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**PRIORITIES AND STRATEGIES FOR ADDRESSING THE  
APPLICATION OF ECOLOGICAL THEORY TO REEF  
MANAGEMENT IN THE MAMANUCAS, FIJI**

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## **1. GLOSSARY OF ABBREVIATIONS**

|        |                                                                  |
|--------|------------------------------------------------------------------|
| ANOVA  | Analysis of Variance                                             |
| CCC    | Coral Cay Conservation                                           |
| CC     | Conservation Class                                               |
| COT    | Crown-of-Thorns starfish                                         |
| GBR    | Great Barrier Reef                                               |
| IT     | Information Technology                                           |
| IDH    | Intermediate Disturbance Hypothesis                              |
| MCRCP  | Mamanuca Coral Reef Conservation Project                         |
| MDS    | Multi-Dimensional Scaling ordination plot                        |
| MFHA   | Mamanuca Fiji Hoteliers Association                              |
| MPA    | Marine Protected Area                                            |
| PA     | Protected Area                                                   |
| PRIMER | Plymouth Routines in Multivariate Ecological Research            |
| SIMPER | Similