3.3)	0.8 (1.0)	1.5 (1.9)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.3 (2.6)	0.0 (0.0)	11.5 (6.2)	0.5 (1.0)	0.0 (0.0)
RHM1	9.5 (5.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.5 (1.0)	0.5 (1.0)	0.5 (1.0)	0.3 (0.5)	3.0 (2.6)	121.3 (61.4)	5.8 (3.4)	1.0 (2.0)	0.0 (0.0)
RIB1	6.3 (5.0)	0.0 (0.0)	1.8 (2.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.5)	0.8 (0.5)	0.0 (0.0)	0.0 (0.0)	4.5 (5.3)	0.0 (0.0)	0.0 (0.0)
RIB2	3.8 (2.1)	0.0 (0.0)	0.3 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
RIB3	2.3 (1.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (0.8)	0.0 (0.0)	2.5 (3.0)	0.0 (0.0)	0.0 (0.0)
RMI1	11.5 (5.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.5 (0.6)	0.0 (0.0)	0.0 (0.0)	2.0 (1.4)	0.5 (1.0)	1.5 (1.0)	18.3 (16.1)	33 (25.1)	0.0 (0.0)	0.0 (0.0)
RMI3	9.3 (2.2)	0.3 (0.5)	0.3 (0.5)	0.0 (0.0)	0.0 (0.0)	0.5 (1.0)	0.8 (1.0)	0.3 (0.5)	0.8 (1.0)	10.0 (5.0)	0.0 (0.0)	14.3 (2.2)	0.5 (1.0)	1.3 (2.5)
RMI4	4.0 (1.4)	0.3 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.5 (1.7)	15.0 (30.0)	14.8 (1.3)	0.0 (0.0)	0.0 (0.0)
RML1	0.8 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.8 (1.5)	0.0 (0.0)	0.0 (0.0)
RML2	3.0 (2.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.5)	0.5 (0.6)	0.0 (0.0)	19 (11.4)	1.3 (2.5)	0.0 (0.0)
RML3	11.5 (9.7)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (2.0)	0.0 (0.0)	1.3 (1.0)	0.0 (0.0)	9.5 (8.9)	0.0 (0.0)	0.0 (0.0)
RNA1	7.8 (3.8)	4.0 (6.2)	4.5 (5.2)	0.0 (0.0)	0.3 (0.5)	0.0 (0.0)	0.3 (0.5)	0.5 (0.6)	0.0(0.0)	0.3 (0.5)	0.0 (0.0)	11.5 (7.8)	0.8 (1.5)	1.3 (2.5)
RNI1	5.5 (2.6)	1.3 (1.5)	0.5 (1.0)	0.0 (0.0)	0.0 (0.0)	3.0 (6.0)	0.0 (0.0)	1.3 (1.3)	0.5 (0.6)	8.8 (6.3)	6.3 (12.5)	15 (4.7)	1.8 (1.3)	0.0 (0.0)
RRA1	4.3 (1.7)	1.0 (1.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	14.5 (19.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.5 (1..0)	1.0 (0.8)	0.0 (0.0)
RRA2	6.5 (3.3)	0.0 (0.0)	11.8 (12.9)	0.0 (0.0)	0.0 (0.0)	2.0 (3.4)	2.0 (4.0)	1.3 (1.5)	1.0 (0.8)	0.0 (0.0)	0.8 (1.5)	5.5 (6.8)	3.3 (3)	0.0 (0.0)
RSF1	12.0 (6.2)	0.5 (1.0)	15.8 (7.4)	7.0 (8.1)	1.8 (1.5)	1.5 (0.6)	1.3 (1.9)	1.5 (1.7)	1.5 (1.7)	9.8 (6.8)	38.8 (44.8)	23.5 (13.3)	0.5 (1.0)	0.0 (0.0)
RSF2	14.5 (10.5)	1.8 (2.4)	3.8 (4.8)	0.0 (0.0)	4.5 (3.1)	0.0 (0.0)	0.3 (0.5)	1.5 (1.7)	0.5 (0.6)	4.8 (2.1)	0.0 (0.0)	26.3 (16.5)	2.0 (2.3)	0.8 (1.5)
RSM1	20.5 (14.7)	0.0 (0.0)	1.8 (3.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.5)	0.0 (0.0)	3.0 (1.4)	9.0 (18)	19.3 (11.5)	0.0 (0.0)	0.3 (0.5)
RWI1	7.0 (5.0)	0.5 (0.6)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (1.2)	0.5 (1.0)	3.0 (1.4)	2.3 (4.5)	11.3 (9.0)	0.3 (0.5)	0.0 (0.0)
Mean for all sites	*7.2 (4.7)*	*0.5 (0.9)*	*2.1 (4.0)*	*0.4 (1.5)*	*0.3 (1.0)*	*1.0 (3.1)*	*0.2 (0.5)*	*0.6 (0.8)*	*0.3 (0.4)*	*2.6 (3.1)*	*10.0 (26.5)*	*12.3 (8.6)*	*0.6 (0.8)*	*0.2 (0.4)*

[6] Not bumphead (*Bolbometopon muricatum*) which is recorded separately

Table 22. Summary of abundance of each invertebrate taxa plus coral recruits per 100 m^2 section of the Reef Check belt transect at each site. No squid or triton shells were recorded and have been omitted for clarity. See Table 18 and Figure 32 for location of each site.

	Banded coral shrimp	***Diadema* urchins**	**Pencil urchin**	**Sea cucumber**	**Crown-of-thorns starfish**	**Giant clam**	***Drupella* spp.**	**Octopus**	**Lobster**	**Coral recruits (1-5cm)**
RCA1	0.0 (0.0)	85.5 (14.5)	0.3 (0.5)	0.8 (0.5)	0.0 (0.0)	0.5 (0.6)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	8.3 (1.0)
RCA2	0.0 (0.0)	55.0 (30.0)	0.0 (0.0)	2.8 (2.5)	0.0 (0.0)	4.5 (1.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.0 (0.8)
RCA3	0.0 (0.0)	8.0 (6.8)	0.0 (0.0)	1.3 (1.0)	1.0 (0.8)	0.3 (0.5)	0.0 (0.0)	0.0 (0.0)	0.3 (0.5)	20.0 (23.8)
RCA4	0.0 (0.0)	21.8 (5.0)	0.0 (0.0)	3.0 (2.4)	0.0 (0.0)	1.8 (2.4)	0.0 (0.0)	0.3 (0.5)	0.0 (0.0)	0.0 (0.0)
RHM1	0.0 (0.0)	73.8 (55.0)	0.0 (0.0)	2.5 (2.4)	0.0 (0.0)	2.8 (3.4)	0.0 (0.0)	0.0 (0.0)	0.3 (0.5)	17.8 (3.4)
RIB1	0.0 (0.0)	11.8 (2.6)	0.0 (0.0)	1.0 (1.2)	0.0 (0.0)	0.8 (1.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	33.0 (12.2)
RIB2	0.0 (0.0)	7.0 (5.1)	1.0 (2.0)	0.3 (0.5)	0.8 (1.0)	0.3 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	14.3 (3.4)
RIB3	0.0 (0.0)	0.8 (1.0)	1.5 (1.9)	0.8 (0.5)	0.0 (0.0)	1.5 (1.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.5 (2.6)
RMI1	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.3 (4.0)
RMI3	0.0 (0.0)	7.8 (3.9)	0.3 (0.5)	13.5 (16.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.5)	1.8 (1.7)
RMI4	0.0 (0.0)	3.0 (1.8)	0.0 (0.0)	0.3 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
RML1	0.0 (0.0)	25.0 (12.4)	0.0 (0.0)	2.0 (1.2)	0.0 (0.0)	0.3 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	6.0 (2.9)
RML2	0.0 (0.0)	34.8 (13.4)	0.5 (1.0)	3.0 (2.4)	0.0 (0.0)	1.8 (1.7)	0.8 (1.5)	0.0 (0.0)	0.0. (0.0)	0.3 (0.5)
RML3	0.5 (1.0)	46.0 (14.6)	0.0 (0.0)	2.0 (1.2)	0.0 (0.0)	1.8 (0.5)	0.3 (0.5)	0.0 (0.0)	0.0 (0.0)	5.3 (3.5)
RNA1	0.0 (0.0)	6.8 (6.1)	0.3 (0.5)	2.3 (1.3)	0.0 (0.0)	1.0 (2.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	4.3 (1.7)
RNI1	0.0 (0.0)	25.8 (13.5)	0.3 (0.5)	4.5 (2.1)	0.0 (0.0)	0.8 (0.5)	0.0 (0.0)	0.5 (0.6)	0.0 (0.0)	8.8 (7.2)
RRA1	0.0 (0.0)	9.3 (3.8)	0.3 (0.5)	2.0 (1.4)	0.3 (0.5)	3.5 (3.7)	0.0 (0.0)	0.3 (0.5)	0.0 (0.0)	6.0 (3.9)
RRA2	0..0 (0.0)	21.0 (4.7)	0.0 (0.0)	3.8 (2.2)	0.5 (1.0)	1.0 (0.8)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	18.3 (4.6)
RSF1	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	31.0 (26.1)
RSF2	0.0 (0.0)	1.0 (1.2)	0.0 (0.0)	0.8 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.8 (1.0)
RSM1	0.0 (0.0)	79.8 (51.1)	0.0 (0.0)	0.3 (0.5)	0.0 (0.0)	0.3 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.8 (3.2)
RWI1	0.0 (0.0)	23.5 (14.1)	0.0 (0.0)	0.3 (0.5)	0.0 (0.0)	2.5 (2.9)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	7.5 (7.9)
Mean for all sites	*0.0 (0.1)*	*24.9 (26.8)*	*0.2 (0.4)*	*2.1 (2.8)*	*0.1 (0.3)*	*1.1 (1.2)*	*0.0 (0.2)*	*0.0 (0.1)*	*0.0 (0.1)*	*8.8 (9.6)*

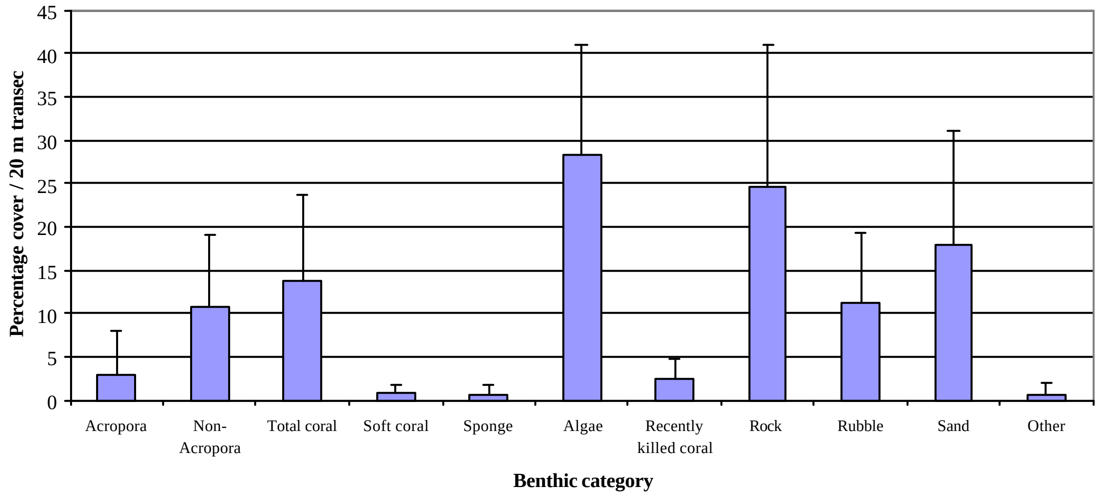


Figure 33. Mean percentage cover (all sites combined) of each benthic category recorded during Reef Check line transects. Bars represent standard deviation. n = 88.

4.4.4 Variations in health between reef complexes

In order to assess any variations in reef health indicators between the reef complexes, data from each site was aggregated (see Table 18 for reef complex assignment of each site). Benthic parameters were then analysed using ANOVA and fish and invertebrate taxa were analysed using the Kruskal-Wallis test. Table 23 shows the statistically significant results of this analysis. Note that only the Namotu Group and Inner and Outer Malolo Group complexes were included in this analysis as there was only one site (i.e. not the requisite replication) at Mana and Navini Islands.

Table 23. The significant results of ANOVA (benthic parameters) and Kruskal-Wallis (fish and invertebrate taxa) analysis of variation between three reef complexes. * = $p<0.05$; ** = $p<0.01$ and *** = $p<0.005$. For each significant result, order of reef complexes is shown. Reef complexes: NO = Namotu Group; IM = Inner Malolo Group; OM = Outer Malolo Group.

Taxa	Significance level	Order of reef complexes
	Benthic parameters	
Acropora	**	OM>IM>NO
Soft corals	***	NO>IM>OM
Sponges	***	NO>OM>IM
Rubble	*	IM>OM>NO
	Fish and invertebrate taxa	
Black-and-white snapper	*	OM>NO>IM
Flagtail grouper	***	NO>IM=OM
Diadema	***	IM>OM>NO
Clams	*	IM>OM>NO

Table 23 shows that of the 45 parameters measured during Reef Check surveys, only eight (17.8%) varied significantly between reef complexes.

4.4.5 Correlations between reef parameters

Since Reef Check surveys generate quantitative data, a series of correlations were examined in order to explore ecological processes within the project area. There was a slight negative correlation between coral cover and algal cover but this was not significant ($p>0.05$). Regression analysis between each fish and invertebrate taxa and percentage coral cover highlighted seven significant correlations ($p<0.05$; Table 24). The significant correlations between coral cover and the four fish families are shown in Figure 34 (individual species have been omitted for clarity). Although expected, there were no correlations between algal cover and the abundance of herbivorous fish species (parrotfish, surgeonfish and rabbitfish) and *Diadema* urchins ($p>0.05$).

Table 24. The significant ($p<0.05$) correlations between coral cover and fish and invertebrate taxa. R^2 is the correlation coefficient that varies from –1 (strong negative correlation) to 1 (strong positive correlation).

Taxa	R^2	Significance level
Snapper	0.30	0.009
Two-spot snapper	0.45	<0.001
Black-and-white snapper	0.31	0.008
Grouper (> 30 cm)	0.21	0.033
'Honeycomb' groupers	0.21	0.032
Other parrotfish (> 20 cm)	0.25	0.019
Surgeonfish	0.21	0.033

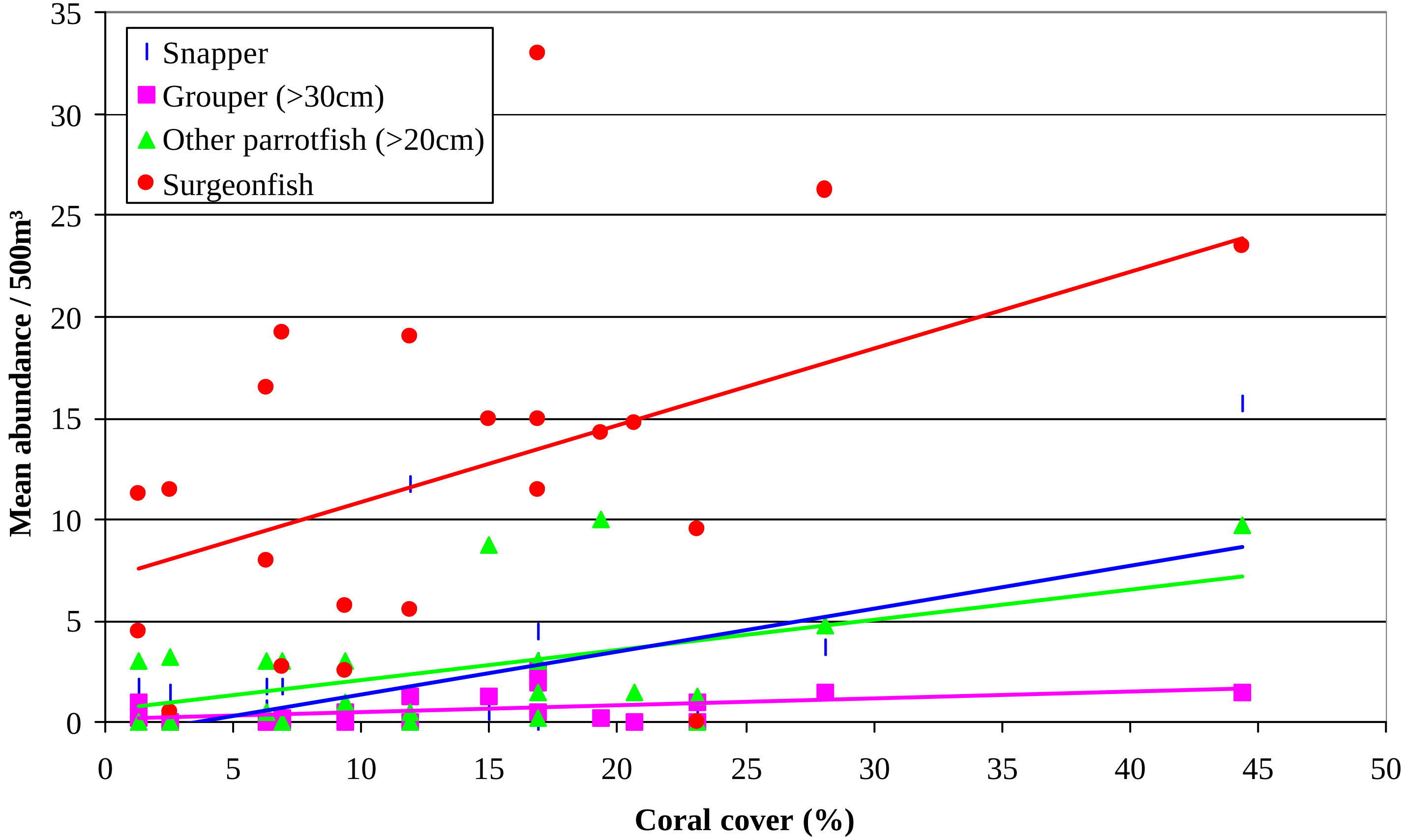


Figure 34. The five significant ($p<0.05$) correlations between the abundance of each fish family and coral cover. Trendlines represent linear relationships via regression analysis. R^2 values shown in Table 24.

4.4.6 Assessment of the conservation value of each site

The ternary diagram of coral morphology showing the conservation class of each Reef Check site, following the protocol of Edinger and Risk (2000), is shown in Figure 35. Figure 35 shows that of the sites surveyed using the Reef Check protocol during the pilot phase of the MCRCP, there were no sites dominated by foliose and branching non-*Acropora* corals (competitors; conservation value = 2) and only one site (RSF2) dominated by branching and tabular *Acropora* (disturbance adapted; conservation value = 3). Twelve of the sites (54.5%) had communities of mixed coral morphologies (conservation value = 4) and nine sites (40.9%) were dominated by massive and submassive corals (conservation value = 1). The locations of the sites with their assigned conservation values are shown on Figure 36.

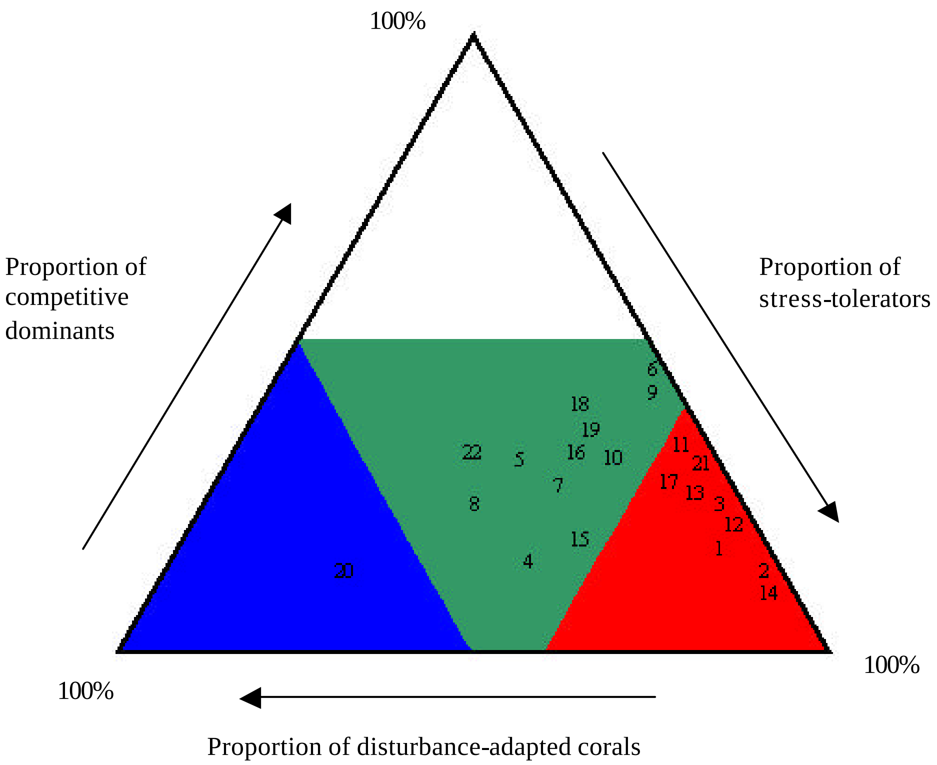


Figure 35. Ternary diagram of coral morphology showing the coral reef conservation value of each Reef Check site. Conservation values: red area = 1; white = 2; blue = 3; green = 4. Reef Check site codes: 1=RCA1; 2=RCA2; 3=RCA3; 4=RCA4; 5=RHM1; 6=RIB1; 7=RIB2; 8=RIB3; 9=RMI1; 10=RMI3; 11=RMI4; 12=RML1; 13=RML2; 14=RML3; 15=RNA1; 16=RNI1; 17= RRA1; 18=RRA2; 19=RSF1; 20=RSF2; 21=RSM1; 22=RWI1. See Figure 32 for site locations.

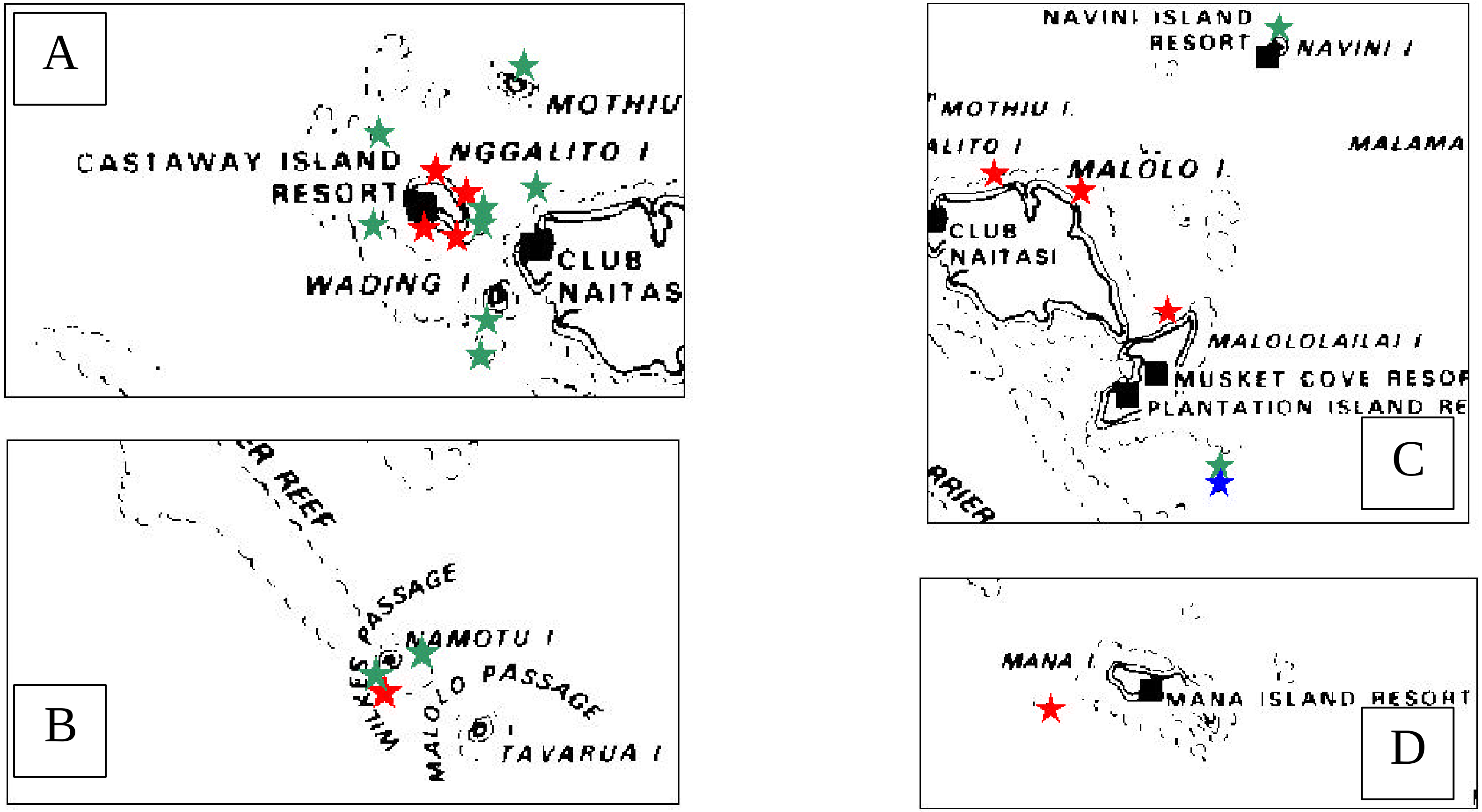


Figure 36 (a-d). Location of each Reef Check site surveyed during the pilot phase of the MCRCP and its assigned conservation value as derived from the ternary diagram of coral morphology. Conservation values: red = 1 (low); blue = 3 (medium); green = 4 (high). No sites had a conservation value of 3.

4.5 Coral size-frequency

The coral size-frequency surveys, completed during the final week of Phase 2 of the MCRCP, were conducted at six sites (Table 25 and Figure 37). Note that because of time limitations, data were collected from only three of the five reef complexes and there are only two sites per reef complex compared to the much larger sample sizes for baseline transects and Reef Check sites. A total of 838 colonies were surveyed and the number of colonies of each species or genus is shown in Table 26. Table 26 also shows the mean percentage of live tissue on the colonies of each target species or genus. Note that the sample size for *Seriatopora hystrix* was very small and hence this species has been excluded from subsequent analysis. Table 26 shows that the colonies of each species were generally healthy with the percentage of live tissue being > 78%.

Table 25. Summary of the sites used for coral size-frequency surveys during the pilot phase of the MCRCP. See Figure 37 for exact locations. Maximum number of quadrats per site = 12.

Site	Reef complex	Number of quadrats completed	Mean colony depth (m)	Median coral cover class (%)
Qalito (Castaway) Island	Inner Malolo Group	10	3.7 (1.9)	10 - 25
Mothiu (Honeymoon) Island	Inner Malolo Group	12	1.5 (0.7)	10 - 25
Rainbow Patch	Outer Malolo Group	12	6.7 (1.8)	10 - 25
Sunflower	Outer Malolo Group	12	5.2 (2.9)	25 - 50
Namotu (Magic) Island	Namotu Group	10	18.7 (1.8)	10 - 25
Tavarua Island	Namotu Group	12	15.3 (1.2)	1- 10

Table 26. Number of colonies of each species or genus surveyed during size-frequency work. Mean percentage of live tissue for each species or genus also shown. Figures in parentheses indicate standard deviations.

Total	Number of colonies surveyed	Mean % live tissue
Porites 'massive'	485	83.0 (21.9)
Pocillopora 'medium'	182	90.3 (17.5)
Ctenactis echinata	51	92.9 (18.6)
Diploastrea heliopora	114	78.1 (27.3)
Seriatopora hystrix	6	82.5 (36.0)

Size-frequency graphs for the four species or genera are shown in Figures 38 and 39. These graphs also show the mean percentage of live tissue within each size class in order to assess changes in colony health (amount of live tissue) with changing size.

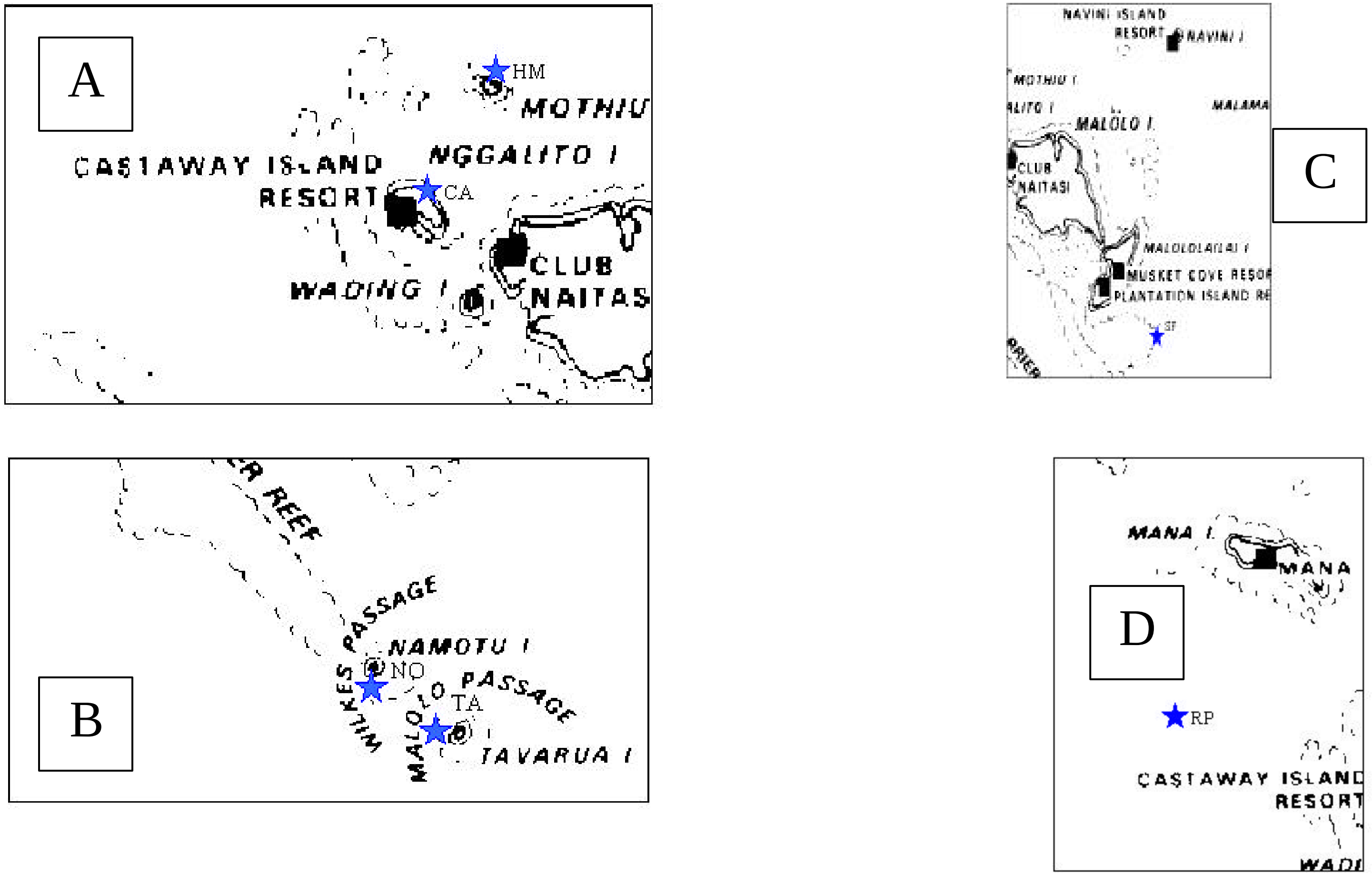
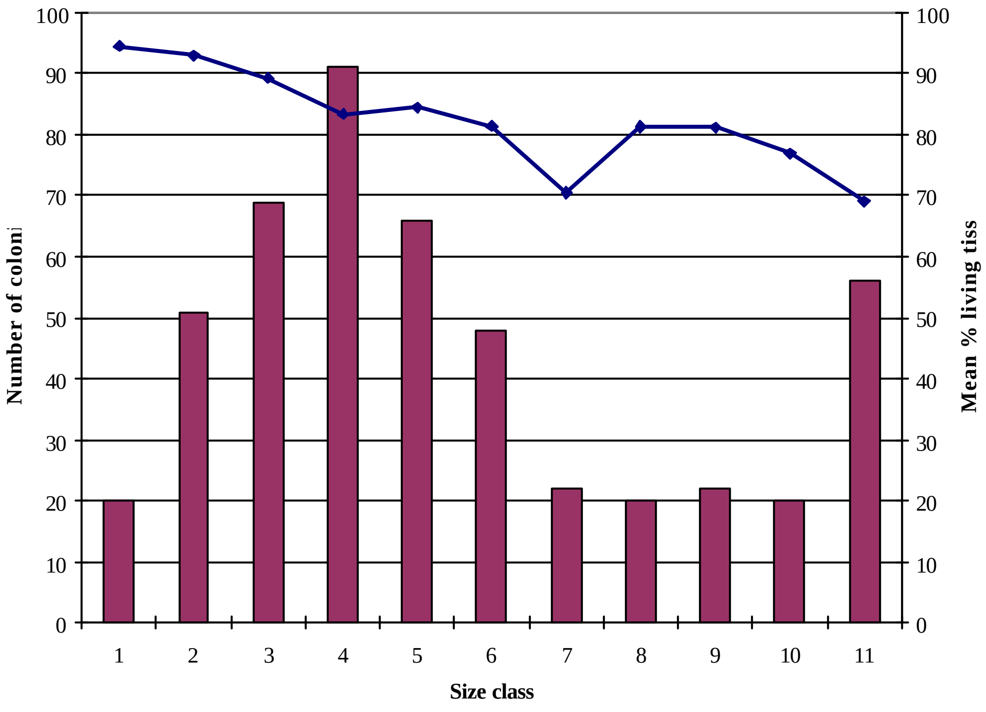
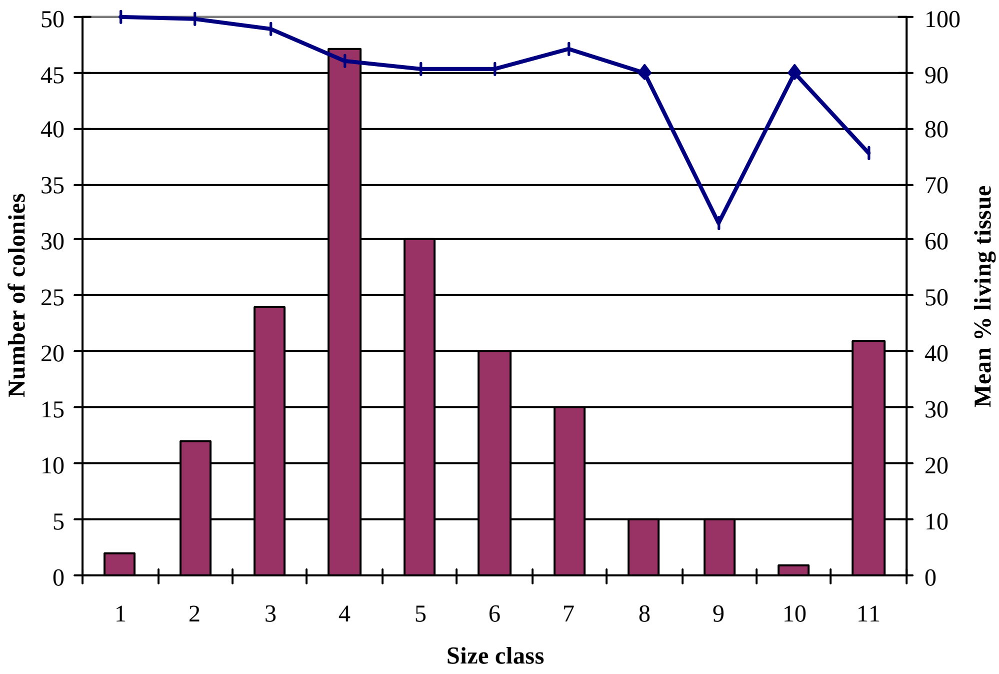


Figure 37 (a-d). Location of the coral size-frequency sites (blue stars) completed during the pilot phase of the MCRCP. CA = Castaway Island; HM = Honeymoon Island; SF = Sunflower; RP = Rainbow Patch; NO = Nomotu Island; TA = Tavarua Island. See Table 25 for details of each site.

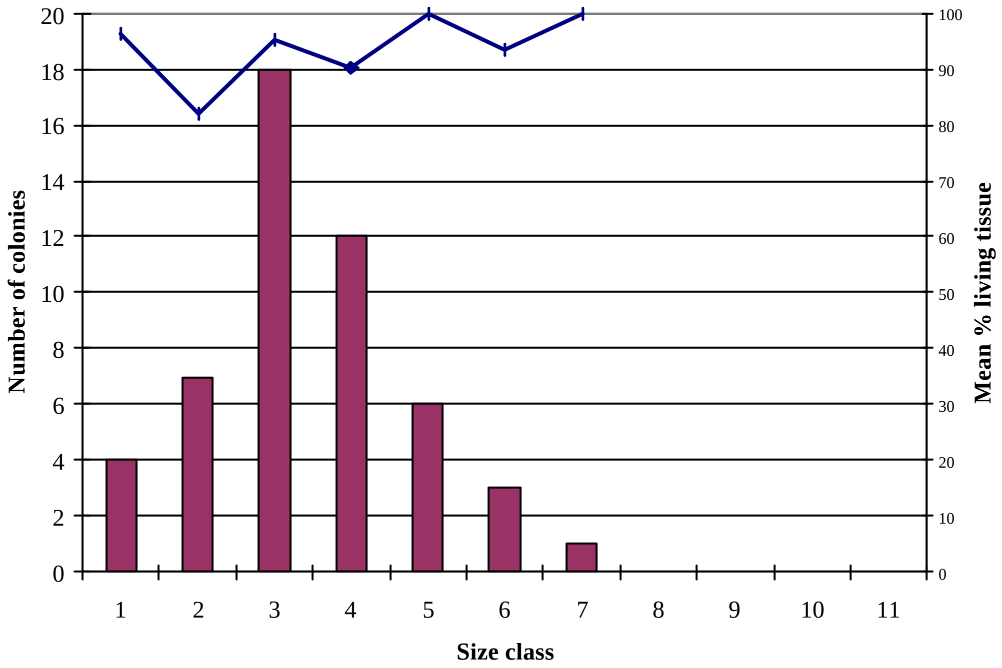


(a)

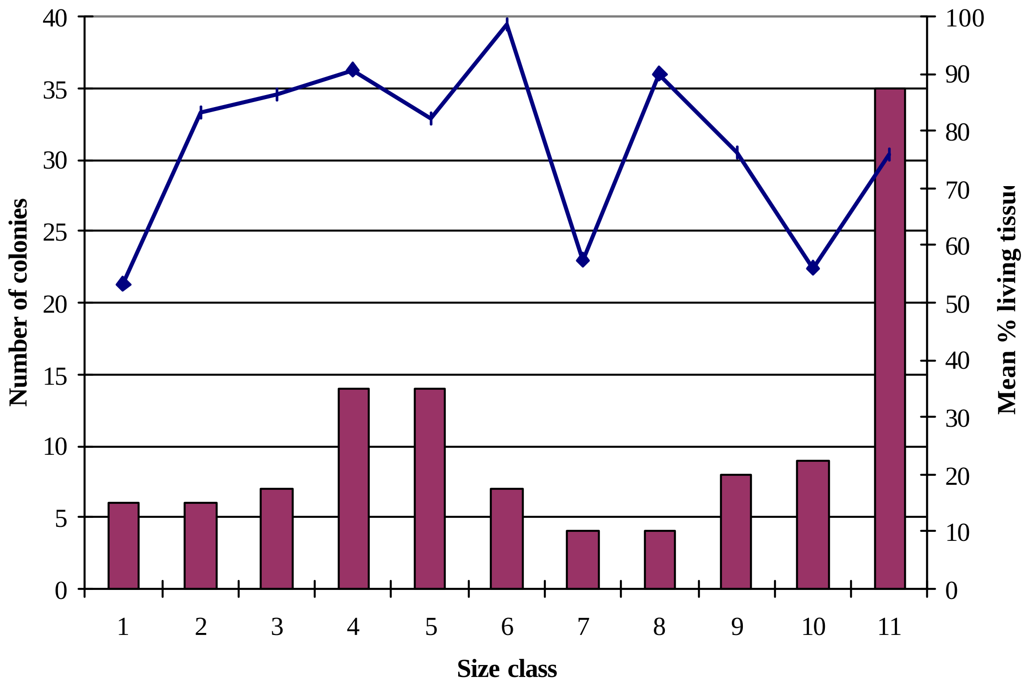


(b)

Figure 38. Size-frequency graphs (bars; primary y-axis) and mean percentage of living tissue (line; secondary y-axis) for all colonies of (a) *Porites* 'massive' and (b) *Pocillopora* 'medium'. Size classes refer to maximum diameter (cm) and are: 1=1-5; 2=6-10; 3=11-15; 4=16-20; 5=21-25; 6=26-30; 7=31-35; 8=36-40; 9=41-45; 10=46-50; 11=>50.



(a)



(b)

Figure 39. Size-frequency graphs (bars; primary y-axis) and mean percentage of living tissue (line; secondary y-axis) for all colonies of (a) *Ctenactis echinata* and (b) *Diploastrea heliopora*. Size classes refer to maximum diameter (cm) and are: 1=1-5; 2=6-10; 3=11-15; 4=16-20; 5=21-25; 6=26-30; 7=31-35; 8=36-40; 9=41-45; 10=46-50; 11=>50.

Figures 38 and 39 show the inter-species variations in colony size parameters. For example, *Porites* ‘massive’ and *Pocillopora* ‘medium’ had a modal size of 16-20 cm but also a large number (56 and 21 respectively) of colonies larger than 50 cm. In contrast, *Ctenactis echinata* had a modal size class of 11-15 cm and no colonies larger than 31-35 cm. Colonies of *Diploastrea heliopora* were generally the largest of the four species, with joint modal size classes of 16-20 cm and 21-25 cm and the highest proportion of colonies >50 cm (30.7%). Data for mean percentage of living tissue within each size class showed that for *Porites* ‘massive’ and *Pocillopora* ‘medium’ there was a general trend for decreasing colony health (i.e. decreasing % of living tissue) with increasing size. *Ctenactis echinata* colonies had high mean amounts of live tissue (>80% for all size classes) and there was no clear pattern for *Diploastrea heliopora*.

Finally, variations in colony size and the percentage of living tissue between survey sites and reef complexes were investigated via ANOVA (% living tissue) and Kruskal-Wallis (colony diameter). Only Inner Malolo Group sites at Qalito (Castaway) Island and Mothiu (Honeymoon) Island and Outer Malolo Group sites at Rainbow Patch and Sunflower were included in this analysis since the Namotu Group sites were much deeper (Table 25). Depth is an important factor affecting coral size and morphology (Sheppard, 1982) and hence any comparisons with outer barrier sites would reflect variations between sites *and* varying depths rather than just variations between sites as required. The results of the ANOVA and Kruskal-Wallis analysis are shown in Table 27.

Table 27. Results of analysis of variations in percent of living tissue (using ANOVA) and colony diameter (using Kruskal-Wallis) between survey sites and reef types. ns = not significant; * = p<0.05; ** = p<0.01; *** = p<0.0005. For each significant result, order of survey sites or reef complexes is shown. Survey sites: CA=Castaway; HM=Honeymoon; RP = Rainbow Patch; SF = Sunflower. Reef complexes: IM = Inner Malolo Group; OM = Outer Malolo Group.

Species / genus	**% living tissue**		**Colony diameter**	
	Survey site	Reef complex	Survey site	Reef complex
Porites ‘massive’	*** SF>RP>HM>CA	*** OM>IM	*** CA>HM>RP>SF	*** IM>OM
Pocillopora ‘medium’	ns	ns	ns	ns
Ctenactis echinata	* CA=HM>SF>RP	* IM>OM	ns	ns
Diploastrea heliopora	ns	ns	** RP>HM>SF>CA	** OM>IM

Table 27 shows that the percentage of living tissue and diameter of *Porites* ‘massive’ colonies varied very significantly between survey sites and reef complexes. Colonies at the Castaway Island site had less living tissue but were larger. In contrast, colonies at the Sunflower site were smaller but had more living tissue. Overall, colonies in the Inner Malolo Group complex had less living tissue but were larger than those in the Outer Malolo Group. The only other patterns were for more living tissue on colonies of *Ctenactis echinata* in the Inner Malolo Group and for colonies of *Diploastrea heliopora* to be larger in the Outer Malolo Group compared to the Inner Malolo

Group complex. Since the variation between *Porites* ‘massive’ colonies was so significant, an example of these differences are shown in Figure 40 (between the sizes of colonies in the Inner and Outer Malolo Groups). Figure 40 shows that colonies in the Inner Malolo Group were generally larger (modal size class 4 compared to 2 / 3 for platform reefs). Similarly, 97.5% of colonies >50 cm were found in the Inner Malolo Group.

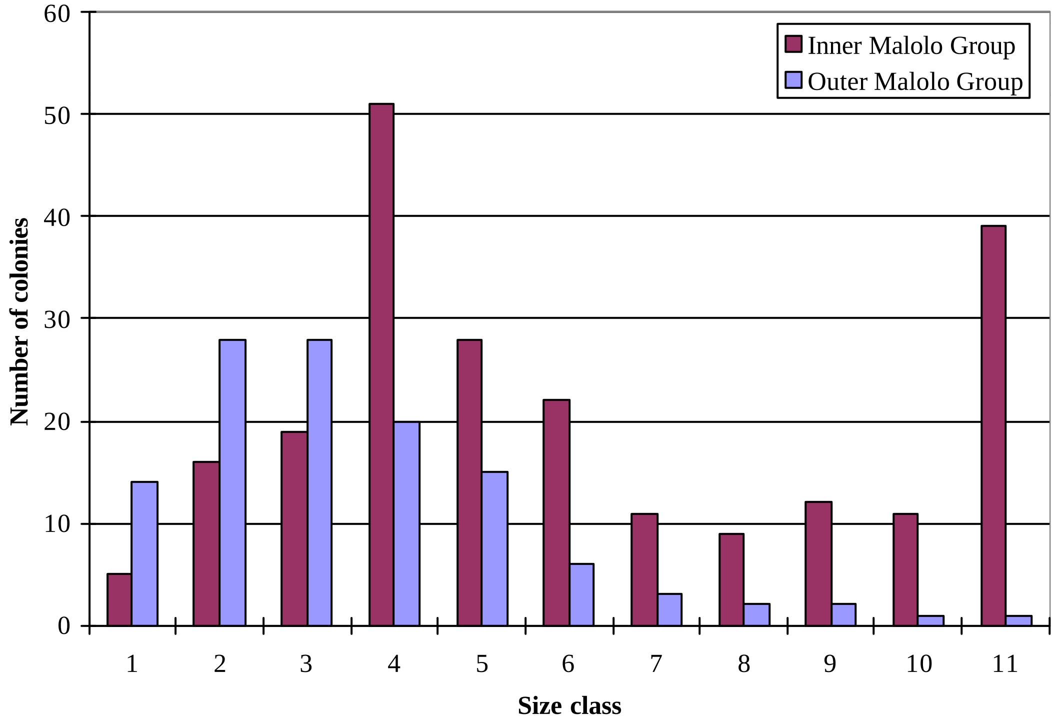


Figure 40. Size-frequency graphs for colonies of *Porites* ‘massive’ in the Inner and Outer Malolo Group reef complexes. Size classes refer to maximum diameter (cm) and are: 1=1-5; 2=6-10; 3=11-15; 4=16-20; 5=21-25; 6=26-30; 7=31-35; 8=36-40; 9=41-45; 10=46-50; 11=>50.

4.6 Observations of megafauna

Several observations of sharks were recorded. The outer barrier reef is known by local dive operators as a good location to view sharks in their natural environment without artificial feeding and baiting. For example, in front of Namotu Island on the outer barrier reef, surveyors recorded two reef whitetip sharks (*Triaenodon obesus*). ‘Supermarket’ has been the site of a shark feed for over 10 years and has become very popular dive site. One grey reef shark (*Carcharhinus amblyrhynchos*) and three reef whitetip sharks (*Triaenodon obesus*) were recorded on transects at Supermarket.

Whales are occasionally observed within the Mamanuca Islands and sightings of gray (*Eschrichtius robustus*) and humpback whales (*Megaptera novaeangliae*) were both reported by local people during the course of the pilot project. A survey team also observed a single humpback whale during a dive on the outer barrier reef.

Identification was confirmed by both divers underwater and observers on the surface. Other observations of megafauna included:

- Pods of spinner dolphin (*Stenella longirostris*) on the outer barrier reef and at the 'Supermarket' dive site;
- Leopard shark (*Stegastoma fasciatum*) and great hammerhead shark (*Sphyrna mokarran*) on the inner barrier reef;
- Nurse shark (*Nebrius ferrugineus*), tiger shark (*Galeocerdo cuvier*) and schools of gray reef sharks (*Carcharhinus amblyrhynchos*) on the outer barrier reef;
- Turtles (species not confirmed) were seen on a number of occasions in locations ranging from the outer barrier reef to the fringing reefs of Qalito (Castaway) Island.

4.7 Community work

4.7.1 Marine Ecology Workshop for the Professional Diver

Many of the participants of the 'Marine Ecology Workshop for the Professional Diver' (Table 28) had been working as professional divers in the Mamanuca Islands for many years and already had a vast observational knowledge of coral reefs. The workshop focused on extending and formalising this information, along with looking at conservation issues and strategies associated with tourism, sustainable development and how to communicate this information to customers.

Table 28. 'Marine Ecology Workshop for the Professional Diver' participants and their respective organisations.

Workshop participants	
Eric Enderson - Castaway Island Resort	Seva Sakai – Subsurface Fiji
Tevita Layasewa – Castaway Island Resort	Mereseni Tubuiratu – FVB Marketing Officer
Simeli Loganimoce – Castaway Island Resort	Navi Ului – Castaway Island Resort
Veresa Naiqara – Castaway Island Resort	Ovisi Vuki – Castaway Island Resort
Andrew Redfern – Aqua Trek Course Director	

Following the workshop, participants were asked to fill out a feedback form with several questions on the importance of the workshop, new information learned and who else may benefit from such information. All participants strongly concurred that the information was applicable to their work and that such workshops should continue. The following quotes are taken from the feedback forms:

"The people of Castaway, the divers and the people in our local community will learn how important this workshop is when we share this with them"

"I will extend my briefing to include the concerns of corals and fishes to the divers"

"I have learnt to appreciate everything that I have seen on the reef because everything on the reef depends on each other"

5. DISCUSSION

5.1 Training

The training programme used by CCC for the pilot phase of the MCRCP proved to be appropriate for volunteer survey work in Fiji. For example, the results in the tests and in-water validation exercises were excellent and, therefore, the data collected during survey work are likely to be accurate and consistent. Although the volunteers during the pilot phase were relatively experienced divers (a lower proportion of non-divers was accepted for training compared to other CCC projects) the training schedule is also likely to be appropriate for numerous novice divers who would participate on any longer-term work by CCC in the Mamanuca Islands.

5.2 Baseline data

5.2.1 Oceanography, climate and anthropogenic impacts

The climate data collected during the pilot project showed that the environmental conditions were seasonally typical for the area. For example, the winds were predominately from the south-east, as would be expected since the climate is influenced by the Southeast Trade Winds, which are more persistent between July and December (Vuki *et al*., 2000). Similarly, sea surface temperatures are known to vary from 24 to 31°C (26.4°C during this project and well below the critical threshold for large-scale coral bleaching) and normal surface salinity is 35‰ (34.6‰ during this project). However, salinity did vary between the five reef complexes, possibly highlighting the influence of the freshwater influx from the mainland that may have caused the lower salinities at Navini Island and the Malolo Group since they are slightly further inshore. Timing of the surveys with respect to rainfall is also likely to be a key factor, along with run-off from the islands, which will be a function of their geology and topography.

In order to assess detailed changes in salinity and temperature throughout the water column and also spatially and temporally, more sophisticated measuring equipment is required. South Pacific Applied Geoscience Commission (SOPAC) has indicated a willingness to lend the project digital monitoring meters that can be moored on the reef and left for extended periods of time and these would be ideal for the task. It is hoped that they will be employed at key locations within the project site during any longer term work by CCC in the Mamanuca Islands.

The SOPAC meters also monitor current flow and this will be equally important for documenting detailed water movement patters around the project area. Current data collected by the volunteers during baseline surveys are highly qualitative, large scale and dependent on the time of the survey (i.e. they are not systematically collected across the tidal regime). Consequently it is difficult to interpret the current data from the pilot project of the MCRCP. However, there is an indication of currents along the length of the outer barrier reef and complex flows around the platform reefs and between the islands of the Inner Mololo Group. Accurately modelling water movement patterns is vital for conservation since fish and coral larvae are entrained by currents and moved between ‘source’ and ‘sink’ areas (e.g. Caley *et al*., 1996). Hence, for example, it is important to place marine reserves in areas that provide larvae (sources) via current flow to other local reefs and, therefore, can replenish fish stocks and regenerate benthic communities after degradation by anthropogenic impacts (Roberts and Hawkins, 2000).

Data from the pilot phase of the MCRCP shows that there are a number of anthropogenic impacts affecting the area, although more data are required to fully document them and their effects on the marine ecosystem. For example, there is evidence of significant turbidity (sediment load) in the Mamanuca Islands. Sedimentation, caused by coastal development and conversion of natural landscapes, is one of the most widespread threats to the global health of coral reefs via smothering of coral colonies (Stafford-Smith and Ormond, 1992) reducing fish diversity and density (Letourneur *et al*., 1998). As might be expected the water was clearest in the Namotu Group, which includes the outer barrier reef, since there are only a few small islands and hence limited development and erosion. Water clarity in this area was often excellent with horizontal visibilities reaching approximately 50 m. Similarly, the reefs around Mana Island experienced good water quality since the resorts there are relatively low impact. In contrast, the water within the Inner Malolo Group reef complex was turbid, with vertical and horizontal visibilities of less than 14 m, possibly linked to the development of a series of major resorts and felling natural forests. Consequently sedimentation on the reef was commonly recorded as an underwater impact in the Inner Malolo Group complex. Turbidity in the Outer Malolo Group complex was lower because of the distance between the platform reefs and the islands. The low visibility at Navini Island is harder to explain but may be a function of low sample sizes or stochastic oceanographic conditions that increased flocculation within the water column during surveys in this area.

Surface impacts were uncommon and absent entirely from the Mana Island reef complex. Algae (a gross proxy for storm damage) were seen on approximately 15% of surveys and all other categories having a frequency of occurrence of less than 7%. Although litter was only seen at the surface on 6.8% of surveys, it was seen underwater on 26% of surveys. Litter is known to be a conspicuous source of pollution in the marine environment of Fiji (Vuki *et al*., 2000).

Underwater, generic coral damage was common in the Mana Island, Namotu Group and Inner Malolo Group reef complexes and may indicate relatively high levels of either storm damage or anthropogenic impacts such as diver or anchor damage. For example, anchoring is commonly seen close to Namotu (Magic) Island. Coral bleaching was frequently seen on the surveys (23%) but was generally limited to a few colonies and is certainly not indicative of another mass bleaching event. Since water temperatures were approximately 27^{o}C during the pilot project, which is well below the critical threshold for bleaching (approximately 30^{o}C), these bleached corals presumably represent colonies that have very susceptible zooxanthellae or are subject to warm water micro-climates. Like bleaching, coral diseases are increasingly being recognised as a significant threat to reef health, often affecting corals weakened by other effects, but incidents were low within the project area and were only seen in the Outer Malolo Group (<5% of surveys). The absence of fish traps and evidence of explosive and cyanide fishing indicates that fishing effort has only a limited impact on coral communities. However, lost lines and nets, which can damage corals and also 'ghost fish' (e.g. fish trapped in lost nets), were relatively frequent, particularly in the Namotu Group and Inner and Outer Malolo Group complexes, and may represent significant, localised damage.

Boat activity is also recorded during baseline surveys as a gross proxy of anthropogenic activity in any given area. During the pilot phase of the MCRCP, the highest density was seen in the Namotu Group reef complex, presumably because of this area's use by both fisherfolk and surfers and also the proximity of the survey sites to the cut used by many boats to get through the outer barrier reef. Boats were also common in the Inner Malolo Group complex and were likely to be serving the numerous resorts in this area (they were mainly commercial and pleasure craft). Further analysis of boat activity showed that many of the boats visiting the areas around Mana and Navini Islands were for diving. However, Mana Island and the Outer Malolo Group complex were also popular sites for fisherfolk, possibly because they are relatively sheltered and there are numerous platform reefs, which are known to aggregate many fish species. The outer barrier reef was generally used for diving and pleasure boats, many of which were for surfers.

Although many of the indices used to assess anthropogenic impacts to the reef are very general and qualitative, they do provide a gross impression of damage to the area. Overall, the indication is that all the reefs of the project area have been subjected to some degradation but the reefs of the Inner Malolo Group seem most heavily impacted since most of the suite of factors are present. Each of the other reef complexes have indicators of more specific damage. The result of these impacts, particularly in the Inner Malolo Group complex, was reflected in the aesthetic and biological ratings assigned by the survey teams. Generally these ratings were low (<3) and this is certainly caused in part by the 2000 bleaching event which reduced coral cover significantly. However, the reefs of the Inner Malolo Group complex were only rated as poor to average compared to average to good on the outer barrier reef and around Mana Island. Some of this variation can be attributed to anthropogenic influences but it is also a function of differing reef types. For example, the topography on the western side of the outer barrier reef is naturally more impressive than that of a fringing reef around one of the islands.

5.2.2 Benthic data

Baseline transects during Phase 1 of the MCRCP discriminated seven benthic classes within the project area. Since these classes are derived from over 120 'Site Records' from across a wide geographical range they are likely to cover all the major classes present on the reefs surveyed. However, there are certain to be additional classes within and outside the project area. For example, there are likely to be a number of additional benthic classes in shallow water, particularly associated with seagrass beds and back reef areas. These habitats are generally too shallow to survey with divers but snorkellers, using similar baseline transects, could collect the requisite data. Further data may show that some or all of the seven site records that were excluded by the cluster analysis represent rare examples of these additional habitats. Outside the project area, there are likely to be additional benthic classes related to, for example, the high turbidity / low salinity environments around Viti Levu itself. By combining these benthic classes with geomorphological reef zones it seems, therefore, that the Mamanuca Islands have a high habitat ('beta') diversity. Habitat diversity is important since the number of habitat types has been shown to be a good surrogate of species biodiversity.

The seven benthic classes that were distinguished were all relatively coral poor, with no coral life form having a median abundance of greater than 1.8. Coral cover was certainly higher before the 2000 coral bleaching event (Cumming *et al*., 2000; South and Skelton, 2000) that obviously had a major effect on the Mamanuca Islands. This is highlighted not only by the current low coral cover but also by anecdotal evidence from divers who knew the area pre-2000 and the abundance of dead coral. Many of the fringing reefs around the Mamanuca Islands have been particularly affected because much of the best coral growth is naturally in shallower water where water is often poorly mixed (and hence warms more than deeper areas) and solar irradiance is less attenuated. Hence susceptible *Acropora* corals (Marshall and Baird, 2000) are now infrequent and were only characteristic of one benthic class ('Bedrock and mixed corals'). Data from the baseline transects indicates that coral mortality has led to increased algal growth, since algae are normally out-competed by corals in a healthy community.

5.2.3 Fish populations

Damselfish (Pomacentridae) were the most abundant reef associated fish recorded during baseline transect surveys. This is not unusual as on most reefs this family constitutes a major part of the fish community. Most of the species were site attached such as *Dascyllus* spp. and *Chromis* spp., which feed on zooplankton. Benthic herbivorous and detritivorous species, such as the honey-head damselfish (*Dischistodus propotaenia*), were generally rarer than the zooplanktivores. It is noticeable that none of the ten most abundant families or species are targeted by fisherfolk. Commercially important fish are naturally large and less common than, for example, damselfish but abundances of whole families such as groupers would normally be expected to be much higher in unfished systems.

A recurring pattern in the baseline transect data was the greater abundance and diversity of fish in coral rich classes, which reflects a commonly observed phenomenon. For example, analysis of all the survey sites showed that there was a clear correlation between coral and fish species richness. The increased spatial complexity of coral rich habitats provides a larger variety of niches that support greater diversities of fish at the family and species level (Luckhurst and Luckhurst, 1978) via additional food sources (Thresher, 1983) and hiding places (Roberts and Ormond, 1987). Indeed species of butterflyfish that are obligate corallivores have been proposed as indicators of reef health because this link is so clear (e.g. Crosby and Reese, 1996).

Similarly, at the fish community level, the variation between benthic classes (five of the 11 target taxa) was not surprising with sandy benthic classes generally containing fewer fish than those with more abundant bedrock and coral. For example, parrotfish feed on the algae growing on hard substrates in coral rich areas, or in areas of shallow bedrock that support significant algal biomass. Their distribution is linked to surge (low to moderate), food availability (high algal productivity in shallow-medium depths >5m, <30m) and shelter availability (needed for nocturnal hiding from predator fish) (Bouchon-Navarro and Harmelin-Vivien, 1981; Hay, 1981). Exceptions to the pattern of increasing abundance with coral cover included the goatfish (Mullidae), which were equally distributed between many different habitats. Species in this family are invertivores that feed on crustaceans and worms stirred up by foraging in soft sediment areas that were found in all benthic classes.

Within the coral rich 'Bedrock and mixed coral' benthic class there were no overall significant differences in the fish communities seen in each reef complex. This might be expected since the majority of species are not affected by fishing or other anthropogenic impacts and, therefore, will be found wherever there is suitable habitat. However, analysis of individual commercially and ecologically important taxa highlighted some variation. Overall there was an indication that the target taxa were less abundant in the Inner and Outer Malolo Group complexes, possibly reflecting higher fishing pressure or other anthropogenic or natural factors that reduce the attractiveness of these areas at the intra-habitat scale.

The most obvious significant variation for an individual taxa was for rabbitfish (Siganidae), particularly their abundance at Navini Island. This may be a result of the private marine reserve that has been established around the island or the abundance of preferred algal species but it is more likely to be an artefact of the small number of surveys (four), which may have encountered a school of rabbitfish which biased the median abundance. The same factors may have caused the abundance of convict surgeonfish (*Acanthurus triostegus*).

Flagtail groupers (*Cephalopholis urodeta*), although uncommon, also varied significantly between reef complexes and were most abundant in the Namotu Group. There are numerous reasons for this pattern, including a lower fishing pressure on the outer barrier reef since all groupers are commercially valuable. Furthermore, Namotu Island is the location of a privately owned marine reserve. However, it may also be caused by the currents and water mixing that bring zooplankton to its food fish (e.g. fusiliers and anthias).

Finally, although the variation of abundances of triggerfish (Balistidae) between reef complexes was only a trend rather than statistically significant, they had high abundances around Mana Island and in the Namotu Group. Triggerfish are invertivores, and specialise in feeding on species such as *Diadema* spp. and certain gastropods (such as cowries). Their abundance at Mana Island and on the outer barrier reef may be linked to the number of these prey species since they are often gleaned on the fringing reefs of, for example, the Inner Malolo Group.

5.2.4 Invertebrate data

Invertebrates were generally uncommon during baseline surveys and this is partly because many of them are cryptic, and often nocturnal, and hence are missed by divers (e.g. squid and octopi). Therefore, the relative abundance of obvious tunicates, feather stars and echinoderms was expected. More specialised survey techniques and taxonomic expertise are required to fully inventory the invertebrate communities of the project area. However, the low abundance of commercially important invertebrates was noticeable and, for example, tritons (*Charonia tritonis*), which are collected for decoration, were not seen. Similarly, there were few cowries and conch. Furthermore, although clams were one of the 10 commonest taxa, these were all the smaller *Tridacna squamosa* rather than the large *T. gigas*, which have been fished to near extinction throughout the Indo-Pacific.

Although many commercially important invertebrate species were rare because of over-harvesting, the low abundances of the corallivorous *Drupella* snails and crown-of-thorns starfish indicated that the threat from these species is currently minimal. Both species, but particularly crown-of-thorns, can decimate coral populations during outbreaks and these have been known in the Mamanuca Islands (South and Skelton, 2000). Their population dynamics are poorly known, but may be linked to decreasing reef health, so outbreaks could occur at any time and hence these species represent a constant threat to the health of the project area. For example, there was some evidence that *Drupella* were more abundant in the Inner Malolo Group than other parts of the project area.

Like fish, the abundances of many invertebrate taxa are correlated with coral cover and substratum complexity and the variation between benthic classes was expected. For example, no invertebrates were seen in the 'Sand and algae' benthic class. Sandy areas of reefs are fairly depauperate of epifaunal communities, although there are abundant meiofauna, which are too small to be recorded by visual surveys. However, sea cucumbers are often found on soft substrates but many need to be adjacent to coral reefs as these areas provide much of the organic detritus and microalgae that are required for feeding (Uthicke, 1999). Such habitat requirements explain their abundance in the benthic classes 'Mixed substratum, green algae and coral' and to a lesser degree 'Sand with large coral patches'. This latter benthic class was also particularly attractive to *Diadema* urchins, presumably because of the same combination of shelter and food.

Diadema in the 'Bedrock and mixed coral' benthic class varied significantly between reef complexes and was most abundant in the Inner Malolo Group. The distribution of high densities of this echinoid could be linked to aggregative behaviour (Pearse and Arch, 1969), abundance of complex habitat for shelter (Carpenter, 1984), or reduction in predation pressure from invertivores such as triggerfish (McClanahan, 2000). For example, there were few triggerfish seen on the dives in this area. Urchins may, therefore, be subject to reduced predation pressure.

5.3 Habitat mapping

The habitat map generated by the pilot phase of the MCRCP is intended to be a preliminary indication of the distribution of benthic classes. Further data are required to improve the classification of the satellite image and more sophisticated processing will result in a better map. However, the current version of the map is appropriate for assessing, for example, the locations of coral rich areas and patterns of zonation. Hence, both current and future versions of the habitat map should provide a framework for all information gathered for the project area and GIS technology will allow detailed spatial analysis of all existing data sets. For instance, patterns of fish abundance can be overlaid on existing fishing pressure to assess areas of conflict. Such analysis is vital for conservation, especially for discussing the location of marine protected areas.

Knowledge of the accuracy of marine habitat maps is vital (Green *et al*., 2000) but unfortunately there was insufficient time to gather the independent data set required for a true accuracy assessment. However, since (a) the image was cloud free and taken at the same time as the fieldwork (b) there were a reasonable amount of field data and (c) there were a limited number of benthic classes, it seems likely that the accuracy is approaching that found for other studies with Landsat satellites (summarised in Green *et al*., 2000). Hence the accuracy of the preliminary habitat map is likely to be between 50 and 70%.

Assuming that the map is reasonably accurate, the estimates of areal extents of each benthic class are instructive. For example, although the project area (as defined by the current map) is over 1800 km^2, there is only approximately 70 km^2 of reefal habitats. Similarly, the area supporting the most coral rich benthic class ('Bedrock and mixed coral') is only approximately 20 km^2 with a further 22 km^2 of sand with coral patches. These statistics both highlight the damage caused by the bleaching event and other anthropogenic impacts and the urgent need to conserve remaining coral rich areas.

5.4 Reef Check

Reef Check surveys were completed at a range of geographic locations and hence provide a good preliminary assessment of reef health in the project area. However, it should be noted that the surveys were generally limited to shallow reef areas, because of the topography, and further data are required from deeper zones and also additional locations to complete a full assessment of reef health. Similarly, more surveys are required to fully quantify the composition of the benthic communities delineated by the baseline transects. Despite the limited data set, the pilot phase of the MCRCP showed the compatibility of the baseline transects and Reef Check protocols. For example, baseline transects rapidly documented the habitat types and provided ideal data for habitat mapping but Reef Check facilitated an assessment of percentage cover and showed that the most coral rich benthic class, 'Bedrock with mixed coral', was characterised by approximately 20% coral cover. With additional analysis, such links can be incorporated into a GIS and the habitat map could, for example, be converted into a map of coral cover. Both baseline transects and Reef Check (whether the 'standard' protocol or with the CCC adaptations) should, therefore, be viewed as vital components of the 'toolbox' for assessing reefs in the Mamanuca Islands.

Overall, the Reef Check data showed that the reefs within the project area have been significantly impacted, much of which can be attributed to the 2000 coral bleaching event (South and Skelton, 2000). For example, coral cover is often used as a gross surrogate of reef health and the ASEAN-Australia Living Coastal Resources project has proposed the criteria that: >75% = excellent; 75-50% = good; 50-25% = fair and <25% = poor (Chou *et al*., 1994). While these classes were designed primarily for Southeast Asia they are also a useful indicator for the South Pacific. The data presented in this report indicate that overall the reefs are currently in 'poor' condition (mean cover 13.7%). However, two of the sites, both on the 'Sunflower' platform reef, were in 'fair' condition. This platform reef is known to have even higher coral cover in some sections and obviously avoided the major effects of the bleaching event. This is presumably because of a relatively high current flow that mixed the water column and prevented extended exposure to warm water. Although currently unquantified, this high current flow could be a function of the fact that Sunflower is not sheltered by the inner barrier reef and may be affected by currents moving through the break in the reef close to Namotu Island. Indeed, during baseline transects, currents were recorded on each dive but further data are required to confirm this hypothesis.

The shallow site on the Sunflower platform reef also had by far the highest cover of *Acropora* (21.3%; largely the 'bottlebrush' life form) and the mean cover for all sites was only 3%. The generally low percentage cover of *Acropora* corals in the project area would be an expected result of a major bleaching event. *Acropora* have been repeatedly shown to be particularly susceptible to bleaching (for example Marshall and Baird, 2000) and this is one reason why data for *Acropora* and non-*Acropora* data are presented separately in this report. However, *Acropora* are generally disturbance-adapted as they characteristically have rapid growth and mechanical fragility (e.g. Done, 1982). Hence these species would be expected to recover given a source of larvae and no further bleaching or other detrimental anthropogenic influences. Currently, however, the substratum previously occupied by *Acropora*, and other affected coral groups, has been covered by algae (cover approximately 30%).

Reef Check surveys also record the abundances of a suite of fish and invertebrate taxa that are indicators of reef health (Hodgson, 1999), although CCC extended this list for the MCRCP. Similarly to the results of the benthic surveys, the fish and invertebrate data indicated significant human impacts in the Mamanuca Islands. For example, the abundances of the most commercially important fish families were less than 1 per 500 m^3 (sweetlips, groupers and trevallys) and 2.1 for snappers. Similarly to the results of the baseline transects, although these large carnivores are naturally less abundant than herbivores such as surgeonfish, these densities are lower than might be expected and highlight the effects of over-fishing. Indeed, some valuable species, such as the bumphead parrotfish (*Bolbometopon muricatum*), were not recorded during the Reef Check surveys and may be locally extinct on some of the reefs. As expected, the smaller herbivores, corallivores and planktivores (butterflyfish, fusiliers and surgeonfish) were more abundant (>7 per 500 m^3).

As for the fish indicator species, most of the invertebrate target taxa were rare. The results generally mirrored those of the baseline transects with *Diadema* most abundant. Again, the Reef Check data showed their densities varied dramatically, as shown by the high standard deviations. The explanation for this pattern, and the obvious clusters at some sites and not others, is not clear and requires further research. However, the reasons are likely to be complex and a synergy of natural and anthropogenic factors such as nutrient input which increases algal productivity, reduction of triggerfish predators, meta-population dynamics and physical and biological habitat preferences. *Diadema* are an important part of a reef's ecology and are required, along with herbivorous fish, to graze and hence maintain the competitive balance between corals and macro-algae. When insufficient herbivores are present, coral cover is reduced and macro-algae flourish.

The most commercially valuable invertebrate species were rare or absent within the project area. For example, few edible lobsters and no triton shells (*Charonia tritonis*) were recorded. Lobster populations can sustain a commercially important fishery and their absence indicates significant past fishing pressure and that they may be ecologically extinct in the area. The curios trade prizes triton shells and again their absence seems to indicate significant collecting in the past. Such removal may have important ecological effects since tritons are known to feed on crown-of-thorns starfish. Clams were seen on many of the Reef Check transect but it should be noted that most were *Tridacna squamosa* and that *T. gigas* were not observed. *T. gigas* is the largest of all bivalves (Colin and Arneson, 1995) and a highly prized fishery item.

Coral 'recruits' (colonies sized from 1-5 cm) were also recorded during Reef Check surveys. These colonies are a gross surrogate of reef recovery but more detailed data are required to assess this ecological process accurately. However, the evidence from this study indicates that there are small corals present on the reefs (mean 8.8 per 100 m^2), which is encouraging. There was also some evidence of patchy recruitment with, for example, more than 30 recruits on the shallow transect on the Sunflower platform reef and such 'sinks' of juveniles, along with their corresponding 'sources', should be considered when siting marine reserves. This will, however, require much further research as coral recruitment is complex and is affected by localised factors such as the amount of coralline algae present (Morse *et al*., 1988) and density of *Diadema* (McClanahan and Muthiga, 1988).

Analysis of the variation of the reef health parameters between reef complexes showed that there were some spatial patterns within the project area. Four benthic parameters varied significantly between the three complexes, although the result for *Acropora* is almost entirely caused by the anomalously high percentage cover on the Sunflower platform reef. The higher abundances of soft corals and sponges in the Namotu Group complex are likely to be related to the increased water flow and mixing on the outer barrier reef that provide higher concentrations of the planktonic food required by these creatures. The variation in rubble cover in the Inner and Outer Malolo Group complexes is harder to explain but may be caused by increased storm damage at these shallower sites.

The variations seen between the fish and invertebrate taxa, particularly the very significant results for flagtail groupers (*Cephalopholis urodeta*) and *Diadema*, are similar to those highlighted by the baseline data. As discussed in Section 5.2.3, these patterns are likely to be related to fishing pressure, a privately owned marine reserve and increased zooplankton on the outer barrier reef (for flagtail grouper) and aggregative behaviour, abundance of complex habitat for shelter and reduction in predation pressure from invertivores (for *Diadema*). The patterns observed for black-and-white snappers (*Macolor macularis*) and clams may be caused by variations in fishing pressure, habitat suitability and larval supply.

The quantitative nature of the Reef Check data allowed further analysis of the clear pattern seen during the baseline transects of fish and invertebrate abundances increasing with increasing coral cover. Using the Reef Check data, no invertebrate taxa were correlated with coral cover but there were significant results for four fish families and four other taxa (two species and two artificial species groupings). These results further highlight the importance of healthy benthic communities for sustaining commercially important fish species. For example, the equation of the trendline for snappers (Lutjanidae) indicates that, all other things being equal, their abundance increases by 1.4 fish per 500 m^3 with an increase of coral cover of 10%. The lack of correlations between algal abundance and herbivorous species was unexpected but may be caused by either the high abundance of algae in all locations or insufficient data.

The final analysis with the Reef Check data was the use of ternary diagrams to assign 'conservation values' to each site. The results of this work were intriguing and showed that, despite the impacts to the area, a large proportion of the sites had a high conservation value (>50%). Although such results are encouraging, it must be recognised that there were few communities of conservation values 2 and 3, which would limit the ability to protect a mosaic of marine habitats as recommended within the literature (e.g. Gray, 1997). Similarly, further data from additional sites are required, along with equivalent data from deeper areas at existing sites. For a site to truly represent a conservation priority both the whole depth profile and the surrounding area should have a high conservation value.

Conservation values can be extremely useful since they embody a range of important parameters and can be used for coastal zone management by aiding, for example, siting the location of marine reserves. The results of the pilot phase, therefore, highlight 12 possible priority sites for conservation within the project area. However, it is important to recognise that this technique is not sufficient on its own and must be combined with data such as live coral cover (Edinger and Risk, 2000). For example, the site at Waidigi Island was assigned a conservation value of 4 even though it has a very low coral cover (<1.5%) and simply happened to have one colony of each coral morphology. Furthermore, as suggested by the authors who described the technique (Edinger and Risk, 2000), the conservation values must be tailored for each geographical area to take into account conservation priorities and the major threats to reef health.

5.5 Coral size-frequencies

The coral size-frequency data collected during the pilot phase of the MCRCP was inevitably limited by time constraints. However, this type of data is important since the population ecology and demographic structure of coral communities are poorly studied but provide useful insights into the health of the system by encompassing temporal information. Hence there has recently been a growing interest in coral size-frequency data of specific coral communities (Bak and Meesters, 1998) and more data should be collected for the project area. Although such data should ideally be collected at the species level, using taxa such as *Porites* 'massive' is appropriate since it has been shown to be an operational taxonomic unit (Done and Potts, 1992).

Size-frequency graphs for the four target taxa that were sufficiently abundant for detailed analysis showed that, despite recent mortality from bleaching, population structures were typical. For example, each coral taxa had an obvious modal (most frequent) size and then fewer and fewer colonies in each smaller (younger) and larger (older) size class away from the mode. These distributions provide useful information on the species' life histories. Note that the high abundances in the largest size class (e.g. for *Diploastrea heliopora*) are artificial since this class encompasses a wide range of sizes above 50 cm. The information provided in the size-frequency diagrams from this project can also be used in conjunction with data from both other areas of Fiji and future re-surveys in the Mamanuca Islands to assess spatio-temporal variations in population structures. Furthermore, these data can be used to assess the impacts of the aquarium trade by comparing the demographics of the natural and harvested colonies.

During this study, the size of coral communities was combined with data on the percentage of live tissue. Summary statistics for the whole project area indicates that the colonies that survived the bleaching event and other anthropogenic impacts are healthy (mean live tissue cover > 78%). This is encouraging since it indicates that the corals should be able to reproduce sexually (via mass spawning) and provide larvae for regenerating areas damaged by bleaching. The large, old corals (>100 years for 'massive' *Porites*) that have been shown to be present on the reefs in the Mamanuca Islands will be particularly important sources of larvae. All taxa had reasonable numbers of colonies in the smaller size classes and this indicates that some replenishment has already occurred since the bleaching event in 2000.

Previous studies (e.g. Bak and Meesters, 1998) had shown a clear trend of decreasing live tissue cover with increasing colony size since tissue mortality kills smaller corals but can be withstood by larger individuals. There was some evidence of this pattern within the data presented in this report, especially for *Porites* 'massive' and *Pocillopora* 'medium'. In contrast, live tissue cover was high in all size classes for *Ctenactis echinata*, which is expected for fungid corals that only have one or a few polyps and little visible tissue. Consequently the significant variation in the percentage of living tissue between reef complexes is likely to be a statistical artefact rather than true variations in reef health.

Other comparisons of variations of the percentage of living tissue and coral sizes between reef complexes appear more instructive. For example, analysis showed that *Porites* 'massive' were larger and had less living tissue in the Inner Malolo Group. The lower percentage of living tissue seems likely to be caused by the relatively high anthropogenic impacts, such as sedimentation, that have been shown by the baseline and Reef Check transects to be present in this complex. In contrast, the larger sizes may be related to lower levels of wave exposure on fringing compared to platform reefs. Wave exposure has been shown to be an important influence on *Porites* 'massive' population dynamics (Done and Potts, 1992). The observed size differences of *Diploastrea heliopora* (larger on the platform reefs) may also be related to exposure or possibly differential survival rates from bleaching (i.e. more larger coral were killed in the Inner Malolo Group). Size differences for both taxa, differences in the number of surrounding corals, which may affect size-frequency data by changing growth rates and energy budgets via competition, seem unlikely to be an important factor for these differences since the sites had similar percentage cover values.

5.6 Observations of megafauna

Megafauna, such as sharks, are only loosely correlated with reef health but these top predators are often the first to be extirpated by over-fishing. Furthermore, megafauna are highly valued by tourists and can be a major attraction to an area. A relatively large number of such species were seen during the pilot phase of the MCRCP, which is encouraging for the tourist industry. Observation of a humpback whale was obviously a highly unusual event but sharks and turtles were seen relatively frequently.

5.7 Community work

All coastal zone management initiatives must take into account the needs and concerns of local communities. This is particularly true in Fiji where there is an extensive system of fishing rights and, for example, no-fishing reserves must be carefully explained. Hence, any long-term conservation work in the Mamanuca Islands will succeed or fail based on the quality of interaction and dialogue with local stakeholders. Such work must include environmental education of stakeholder groups such as fisherfolk, schoolchildren and resort staff.

The community work completed during the pilot phase of the MCRCP was inevitably limited. However, the 'Marine Ecology Workshop for the Professional Diver' and work with students from the International Secondary School showed that such work can be successful and represented a first step that will be subject to evaluation. Feedback from the professional diver workshop will be essential in the design and implementation of a longer-term education program for divers in the Mamanuca Islands. The outputs of this workshop will, therefore, be assessed in consultation with the Fiji Visitors Bureau and the Fiji Ecotourism Association as part of their ongoing plans for development of the tourism industry.

6. CONCLUSIONS

The health of the world's coral reefs is known to be declining significantly (Hodgson, 1999 and many others). Although data are still lacking for many geographical areas and long-term data are scarce, it is likely that no 'pristine' reefs remain anywhere in the tropics (Jackson, 1998). The factors that have caused these changes are complex and vary across space and time but include over-arching problems such as global warming that has lead to more frequent and severe coral bleaching events along with more localised effects, particularly over-fishing, sedimentation and nutrient enrichment (Roberts, 1993). Such changes are affecting the prosperity of the expanding coastal populations throughout the tropics.

What is the status of the reefs in the Mamanuca Islands in this global context? This question is difficult to answer without more data but the pilot project of the MCRCP has certainly shown that a suite of detrimental anthropogenic influences are present in the area. Perhaps the most obvious of these impacts was the mass coral bleaching event which occurred in early 2000. Although quantitative monitoring data are not available it is clear that this event dramatically reduced live coral cover on almost all reefs. Data from this project are certainly consistent with this conclusion: the 'best' habitat was characterised by approximately 20% coral cover; average coral cover at all Reef Check sites was less than 15% and the bleaching susceptible *Acropora* covered less than 4% of shallow reefs. Hence many reefs can currently be categorised as being in 'poor' condition.

Coral cover is a very gross indicator of reef health but is widely used and coral rich areas are known to be attractive to divers. However, reefal ecosystems are complex and such changes have subsequent effects on other groups of organisms. For example, fish are perhaps the most commercially important species on the reef and have been affected by the decreasing coral cover in the project area. This link between habitat complexity (approximately equal to coral cover) and fish abundance was clearly demonstrated by data collected during the pilot phase. While some herbivorous species can benefit from the macro-algae that replace killed corals, the preferred habitat of many valuable species is reduced. Within this study, for example, not only was the general correlation between fish and coral species richness demonstrated but there was a preference of many species for the coral rich 'Bedrock and mixed coral' benthic class. Finally, there was a quantitative link between increasing abundance of snappers, surgeonfish, groupers and parrotfish and increasing percentage coral cover.

Although the coral bleaching event was severe, its impacts appear to be acting synergistically with more localised impacts. Virtually all of the known threats to reef health are present to some degree in the Mamanuca Islands. Hence at least some of the reefs are exposed to: sedimentation; over-fishing; increased nutrient loads; collection of aquarium species; mechanical damage (from dredging, anchors and diving); coral diseases; crown-of-thorns starfish; and litter plus natural disturbance from cyclones. When combined, such a range of factors obviously presents a threat to the long-term integrity of the marine resources in the area.

In addition to documenting the threats to the whole project area, the pilot phase of the MCRCP attempted to assess the variability of the spatial extent and severity of these effects. This was examined via analysis between a series of 'reef complexes', which, although inevitably artificial, do represent groups of similar reef types. The results of this work show, for example, that some parameters indicate lower reef health and greater threats in the 'Inner Malolo Group'. Hence turbidity and sedimentation is higher, some fish species are less abundant and there is a lower percentage of living tissue on 'massive' *Porites* corals. Such a pattern is to be expected since these islands support the majority of the major resorts and local populations but is important to quantify when considering any mitigating measures.

The support by many stakeholders for such mitigating measures in the Mamanuca Islands represents a clear desire to address the threats to reef health and work towards sustainable use. Such a goal could be addressed by both reducing the threats to reef health (e.g. improving water quality) and establishing a chain of marine reserves. Marine reserves are increasingly being used throughout the world to assist sustainable marine resource management and there is a growing body of literature devoted to their design, establishment and effects (see, for example, Roberts and Hawkins, 2000 and Roberts *et al*., 2001 for an introduction). However, the importance of reserves is unequivocal: they conserve biodiversity; increase fish abundances within the reserve and provide 'spill-over' into surrounding areas; facilitate reef recovery; separate conflicting uses (e.g. collection for the aquarium trade away from popular dive sites); serve as a centre for public education and attract sustainable tourist revenue. Such values have already been recognised in the Mamanuca Islands and there are privately owned reserves at Beachcomber Island, Navini Island and Namotu (Magic) Island. These reserves have been in place for approximately 30, 15 and 5 years respectively and there is some anecdotal information of higher fish abundances. Furthermore, the number of small corals seen during this study indicates that reef health would improve within these and other reserves. Finally, even though issues such as coral bleaching cannot be addressed by Fiji alone, there is research to suggest that well managed reefs will recover faster from future bleaching events than unprotected areas. Such recovery will be vitally important if some of the prognoses for the future of coral reefs with continuing global warming are accurate (e.g. Hoegh-Guldberg, 1999).

If the existing network of reserves is to be extended, where should they be sited in the Mamanuca Islands? Although protection of any reefal area will improve its health, there is substantial existing and current research on maximising reserve efficacy by placing them in optimal positions. For example, it is important to try to protect a range of reef and habitat types, including mangroves and seagrass beds, in order to conserve the biodiversity of any given area (Salm and Clarke, 1989; Gray, 1997). However, placement of reserves in the Mamanuca Islands should favour coral rich habitats (particularly the 'Bedrock with mixed coral' benthic class) over sand dominated areas. Furthermore, case studies indicate that a series of small reserves may be easier to establish, spread the risk of a catastrophic impact to one area and provide a network of protection to species with widespread dispersal phases in their life history (e.g. many fish larvae travel large distances before settling on the reef).

The data from the pilot project of the MCRCP indicates that there is a need for marine reserves but insufficient information is currently available to conclusively list the priority sites. However, the preliminary habitat map does give an indication of the total *area* that should be protected from fishing. Theoretical models indicate that 20% of the reefs of an area should be 'no-take' in order to maximise the chances of sustaining the fisheries (Roberts and Hawkins, 2000). Furthermore, it should be noted that the area encompassed by a *whole* marine reserve(s) can be larger than 20% of the total since marine reserves do not have to preclude fishing. For example, ideally the whole MCRCP project area would be a reserve, governed by certain regulations, and 20% of this reserve would be zoned to ban fishing. *Given that the reefs delineated on the habitat map cover approximately 70 km^2, the eventual aim should be to protect 14 km^2 of shallow (<30 m) benthic habitat within the Mamanuca Islands from fishing.*

The ternary diagrams used in this report to provide a 'conservation value' for each Reef Check site represent a good protocol for highlighting priority areas within the project area. Much additional data are required before this list can be considered comprehensive and must be considered in conjunction with other data and most importantly the views of local stakeholders and communities. For example, there is already a sense of ownership of 'house reefs' close to resorts and local villages and these might be excellent areas for conservation since there is an intrinsic value attached to these patch reefs and the fish and coral that live on them. Similarly, different areas can be protected for different functions and, for example, areas on the outer barrier reef may be chosen for the abundance of commercially important fish whilst the Sunflower platform reef might act as a source of *Acropora* larvae for other reefs. However, the 12 sites currently categorised as of high conservation value perhaps represent a preliminary list of possible locations for marine reserves within the islands surveyed.

7. RECOMMENDATIONS

In order to facilitate reef regeneration following the 2000 coral bleaching event, mitigate current anthropogenic influences and protect fisheries, a series of marine reserves with a significant area of 'no-take' zones (i.e. fishing is banned) should be considered. No-take zones have the advantage that they can be effective without requiring growth and mortality statistics for each species that are necessary for conventional management options (Munro and Williams, 1985; see also Mahon, 1997).The siting of these reserves should incorporate both biological data and socio-economic factors and follow extensive discussions with all stakeholders. Tools such as GIS can be used to help manage this variety of biological, economic and political data.

Recommendation 1: Aim to establish one or more multiple use marine protected areas in the Mamanuca Islands with regulations limiting deleterious effects (i.e. integrated coastal zone management). These protected areas should aim to eventually contain approximately 14 km^2 of 'no-take' zones.

Recommendation 2: 'No-take' zones in the Mamanuca Islands should integrate the following factors:

- Preference of many fish species for coral rich habitats. The corollary of this consideration is to integrate measures to protect coral cover.
- Protection of areas incorporating a range of habitat types, including mangroves and seagrass beds, in order to allow for nursery areas, ontogenetic shifts and species that rely on non-coral rich habitats.
- Consideration of species-specific management techniques may be required for particularly rare species.
- Location of spawning sites, which can be protected via seasonal closures.
- 'Conservation values' provided by ternary diagrams and other techniques. Workshops with local experts should be convened to fine-tune these protocols for use in both the project area and Fiji generally.
- 'Sources' and 'sinks' of marine larvae. Such work will require dedicated research on, for example, current flows in the area and meta-population dynamics. Oceanographic variables could be measured in collaboration with SOPAC.

Recommendation 3: Consider the establishment of a 'Mamanuca Coastal Zone Management Group', which would include representatives from local communities, the tourist industry, Fijian NGOs, government agencies, the University of the South Pacific and other stakeholders.

The establishment of an effective system of marine reserves will require the support of local stakeholders and communities and hence a series of conservation education programmes will be required.

Recommendation 4: Establish conservation education programmes, including the rationale for marine protected areas, for all stakeholders at the local and national level but particularly targeted at local communities and the tourist industry.

The pilot phase of the MCRCP provides a baseline data set on current reef health and future surveys will allow recovery or further declines to be monitored. Furthermore, monitoring the efficacy of any future programme of marine reserves is vital to maintain the support of local stakeholders and allow adaptive management.

Recommendation 5: Establish an integrated programme to monitor reef health in the Mamanuca Islands. Reef Check has been shown to provide a good basis for reef health monitoring and non-professional divers can collect these data accurately and rapidly. The sites surveyed during the pilot phase of the MCRCP could form the basis of this monitoring programme and could be re-surveyed by local people (such as resort staff) following appropriate training programmes. All data collected by this monitoring programme should feed into both the Southwest Pacific nodes for Reef Check and GCRMN.

Along with monitoring biological parameters, successful coastal zone management in the Mamanuca Islands will require data documenting fishing pressure, including catches, species taken and sites used.

Recommendation 6: Establish a programme to monitor fisherfolk and their activities in the Mamanuca Islands. Such a programme should focus on species caught, weights landed, sites used and ideally catch per unit effort. Such a programme should incorporate both artisanal and commercial operations.

Similarly, there is significant diving pressure in the project area that should be monitored and managed to maintain the integrity of popular dive sites. Furthermore, Medio *et al*. (1996) suggest briefing divers to increase their environmental awareness can significantly reduce the number of contacts divers make with the benthic community.

Recommendation 7: Use the data already recorded by resorts on the number of dives undertaken at sites in the Mamanuca Islands. These data could be used to help interpret monitoring programmes and assist any future 'carrying capacity' calculations.

Recommendation 8: Establish a standard environmental awareness briefing for all divers that can be used by dive resorts in the Mamanuca Islands. Such a briefing could be developed using the PADI AWARE programme. Mechanical damage to dive sites could also be reduced by extending and improving the system of permanent mooring buoys.

All the data collected by the pilot phase of the MCRCP are spatially referenced and could be integrated, within a GIS, with other information available for the area and future data sets.

Recommendation 9: Establish an integrated GIS and associated meta-database for the Mamanuca Islands, including data from the pilot phase of the MCRCP. Such a system could also be combined with any future national database and information held by the Southwest Pacific node of GCRMN.

Recommendation 10: Examine the potential of using data collected by the pilot phase of the MCRCP as the basis of national habitat classification scheme and subsequent national habitat map.

Many of the recommendations listed here could be achieved by extending the pilot phase of the MCRCP to a long-term commitment by CCC, in conjunction with Fijian partners, to the Mamanuca Islands. A brief outline of such a collaborative project, requiring detailed discussion, is as follows:

AIM	OBJECTIVE	ANTICIPATED OUTPUTS
➲ Resource assessment.	❶ Systematic surveys of all reefs within the project area. ❷ Assess human impacts to reefs in the project area. ❸ Initiate mangrove and seagrass bed surveys. ❹ Develop a marine habitat classification scheme for the Mamanuca Islands.	🗎 Establishment of a GIS database for project area. 🗎 Refinements to existing habitat base map. 🗎 Documentation of anthropogenic impacts. 🗎 Further management recommendations, including locations of possible marine reserves.
➲ Environmental monitoring.	❶ Establish a biological monitoring programme for the major habitats in the project area. ❷ Establish monitoring programmes for fisheries and SCUBA diving activity.	🗎 Establishment of permanent monitoring sites. 🗎 Expansion of current baseline data set. 🗎 Generation of socio-economic data to assist with coastal zone management.
➲ Training and conservation education.	❶ Provide scientific and SCUBA training for key project counter-parts and regional representatives. ❷ Establish a schools curriculum for conservation education. ❸ Establish a system of SCUBA diver briefings	🗎 Establishment of a team of trained Fijian divers for e.g. monitoring surveys. 🗎 Creation of conservation education opportunities for local schoolchildren and community members. 🗎 Reduction impacts by divers in the project area.

CCC is willing to commit to a long-term programme of research, training and education in Fiji, in partnership with all stakeholders.

8. REFERENCES

Bak, R.P.M. and E.H. Meesters. 1998. Coral population structure: the hidden information of colony size-frequency distributions. *Marine Ecology Progress Series* **162**: 301-306.

Biña, R.T. 1982. Application of Landsat data to coral reef management in the Philippines. Pages 1-39. Proceedings of the Great Barrier Reef Remote Sensing Workshop, James Cook University, Townsville, Australia.

Bouchon-Navarro, Y. and M.L. Harmelin-Vivien. 1981. Quantiative distribution of fishes in the Gulf of Aqaba (Red Sea). *Marine Biology* **63**: 79-86.

Bray, J.R., and J.T. Curtis. 1957. An ordination of the upland forest communities of Southern Wisconsin. *Ecological Monographs* **27**: 325-349.

Brown, B. 1997. Coral bleaching: causes and consequences. *Proceedings of the 8th International Coral Reef Symposium* **1**: 65-74.

Caley, M.J., M.H. Carr, M.A. Hixon, T.P. Hughes, G.P. Jones and B.A. Menge. 1996. Recruitment and the local dynamics of open marine populations. *Annual Review of Ecology and Systematics* **27**: 477–500.

Carpenter R.C. 1984. Predator and population density control of homing behaviour in the Caribbean echinoid *Diadema antillarum*. *Marine Biology* **82**: 101-108.

Chou, L.M. and 9 other authors. Status of coral reefs in the ASEAN region. Pages: 1-10. *In:* Wilkinson, C.R., Suraphol Sudara and Chou, L.M (Eds). *Proceedings of the Third ASEAN-Australia Symposium on Living Coastal Resources. Volume 1: Status reviews.* Australian Institute of Marine Science.

Clarke, K.R. 1993. Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* **18**: 117-143.

Cendrero, A. 1989. Mapping and evaluation of coastal areas for planning. *Ocean and Shoreline Management* **12**: 427-462.

Colin, P.L. and C. Arneson. 1995. Tropical Pacific Invertebrates. Coral Reef Press, Beverly Hills.

Craik, W., R. Kenchington and G. Kelleher. 1990. Coral-reef management. Pages 453-465. *In*: Z. Dubinsky. Coral reefs. Elsevier Science Publishers, Amsterdam.

Crosby, M.P. and E.S. Reese. 1996. A manual for monitoring coral reefs with indicator species: butterflyfishes as indicators of change on Indo Pacific reefs. Office of Ocean and Coastal Re-source Management, National Oceanic and Atmospheric Administration, Silver Spring, MD.

Cumming, R.L. and 10 other authors. In press. Mass bleaching in the Fiji Islands, 2000. *Proceedings of the 9th International Coral Reef Symposium.*

Darwall, W.R.T. and N.K. Dulvy. 1996. An evaluation of the suitability of non-specialist volunteer researchers for coral reef fish surveys. Mafia Island, Tanzania – A case study. *Biological Conservation* **78**: 223-231.

Done, T.J. 1982. Patterns in the distribution of coral communities across the central Great Barrier Reef. *Coral Reefs* **1**: 95-107.

Done, T.J. and D.C. Potts. 1992. Influences of habitat and natural disturbances on contributions of massive *Porites* corals to reef communities. *Marine Biology* **114**: 479-493.

Edinger, E.N. and M.J. Risk. 2000. Reef classification by coral morphology predicts coral reef conservation value. *Biological Conservation* **92**: 1-13.

English, S., C.R. Wilkinson and V. Baker (Eds). 1997. Survey manual for tropical marine resources. Australian Institute of Marine Science. 2nd edition.

Erdmann, M.V., A. Mehta, H. Newman and Sukarno. 1997. Operational Wallacea: Low-cost reef assessment using volunteer divers. *Proceedings of the 8th International Coral Reef Symposium* **2**: 1515-1520.

Faith, D.P., Minchin, P.R., and L. Belbin. 1987. Compositional dissimilarity as a robust measure of ecological distance. *Vegetatio* **69**: 57-68.

Gray, J.S. 1997. Marine biodiversity: Patterns, threats and conservation needs. *Biodiversity and Conservation* **6**: 153-175.

Green, E.P., P.J. Mumby, A.J. Edwards and C.D. Clark. (Ed. A.J. Edwards). 2000. Remote sensing handbook for tropical coastal management. *Coastal Management Sourcebooks 3,* UNESCO, Paris.

Harborne, A.R., D.C. Afzal, M.J. Andrews and J.M. Ridley. In press. Beyond data: The expanded role of a volunteer programme assisting resource assessment and management in the Bay Islands, Honduras. *Proceedings of the 9th International Coral Reef Symposium*.

Hay, M.E. 1981. Spatial patterns of grazing intensity on a Caribbean barrier reef: Herbivory and algal distribution. *Aquatic Botany* **11**: 97-109.

Hodgson, G. 1999. A global assessment of human effects on coral reefs. *Marine Pollution Bulletin* **38:** 345-355.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. *Marine and Freshwater Research* **50**: 839-866.

Hunter, C. and J. Maragos. 1992. Methodology for involving recreational divers in long-term monitoring of coral reefs. *Pacific Science* **46**: 381-382.

Jackson, J.B.C. (1997) Reefs since Columbus. *Proceedings of the 8th International Coral Reef Symposium* **1**, 97-106.

Jennings, S. and N.V.C. Polunin. 1996. Impacts of fishing on tropical reef ecosystems. *Ambio* **25**: 44-49.

Kenchington, R.A., and D.R. Claasen. 1988. Australia's Great Barrier Reef - management technology. Pages KA2.2-2.13. Proceedings of the Symposium on Remote Sensing of the Coastal Zone, Gold Coast, Queensland, Department of Geographic Information, Brisbane.

Letourneur, Y., M. Kulbicki and P. Labrosse. Spatial extent of commercial reef fish communities along a terrestrial runoff gradient in the northern lagoon of New Caledonia. *Environmental Biology of Fishes* **51**: 141-159.

Loubersac, L., A.L. Dahl, P. Collotte, O. LeMaire, L. D'Ozouville and A. Grotte. 1989. Impact assessment of Cyclone Sally on the almost atoll of Aitutaki (Cook Islands) by remote sensing. *Proceedings of the 6th International Coral Reef Symposium*, 2: 455-462.

Luckhurst B.E. and K. Luchurst. 1978. Analysis of the influence of substrate variables on coral reef fish communities. *Marine Biology* **49**: 317-323.

Luczkovich, J.J., T.W. Wagner, J.L. Michalek and R.W. Stoffle. 1993. Discrimination of coral reefs, seagrass meadows, and sand bottom types from space: a Dominican Republic case study. *Photogrammetric Engineering and Remote Sensing* **59**: 385-389.

Mahon, R. 1997. Does fisheries science serve the needs of managers of small stocks in developing countries? *Canadian Journal of Fisheries and Aquatic Science* **54**: 2207-2213.

Marshall, P.A. and A.H. Baird. 2000. Bleaching of corals on the Great Barrier Reef: differential susceptibilities among taxa. *Coral Reefs* **19**: 155-163.

McClanahan, T.R. 2000. Recovery of a coral reef keystone predator, *Balistapus undulatus*, in East African marine parks. *Biological Conservation* **94**: 191-198.

McClanahan, T.R. and N.A. Muthiga. 1988. Changes in Kenyan coral reef community structure and function due to exploitation. *Hydrobiologia* **166**: 269-276.

Medio, D., R. Ormond and M. Pearson. 1996. Effects on the rates of damage to corals by scuba divers. *Biological Conservation* **79:** 91-95.

Morse, D.E., N. Hooker, A.N.C. More. and R.A. Jensen. 1988. Control of larval metamorphosis and recruitment in sympatric agariciid corals. *Journal of Experimental Marine Biology and Ecology* **116**: 193-217.

Mumby, P.J. and A.R. Harborne. 1999. Development of a systematic classification scheme of marine habitats to facilitate regional management and mapping of Caribbean coral reefs. *Biological Conservation* **8**: 155-163.

Mumby, P.J., A.R. Harborne, P.S. Raines and J.M. Ridley. 1995. A critical assessment of data derived from Coral Cay Conservation volunteers. *Bulletin of Marine Science* **56**: 737-751.

Munro, J.L. and Williams, D.M. 1985. Assessment and management of coral reef fisheries: biological, environmental and socio-economic aspects. *Proceedings of the 5th International Coral Reef Congress* **4**: 544-578.

Pearse, J.S. and S.W. Arch. 1969. The aggregation behaviour of Diadema (Echinodermata: Echinoidea). *Micronesia* **5**: 165-171.

Roberts, C.M. 1993. Coral reefs: health, hazards and history. *Trends in Ecology and Evolution* **8(12)**: 425-427.

Roberts C.M., B. Halpern, S.R. Palumbi and R.R Warner. 2001. Designing marine reserve networks. *Conservation Biology in Practice* **2**: 10-17.

Roberts C.M. and J.P. Hawkins. 2000. Fully protected marine reserves: A guide. WWF Endangered Seas Campaign.

Roberts C.M. and R.F.G Ormond. 1987. Habitat complexity and coral reef fish diversity and abundance on Red Sea fringing reefs. *Marine Ecology Progress Series* **41**: 1-8

Salm, R.V. and J.R. Clark. 1989. Marine and coastal protected areas: a guide for planners and managers (2nd Edition). International Union for the Conservation of Nature, Gland, Switzerland.

Sheppard, C.R.C. 1982. Coral populations on reef slopes and their major controls. *Marine Ecology Progress Series* **7**: 83-115.

South, R and P. Skelton. 2000. Status of coral reefs in the southwest Pacific: Fiji, Nauru, New Caladonia, Samoa, Solomon Islands, Tuvalu and Vanuata. Pages 159-180. *In*: C. Wilkinson (ed.), Status of coral reefs of the world: 2000. Australian Institute of Marine Science.

Spalding, M.B., and A.N. Grenfell. 1997. New estimates of global and regional coral reef areas. *Coral Reefs* **16**: 225-230.

Stafford-Smith, M.G. and R.F.G. Ormond. 1992. Sediment-rejection mechanisms of 42 species of Australian sclerectinian corals. *Australian Journal of Marine and Freshwater Research* **43**: 683-705.

Thresher R.E. 1983. Environmental correlates of the distribution of coral-reef fishes. *Science* **218**: 70-72.

Uthicke, S. 1999. Sediment patch selectivity in tropical sea cucumbers (Holothurioidea: Aspidochirotida) analysed with multiple choice experiments. *Journal of Experimental Marine Biology and Ecology* **236(1)**: 69-87.

Vuki, C., L.P. Zann, M. Naqasima and M. Vuki. The Fiji Islands. Pages 751-764. *In*: C. Sheppard (Ed.). Seas at the millennium: an environmental evaluation. Elsevier Science.

Veron, J.E.N. 2000. Corals of the World. 3 Vols. M. Stafford-Smith (Ed.). Australian Institute of Marine Science Monograph Series.

Wells, S.M. 1995. Reef assessment and monitoring using volunteers and non-professionals. University of Miami.

Westmacott, S, K.A. Teleki, S.M. Wells and J.M. West. 2000. Management of bleached and severely damaged reefs. IUCN, Gland and Cambridge.

APPENDIX 1

Memorandum of Understanding between the Ministry of Tourism, Government of Fiji and Coral Cay Conservation.

MEMORANDUM OF UNDERSTANDING

between

Ministry of Tourism
Government of Fiji

and

Coral Cay Conservation Ltd.

WHEREAS the Ministry of Tourism (the 'Ministry') and in regards to a resolution passed at the Fiji Tourism Forum 2000 which encompasses technical cooperation with Coral Cay Conservation Ltd. ('CCC') for coral reef conservation initiatives within the Mamanuca Island group **AND;**

WHEREAS CCC has agreed to provide such assistance for an initial period of three (3) months commencing in the year 2001 **AND;**

WHEREAS it is envisaged that this initial period of assistance may form the basis for a longer-term programme of technical, conservation education and training cooperation within the Mamanuca Island group and elsewhere within Fiji as directed and guided by the Ministry and other project partners, **NOW**

THEREFORE both parties hereby agree to enter into the following Memorandum of Understanding:

1

CCC

- CCC will initiate a three (3) month pilot project of work within the Mamanuca Island group commencing in the year 2001. This work will include (but is not necessarily limited to): baseline surveys of targeted coral reef areas; initiation of conservation awareness and training initiatives; and other activities in support of the conservation of marine biodiversity within the project location. Outputs from this initial pilot project will include (but is not necessarily limited to): a resource map of targeted coral reef areas; scoping for the development of longer-term conservation education and training initiatives; initial recommendations for the management of targeted coral reef areas; and preparation of a plan of action for a programme of longer-term cooperation with CCC.

- The pilot project will involve approximately 25 international CCC personal who will be recruited by CCC through its normal *modus operandi*. CCC will accept full liability and responsibility for all CCC personnel during the course of the project, which will include all necessary insurance cover.

- Whilst CCC will require a reasonable degree of support-in-kind from local stakeholders for certain aspects of project implementation, CCC accepts full financial liability for all costs necessary for project implementation.

- CCC will provide weekly progress reports during the project implementation phase to the Ministry for review and dissemination by the Ministry. Within two weeks of the scheduled termination of the pilot project CCC will submit to the Ministry a final project report, which will be presented by CCC personnel to a review committee to be convened by the Ministry. This report will form the basis of discussion for future cooperation between the parties concerned.

The Ministry

- The Ministry agrees to facilitate the project through provision of assistance with all necessary Immigration and Customs requirements for CCC personnel and project equipment.

- The Ministry agrees to provide a coordinating role with all relevant government departments and other national agencies and stakeholders to ensure successful and timely project implementation.
- The Ministry will convene a meeting of all relevant agencies and stakeholders upon completion of the project to review the project outputs and discuss proposals for a longer-term programme of cooperation with CCC.
- The Ministry will provide whatever guidance and assistance it can to CCC for the procurement of project equipment and supplies within Fijim, on the understanding that CCC is ultimately fully liable for all procurement costs.

THIS Memorandum of Understanding will commence upon the date of signature by the competent authorities of the Ministry and of CCC and will remain in force until the scheduled termination of the project and presentation of the final project report to the Ministry. Either party may revoke this Agreement by providing 60 (Sixty) days notice in writing to the other party.

SIGNED by)
for and on behalf of)
Ministry of Tourism) Permanent Secretary for Tourism + Transport

Dated) 29/3/01

WITNESSED by)
) Ministry of Tourism

SIGNED by)
for and on behalf of)
Coral Cay Conservation Ltd.) PETER RAINES
MANAGING DIRECTOR

Dated)

WITNESSED by)
) W Wong
Director of Finance & Admin.
Fiji Visitors Bureau

APPENDIX 2

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

BOAT FORM

DATE: ______________________

STUDY: ______________________

TRANSECT: ______________________

SUBZONE: ______________________

COX: ______________________

BM: ______________________

BUOY: ______________________

COORDINATES

START:

GPS Unit: ______________________

Datum: ______________________

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

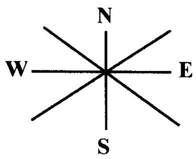
END:

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

CURRENT STRENGTH

none
weak
medium
strong

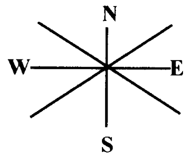
CURRENT DIRECTION (towards)



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 Fiji

Recorder's name ____________ Phys ________ Depth limits: 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 grooves.
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 45°.
Escarpment	☐	Any area of the benthos whose angle of slope exceeds 45°.
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 slope does not exceed 45°.
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 uncertainlty, 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 coralline structures.
Dead corals	☐	Any area of hard bare substratum with visible corallite structure.
Rubble	☐	Any area of loose 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-calcareous algae forming mats or turfs.
Brown fleshy algae	☐	e.g. *Lobophora, Padina, Sargassum, Turbinaria.*
Red/brown branching algae	☐	e.g. *Laurencia, Dictyota.*
Green calcified algae	☐	e.g. *Halimeda, Udotea.*
Red coralline algae	☐	e.g. Cement, crustose coralline.
Seagrass	☐	

Substratum types within the habitat: ______________________________

____

____

Other comments: ______________________________

SPECIES ABUNDANCE

NOTE THAT ALL CORAL AND FISH TARGET SPECIES MUST ALSO BE COUNTED IN THE APPROPRIATE 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	☐
Chaetomorpha sp.	15	☐
Marble - *Valonia* sp.	36	☐
Bornetella sp.	10	☐
Finger - *Neomeris* sp.	29	☐
Spongy - *Codium* sp.	18	☐
Grape - *Caulerpa* sp.	12	☐
Calcified - *Halimeda* sp.	24	☐
- *Tydemania* sp.	33	☐

Further green species:

__________ ☐
__________ ☐
__________ ☐
__________ ☐

TOTAL GREEN ALGAE ☐

PHAEOPHYTA: Brown.

Ralfsia sp.	51	☐
Sphacelaria sp.	54	☐
Rosenvingea sp.	58	☐
Flat-branched - *Dictyota* sp.	44	☐
Fan blade - *Padina* sp.	50	☐
Blade/Ruffle - *Lobophora* sp.	49	☐
Hydroclathrus sp.	48	☐
Pyramid - *Turbinaria* sp.	55	☐
Filamentous	42	☐
Bladder - *Sargassum* sp.	53	☐

Further brown species:

__________ ☐
__________ ☐
__________ ☐

TOTAL BROWN ALGAE ☐

RHODOPHYTA: Red.

Wiry-branched	71	☐
Gelidium sp.	76	☐
Gelidiella sp.	74	☐
Fine branched - *Laurencia* sp.	85	☐
Calcified	70	☐
Galaxaura	73	☐
Amphiroa	63	☐
Jania / spikeweed	83	☐
Filamentous - *Ceramium* sp.	60	☐
Sheet - *Halymenia* sp.	80	☐
Amansia	62	☐
Actinotrichia	61	☐

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	☐

ARTHROPODA: 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	
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
Orange-banded coralfish	923
Humphead bannerfish	669
Pennant bannerfish	939
Angelfish	544
Regal	663
Bicolour	673
Pearlscale	545
Emperor	756
Blue-girdled	937
Vermiculated	938
Surgeonfish	546
Convict	547
"Ringtail" sp.	548
Brushtail tang	638
Thompson's	747
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
Black bar chromis	646
Blue devil	657
Threespot dascyllus	671
Humbug dascyllus	767
Reticulated dascyllus	771
Whitebelly damselfish	654
Staghorn damselfish	745
Black damselfish	759
Behn's damselfish	593
Honeyhead damselfish	594
Alexander's damselfish	764
Anemonefish sp.	591
Sergeant sp.	656
Wrasse	598
Diana's hogfish	931
Mesothorax hogfish	611
Humphead	600
Red-banded	932
Checkerboard	725
Twotone	768
Crescent	647
Sixbar	744
Jansen's	678
Cigar	685
Bird	610
Cleaner	605
Parrot fish	613
Bumphead	933
Goatfish	615
Half-and-half	648
Two-barred	666
Dash-and-dot	781
Multibarred	934
Blackstriped	616
Yellowfin	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
Soapfish	928
Anthias	642
Rabbitfish	579
Foxface	757
Virgate	630
Uspi	896
Spinecheek	581
Twoline	582
Pearly	659
Snapper	565
Two-spot	753
Checkered	665
Black-and-white	569
Bluelined	925
Spanish flag	679
Paddletail	564
Dartfish	774
Blackfin	695
Dottyback	900
Lined	686
OTHER MAJOR FAMILIES:	
Jack / Trevally	553
Sweetlips	577
Barracuda	560
Moorish Idol	551
Emperor	924
MISCELLANEOUS FAMILIES:	
Spadefish / Batfish	595
Cardinalfish	621
Squirrelfish / Soldierfish	619
Filefish	629
Lionfish	631
Scorpionfish / Stonefish	632
Lizardfish	643
Hawkfish	902
Sandperch	675
Porcupine / Puffer / Toby	634
Trunk / Box / Cowfish	640
Goby	749
Blenny	926
Sharksucker	787
Needlefish	562
Pipefish	911
Shrimpfish	790
Trumpetfish	664
Moray eel	637
FURTHER SPECIES:	
TOTAL FISH	

HARDCORAL

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 form, genera and species

Pocilloporadae		
Pocillopora: small	164	☐
medium	165	☐
large	166	☐
Seriatopora hystrix	834	☐
Stylophora pistillata	833	☐
Stylophora mordax	803	☐
Acroporidae		
Montipora foliosa	836	☐
Montipora digitata	808	☐
Bottlebrush *Acropora*	163	☐
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	☐
Caryophylliidae		
Euphyllia	895	☐
Plerogyra	874	☐
Milleporidae		
Millepora platyphylla	827	☐
Millepora intricata	826	☐
Dendrophylliidae		
Tubastrea micrantha	877	☐
Turbinaria reniformis	884	☐

Miscellaneous

Brain:	- small	202	☐
	- medium	273	☐
	- large	253	☐

Further species

(31 blank lines with boxes)

TOTAL TARGET CORALS ☐

NOTE THAT ALL CORAL AND FISH TARGET SPECIES MUST ALSO BE COUNTED IN THE APPROPRIATE FAMILY OR LIFEFORM

APPENDIX 3

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:				

APPENDIX 4

Procedure used to assign coral cover to each quadrat surveyed when using the coral size-frequency protocol. Method is from a personal communication with R.F.G. Ormond (University of York).

Within each size-frequency quadrat, volunteers decided which of the following categories of coral cover to use:

> 100 %
> 90 %
> 75%
> 50 %
< 50 %
< 25 % (corals < 2 coral diameters apart)
< 10 % (corals < 3 coral diameters apart)
< 1 % (corals < 10 coral diameters apart)
< 0.1 % (corals < 30 coral diameters apart)

Procedure: Volunteers looked at the quadrat and decided if more than half or less than half of the block was covered by living coral and then used the following key:

A. If more than half, then decide if more or less than a quarter of the substrate is left uncovered.

If more than three quarters of the substrate is covered by living coral, then decide if more or less than 10% is left uncovered.

If more than 90% of the substrate is covered by living coral, then decide if more or less than 100% is covered.

B. If less than half, then decide if more or less than a quarter of the substrate is covered by coral (this is a density where given more or less equally sized coral heads, corals will be distributed approximately 2 coral head diameters apart – that is coral centre to coral centre).

If less than a quarter is covered by coral, then decide if more or less than 10% of the substrate is covered by coral (this is a density where given more or less equally sized coral heads, corals will be distributed approximately 3 coral head diameters apart – that is coral centre to coral centre).

If less than 10% is covered by coral, then decide if more or less than 1% of the substrate is covered by coral (this is a density where given more or less equally sized coral heads, corals will be distributed approximately 10 coral head diameters apart – that is coral centre to coral centre).

If less than 1% is covered by coral, then decide if more or less than 0.01% of the substrate is covered by coral (this is a density where given more or less equally sized coral heads, corals will be distributed approximately 30 coral head diameters apart – that is coral centre to coral centre).

APPENDIX 5

Median abundances of substratum categories, biological life forms and species (algae, sponges, octocorals, invertebrates, corals and fish) found in each of the seven major benthic classes identified during the pilot phase of the MCRCP.

Note that because of the complex taxonomy and difficult identification of tropical marine fauna and flora, a combination of species, genera, life forms and higher taxonomic classifications are used with both Latin and common names.

(A) Substratum categories

Taxa	Benthic class							
	All surveys combined	Sand with sparse algae and seagrass	Sand and algae	Sand with small coral patches	Bedrock, dead coral and sparse corals	Mixed substratum, green algae and coral	Sand with large coral patches	Bedrock and mixed corals
Bedrock	1.97	0.17	0.75	0.43	4.00	1.50	0.81	3.18
Dead *Acropora*	0.49	0.17	1.25	0.15	0.00	0.10	0.33	0.90
Dead coral	0.94	0.00	1.75	0.22	0.00	1.00	1.36	1.00
Dead coral with algae	1.49	0.17	0.25	1.19	0.25	1.25	2.08	1.69
Mud	0.04	0.17	0.75	0.00	0.00	0.00	0.10	0.01
Recently killed coral	1.16	0.00	0.75	0.60	0.00	2.25	1.78	1.11
Rubble	1.02	0.17	2.00	0.15	1.00	2.50	1.08	1.15
Sand	2.68	4.83	3.00	4.85	0.00	2.17	2.88	1.47

(B) Algae and marine plants

Taxa	Benthic class							
	All surveys combined	Sand with sparse algae and seagrass	Sand and algae	Sand with small coral patches	Bedrock, dead coral and sparse corals	Mixed substratum, green algae and coral	Sand with large coral patches	Bedrock and mixed corals
				Cyanophyta				
Blue green algae	0.36	0.00	0.00	0.43	0.00	0.25	0.28	0.52
				Chlorophyta				
"Filamentous"	0.44	0.00	1.75	0.43	0.75	1.00	0.28	0.53
"Turf"	1.34	1.00	1.25	0.31	0.75	2.00	1.00	1.84
Avrainvillea	0.01	0.00	0.00	0.04	0.00	0.00	0.00	0.02
Bornetella	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Caulerpa	0.13	0.17	2.75	1.00	0.25	0.00	0.04	0.06
Chaetomorpha	0.02	0.00	0.25	0.00	0.00	0.00	0.00	0.03
Chlorodesmis	0.15	0.17	0.25	0.09	0.00	0.00	0.04	0.26
Codium	0.02	0.00	0.75	0.04	0.00	0.00	0.02	0.01
Dictyosphaeria	0.05	0.00	0.00	0.09	0.00	0.00	0.00	0.08
Halimeda	1.12	0.50	2.25	1.25	0.75	1.50	1.00	1.14
Neomeris	0.09	0.00	0.00	0.15	0.00	0.00	0.02	0.14
Tydemania	1.03	0.00	0.25	0.58	0.75	2.50	1.67	0.88
Valonia	0.18	0.00	0.00	0.04	0.75	0.50	0.24	0.18
Ventricaria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
				Phaeophyta				
"Filamentous"	0.13	0.00	1.00	0.04	0.00	0.25	0.02	0.19
Dictyota	0.30	0.00	2.00	0.75	0.75	0.10	0.16	0.32
Hydroclathrus	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Lobophora	0.04	0.00	2.75	0.04	0.25	0.00	0.04	0.01
Padina	0.73	0.17	3.00	0.71	0.75	1.83	2.04	0.32
Sargassum	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
Sphacelaria	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
Turbinaria	0.14	0.00	1.75	0.09	0.75	0.00	0.13	0.14
				Rhodophyta				
"Calcified"	1.66	0.00	2.75	0.43	1.00	2.00	1.64	2.00
"Filamentous"	0.47	0.00	0.25	0.71	0.00	0.25	0.28	1.00
Amansia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Amphiroa	0.27	0.00	2.75	0.04	0.00	0.25	0.13	0.48
Eucheuma	0.08	0.00	2.75	0.00	0.75	0.10	0.10	0.06
Galaxaura	0.13	0.00	2.75	0.00	0.75	0.00	0.28	0.10
Halymenia	0.03	0.00	0.00	0.00	0.00	0.00	1.00	0.04
Jania	0.25	0.00	2.75	0.00	0.00	0.25	0.56	0.26
Laurencia	0.10	0.00	1.00	0.04	0.25	0.10	0.07	0.11
Peyssonnelia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
				Angiospermae				
"Seagrass"	0.05	0.17	0.00	0.31	0.00	0.00	0.04	0.02
Halophila	0.06	0.50	0.00	1.00	0.00	0.00	0.04	0.02
Thalassia	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00

(C) Sponge life forms

Taxa	Benthic class							
	All surveys combined	Sand with sparse algae and seagrass	Sand and algae	Sand with small coral patches	Bedrock, dead coral and sparse corals	Mixed substratum, green algae and coral	Sand with large coral patches	Bedrock and mixed corals
Branching	0.13	0.17	0.00	0.15	0.00	0.00	0.24	0.12
Elephant ear	0.04	0.00	0.00	0.04	0.00	0.10	0.00	0.05
Encrusting	1.51	0.00	1.00	1.00	1.25	0.25	1.69	1.78
Lumpy	1.06	0.00	0.00	0.58	0.75	1.17	1.04	1.39
Plate	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Rope	0.11	0.17	0.25	0.15	0.25	0.00	0.10	0.10
Tube	0.13	0.00	0.00	0.04	0.25	0.10	0.10	0.18
Vase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01

(D) Octocorals and black corals

Taxa	Benthic class							
	All surveys combined	Sand with sparse algae and seagrass	Sand and algae	Sand with small coral patches	Bedrock, dead coral and sparse corals	Mixed substratum, green algae and coral	Sand with large coral patches	Bedrock and mixed corals
				Octocorals				
"Deadman's fingers"	0.54	0.17	0.00	0.15	0.00	0.50	0.39	1.08
"Leathery"	0.76	0.17	1.00	0.22	0.75	0.50	0.46	1.03
"Pulsing"	0.22	0.00	3.00	0.31	0.00	0.10	0.07	0.30
"Tree"	0.29	0.00	0.25	0.09	0.25	0.10	0.10	0.60
Sea fan	0.15	0.00	0.00	0.00	0.00	0.00	0.02	0.35
Sea pen	0.01	0.00	0.00	0.04	0.00	0.00	0.00	0.02
Sea whip	0.09	0.00	0.25	0.04	0.25	0.25	0.02	0.12
Tubipora musica	0.02	0.17	0.00	0.00	0.00	0.00	0.02	0.03
Xenid	0.17	0.00	0.25	0.09	0.00	0.25	0.24	0.18
				Antipatharia				
Black coral	0.22	0.00	0.00	0.15	0.00	0.00	0.16	0.37

(E) Sedentary invertebrates

Taxa	Benthic class							
	All surveys combined	Sand with sparse algae and seagrass	Sand and algae	Sand with small coral patches	Bedrock, dead coral and sparse corals	Mixed substratum, green algae and coral	Sand with large coral patches	Bedrock and mixed corals
Anemone	0.11	0.00	0.25	0.04	0.25	0.00	0.02	0.19
Corallimorph	0.09	0.00	0.00	0.00	0.00	0.00	0.19	0.10
Disc formanifera	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Hydroid	0.49	0.00	0.00	0.22	0.25	0.00	0.07	1.43
Zoanthid	0.12	0.00	0.00	0.04	0.00	0.00	0.04	0.23

(F) Invertebrates

Taxa	Benthic class							
	All surveys combined	Sand with sparse algae and seagrass	Sand and algae	Sand with small coral patches	Bedrock, dead coral and sparse corals	Mixed substratum, green algae and coral	Sand with large coral patches	Bedrock and mixed corals
Asthenosoma	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Basketstars	0.04	0.00	0.75	0.04	0.00	0.25	0.02	0.02
Bivalves	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Blue seastar	0.31	0.00	0.75	0.71	0.00	1.00	0.75	0.09
Brittlestars	0.04	0.00	0.00	0.15	0.00	0.00	0.02	0.04
Brown seastar	0.04	0.00	0.25	0.04	0.00	0.00	0.04	0.04
Bryozoans	0.94	0.00	1.00	0.80	0.75	1.17	0.85	1.14
Choriaster granularis	0.05	0.00	0.00	0.00	0.25	0.00	0.07	0.06
Christmas tree worms	0.08	0.00	0.00	0.00	0.25	0.00	0.02	0.14
Clams	0.25	0.00	0.00	0.04	0.25	0.25	0.56	0.26
Conch	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Cone shell	0.05	0.00	0.00	0.09	0.00	0.00	0.07	0.05
Coralliophila violacea	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Cowrie	0.07	0.00	0.00	0.00	0.00	0.50	0.10	0.06
Crabs	0.06	0.00	0.00	0.09	0.00	0.00	0.10	0.05
Crown-of-thorns starfish	0.03	0.00	0.00	0.00	0.00	0.10	0.02	0.04
Culcita novoguinea	0.02	0.00	0.00	0.04	0.00	0.00	0.02	0.02
Diadema spp.	0.27	0.00	0.00	0.09	0.25	0.25	1.22	0.18
Drupella spp.	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Feather duster worms	0.08	0.00	0.25	0.09	0.25	0.00	0.04	0.09
Featherstars	0.78	0.00	0.25	0.43	0.75	0.25	1.08	0.96
Flatworms	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Gastropods	0.11	0.00	0.00	0.22	0.25	0.00	0.19	0.09
Jellyfish	0.02	0.00	0.75	0.15	0.00	0.00	0.00	0.00
Limpets	0.01	0.00	0.25	0.00	0.00	0.00	0.00	0.02
Murex shells	0.02	0.00	0.00	0.00	0.00	0.00	0.04	0.02
Nudibranchs	0.40	0.00	0.25	0.22	0.00	0.50	0.19	0.67
Octopus	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.01
Oysters	0.09	0.00	0.00	0.04	0.25	0.10	0.13	0.09
Pereclimenes shrimps	0.16	0.00	0.75	0.80	0.00	0.00	0.16	0.12
Sea cucumbers	0.08	0.00	0.00	0.00	0.00	0.50	0.16	0.05
Seastars	0.08	0.00	0.00	0.09	0.00	0.10	0.13	0.08
Segmented worms	0.01	0.00	0.00	0.09	0.00	0.00	0.00	0.01
Short spine urchins	0.28	0.00	0.00	0.00	0.75	0.10	0.39	0.40
Squid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Synapta maculata	0.66	0.00	1.00	0.15	0.75	0.90	1.02	0.55
Synaptid sea cucumbers	0.24	0.00	0.00	0.04	1.00	0.25	0.13	0.40
Topshell	0.04	0.00	0.00	0.00	0.00	0.00	0.07	0.04
Tunicates	1.09	0.00	0.25	0.60	1.25	1.00	1.08	1.30

(E) Coral life forms

Taxa	Benthic class							
	All surveys combined	Sand with sparse algae and seagrass	Sand and algae	Sand with small coral patches	Bedrock, dead coral and sparse corals	Mixed substratum, green algae and coral	Sand with large coral patches	Bedrock and mixed corals
				Acropora				
Branching	1.26	0.00	0.00	0.57	0.25	0.50	1.31	1.73
Digitate	0.38	0.00	0.00	0.15	0.25	0.25	0.28	0.70
Encrusting	0.13	0.00	0.00	0.04	0.25	0.00	0.07	0.21
Sub-massive	0.03	0.00	0.00	0.00	0.00	0.00	0.04	0.04
Tabulate	0.28	0.00	0.00	0.04	0.00	0.25	0.10	0.65
				Millepora				
Fire coral	0.12	0.00	1.00	0.04	0.00	0.25	0.00	0.19
				Non-*Acropora*				
Branching	1.21	0.00	0.00	0.71	0.75	0.90	1.71	1.40
Encrusting	1.18	0.00	1.25	0.69	1.00	0.90	1.13	1.48
Foliose	0.79	0.00	1.00	0.31	1.00	0.00	0.88	0.97
Massive	1.39	0.00	1.00	1.00	1.00	1.00	1.75	1.68
Mushroom	0.59	0.00	0.25	0.04	0.00	0.50	0.68	0.87
Sub-massive	0.98	0.00	0.25	0.22	1.00	0.25	1.56	1.10

(F) Target coral species / genera

Taxa	Benthic class							
	All surveys combined	Sand with sparse algae and seagrass	Sand and algae	Sand with small coral patches	Bedrock, dead coral and sparse corals	Mixed substratum, green algae and coral	Sand with large coral patches	Bedrock and mixed corals
"Upsidedown bowl"	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Bottlebrush *Acropora*	0.32	0.00	0.00	0.04	0.25	0.10	0.24	0.68
Brain "large"	0.03	0.00	0.00	0.00	0.00	0.00	0.02	0.05
Brain "medium"	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.14
Brain "small"	0.21	0.00	0.00	0.00	0.00	0.00	0.04	0.56
Ctenactis echinata	0.17	0.00	0.00	0.00	0.00	0.10	0.24	0.24
Diploastrea heliopora	0.63	0.00	0.00	0.09	1.00	0.50	0.54	0.95
Favia	0.51	0.00	0.00	0.57	0.25	0.75	0.28	1.52
Favites	0.82	0.00	0.00	0.43	1.00	0.50	0.73	1.00
Galaxea	0.55	0.00	0.00	0.09	0.75	0.25	0.16	1.01
Goniopora	0.05	0.00	0.25	0.15	0.00	0.00	0.13	0.02
Herpolitha limax	0.10	0.00	0.75	0.00	0.00	0.00	0.13	0.12
Lobophyllia	0.35	0.00	1.00	0.22	0.25	0.10	0.28	0.45
Millepora intricata	0.06	0.00	0.25	0.00	0.00	0.25	0.00	0.10
Millepora platyphyllia	0.03	0.00	0.00	0.00	0.00	0.10	0.00	0.05
Montipora digitata	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.04
Montipora foliosa	0.15	0.00	0.00	0.00	0.75	0.10	0.04	0.26
Mycedium elephantotus	0.13	0.00	0.00	0.00	0.25	0.00	0.04	0.26
Pachyseris rugosa	0.13	0.00	0.00	0.04	0.00	0.00	0.24	0.15
Pachyseris speciosa	0.18	0.00	0.25	0.09	0.25	0.00	0.24	0.21
Pavona cactus	0.01	0.00	0.00	0.00	0.00	0.00	0.04	0.00
Pavona clavus	0.02	0.00	0.25	0.00	0.00	0.00	0.04	0.01
Pectinia lactuca	0.04	0.00	0.00	0.00	0.00	0.00	0.10	0.04
Pleurogyra sinuosa	0.04	0.00	0.00	0.00	0.00	0.00	0.04	0.06
Pocillopora "large"	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.23
Pocillopora "medium"	0.19	0.00	0.00	0.04	0.25	0.00	0.04	0.42
Pocillopora "small"	0.29	0.00	0.00	0.09	0.75	0.10	0.16	0.53
Polyphyllia talpina	0.06	0.00	0.00	0.00	0.00	0.10	0.10	0.08
Porites "massive"	1.22	0.00	0.25	0.96	1.00	1.00	1.69	1.37
Porites cylindrica	0.19	0.00	0.00	0.04	0.00	0.25	1.63	0.08
Porites nigrescens	0.02	0.00	0.00	0.00	0.00	0.00	0.07	0.01
Porites rus	0.19	0.00	0.00	0.00	0.00	0.10	1.79	0.10
Seriatopora hystrix	0.21	0.00	0.00	0.15	0.00	0.00	0.24	0.30
Stylaster spp.	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Stylophora mordax	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Stylophora pistillata	0.14	0.00	0.00	0.22	0.00	0.00	0.13	0.18
Stylophora spp.	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.09
Symphyllia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Tubastrea micranthus	0.01	0.00	0.00	0.00	0.25	0.00	0.02	0.01
Turbinaria reniformis	0.11	0.00	0.00	0.04	0.00	0.10	0.46	0.05

(G) Fish familes / target species. Fish are ordered alphabetically by family (shown in parentheses).

Taxa	Benthic class							
	All surveys combined	Sand with sparse algae and seagrass	Sand and algae	Sand with small coral patches	Bedrock, dead coral and sparse corals	Mixed substratum, green algae and coral	Sand with large coral patches	Bedrock and mixed corals
Angelfish (Pomacanthidae)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Bicolour angelfish	0.41	0.00	0.00	0.31	0.25	0.25	0.33	0.63
Blue-girdled angelfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Emperor angelfish	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Pearlscale angelfish	1.09	0.00	0.00	0.09	1.00	1.50	0.87	1.68
Regal angelfish	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Barracuda (Sphyraenidae)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Blenny (Blennidae)	0.31	0.00	0.00	0.04	0.25	0.75	0.76	0.26
Yellowtail poison-fang blenny	0.08	0.00	0.75	0.04	0.00	0.00	0.10	0.09
Butterflyfish (Chaetodontidae)	0.27	0.00	0.00	0.15	0.25	0.50	0.28	0.32
Chevroned butterflyfish	0.06	0.00	0.00	0.00	0.00	0.10	0.02	0.10
Eastern triangle butterflyfish	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Humphead bannerfish	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Klein's butterflyfish	0.08	0.00	0.25	0.09	1.00	0.00	0.02	0.10
Latticed butterflyfish	0.02	0.00	0.00	0.04	0.00	0.00	0.00	0.04
Long-nosed butterflyfish	0.06	0.00	0.00	0.00	0.00	0.00	0.02	0.11
Pennant bannerfish	0.06	0.00	0.00	0.00	0.00	0.00	0.04	0.10
Pyramid butterflyfish	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Redfin butterflyfish	0.15	0.00	0.00	0.04	0.00	0.00	0.33	0.16
Saddled butterflyfish	0.11	0.00	0.00	0.00	0.75	0.10	0.10	0.15
Teardrop butterflyfish	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.10
Threadfin butterflyfish	0.15	0.00	0.25	0.31	0.25	0.25	0.13	0.12
Vagabond butterflyfish	0.47	0.00	0.00	0.43	0.00	0.25	0.24	0.84
Emperor (Lethrinidae)	0.08	0.00	0.00	0.04	0.00	0.10	0.00	0.15
Fusilier (Caesionidae)	0.11	0.00	0.00	0.00	0.25	0.00	0.10	0.16
"Blue and yellow" fusilier	0.03	0.00	0.00	0.00	0.25	0.00	0.00	0.04
Bluestreak fusilier	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Ruddy fusilier	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Cardinalfish (Apogonidae)	0.25	0.00	0.75	0.88	0.75	0.50	0.28	0.15
Catfish (Plotosidae)								
Striped catfish	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00
Cornetfish (Fistulariidae)	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Damselfish (Pomacenthidae)	2.63	1.00	1.75	2.00	1.75	2.17	2.20	3.31
Alexander's damselfish	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.02
Anemonefish spp.	0.09	0.00	0.00	0.09	0.00	0.00	0.07	0.12
Behn's damselfish	0.08	0.00	0.00	0.04	0.25	0.10	0.10	0.08
Black damselfish	0.09	0.00	0.00	0.00	0.25	0.10	0.16	0.09
Blackbar chromis	0.10	0.00	0.00	0.00	0.25	0.00	0.00	0.21

Blue devil damselfish	0.04	0.00	0.00	0.00	0.00	0.00	0.02	0.06
Chromis spp.	1.13	0.00	0.25	0.63	0.25	0.25	0.33	1.94
Golden damselfish	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Honeyhead damselfish	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.01
Humbug dascyllus	0.49	0.17	0.25	1.13	0.25	0.50	0.96	0.32
Jewel damselfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Reticulated dascyllus	0.19	0.00	0.00	0.09	0.00	0.00	0.00	0.48
Sergeant majors spp.	0.14	0.00	0.00	0.00	0.25	0.83	0.24	0.12
Staghorn damselfish	0.11	0.00	0.00	0.00	0.25	0.00	0.33	0.09
Threespot damselfish	0.10	0.00	0.00	0.09	0.00	0.00	0.00	0.19
Whitebelly damselfish	0.11	0.00	0.00	0.04	0.25	0.00	0.10	0.15
Dartfish (Microdesmidae)	0.05	0.00	0.00	0.00	0.25	0.00	0.00	0.10
Blackfin dartfish	0.02	0.00	0.00	0.00	0.25	0.00	0.00	0.04
Dottyback (Pseudochromidae)	0.02	0.00	0.00	0.00	0.25	0.00	0.02	0.03
Lined dottyback	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Filefish (Monacanthidae)	0.04	0.00	0.00	0.04	0.00	0.10	0.00	0.06
Goatfish (Mullidae)	0.63	0.00	0.75	0.58	0.75	1.00	0.46	0.70
Dash and dot goatfish	0.18	0.00	0.25	0.22	0.25	0.50	0.16	0.16
Half and half goatfish	0.13	0.00	0.75	0.22	0.25	0.10	0.16	0.09
Multibarred goatfish	0.26	0.00	0.00	0.09	0.25	1.00	0.10	0.40
Two-barred goatfish	0.03	0.00	0.00	0.00	0.25	0.00	0.02	0.04
Yellowfin goatfish	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Goby (Gobiidae)	0.27	1.00	0.75	1.67	0.00	0.25	0.28	0.15
Grouper (Serranidae)								
"Honeycomb" spp.	0.13	0.17	0.25	0.00	0.25	0.00	0.13	0.16
Anthias spp.	0.02	0.00	0.00	0.04	0.00	0.00	0.02	0.02
Flagtail grouper	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Grouper spp.	0.25	0.17	0.75	0.09	0.25	0.00	0.16	0.37
Lyretail grouper	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Peacock grouper	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Soapfish spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Hawkfish (Cirrhitidae)	0.14	0.00	0.00	0.09	0.25	0.25	0.04	0.21
Threadfin hawkfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Jack and trevally (Carangidae)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Lizardfish (Synodontidae)	0.04	0.00	0.00	0.04	0.00	0.00	0.10	0.04
Moorish idol (Zanclidae)	0.04	0.00	0.00	0.00	0.25	0.00	0.04	0.04
Moray eel (Muraenidae)	0.05	0.00	0.00	0.22	0.00	0.10	0.02	0.04
Needlefish (Belonidae)								
Reef needlefish	0.02	0.00	0.00	0.04	0.00	0.00	0.02	0.02
Parrotfish (Scaridae)	0.32	0.00	0.00	0.00	0.25	0.50	0.16	0.70
Bumphead parrotfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Pipefish (Syngnathidae)	0.03	0.00	0.00	0.00	0.00	0.00	0.04	0.04
Porcupinefish (Diodontidae)	0.09	0.17	0.00	0.09	0.00	0.10	0.07	0.10
Sandperch (Pinguipedidae)	0.18	0.17	0.25	0.31	0.00	0.25	0.33	0.12
Scorpionfish (Scorpaenidae)								
Lionfish spp.	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.01
Stonefish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Sharksucker (Echeneidae)	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.01
Snapper (Lutjanidae)	0.14	0.00	0.25	0.04	0.75	0.10	0.00	0.24
Black and white	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.05

snapper								
Bluelined snapper	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Onespot snapper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Two-spot snapper	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Rabbitfish (Siganidae)	0.06	0.00	0.00	0.00	0.25	0.10	0.10	0.06
Pencil streak rabbitfish	0.02	0.00	0.00	0.00	0.00	0.10	0.02	0.03
Uspi rabbitfish	0.01	0.00	0.00	0.00	0.25	0.00	0.00	0.01
Spinecheek (Nemipteridae)	0.46	0.17	0.75	0.00	0.75	0.50	0.61	0.60
Twoline spinecheek	0.44	0.00	0.00	0.00	0.75	0.50	0.62	0.65
Squirrelfish (Holocentridae)								
Bigeye squirrelfish	0.20	0.00	0.00	0.00	0.75	0.10	0.10	0.37
Surgeonfish (Acanthuridae)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Brushtail tang	0.32	0.00	0.00	0.00	0.25	0.25	0.16	0.75
Convict surgeonfish	0.21	0.00	0.00	0.00	0.25	0.75	0.16	0.30
Dusky surgeonfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Mimic surgeonfish	0.04	0.00	0.00	0.00	0.00	0.25	0.00	0.05
Orangespine unicornfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Ringtail surgeonfish	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Striped surgeonfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Thompson's surgeonfish	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.02
Unicornfish spp.	0.08	0.00	0.00	0.00	0.00	0.00	0.02	0.16
Sweetlips (Haemulidae)	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Spade/batfish (Ephippidae)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triggerfish (Balistidae)	0.27	0.00	0.00	0.31	0.25	0.25	0.07	0.45
Clown triggerfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Halfmoon triggerfish	0.09	0.00	0.00	0.04	0.00	0.10	0.04	0.15
Moustache / titan triggerfish	0.03	0.00	0.25	0.00	0.00	0.10	0.02	0.04
Orangestriped triggerfish	0.08	0.00	0.00	0.00	0.25	0.00	0.00	0.16
Picasso fish	0.03	0.00	0.00	0.15	0.00	0.10	0.00	0.02
Pinktail triggerfish	0.05	0.00	0.00	0.09	0.25	0.10	0.02	0.05
Redtooth triggerfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Scythe triggerfish	0.03	0.00	0.00	0.00	0.00	0.10	0.00	0.04
Trumpetfish (Aulostomidae)	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.02
Trunkfish (Ostraciidae)	0.02	0.00	0.00	0.04	0.00	0.10	0.00	0.03
Tuna / mackerel (Scombridae)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Narrow-banded king mackerel	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Wrasse (Labridae)	1.69	0.50	1.00	0.58	1.25	1.90	1.25	2.00
Bird wrasse	0.11	0.00	0.00	0.04	0.00	0.10	0.07	0.16
Blackedge thicklip wrasse	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Checkerboard wrasse	0.09	0.00	0.00	0.09	0.25	0.00	0.04	0.12
Cigar wrasse	0.01	0.00	0.00	0.04	0.00	0.00	0.02	0.00
Cleaner wrasse	0.44	0.00	0.00	0.43	0.75	1.00	0.24	0.60
Crescent wrasse	0.09	0.00	0.00	0.00	0.25	0.10	0.07	0.12
Dianas hogfish	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Jansen's wrasse	0.06	0.00	0.00	0.00	0.25	0.10	0.00	0.10
Mesothorax hogfish	0.09	0.00	0.00	0.00	0.00	0.00	0.07	0.15
Redbanded wrasse	0.12	0.00	0.00	0.04	0.00	0.25	0.04	0.19
Six bar wrasse	0.35	0.00	0.00	0.09	0.25	0.90	0.28	0.48
Two tone wrasse	0.08	0.00	0.00	0.00	0.75	0.00	0.07	0.11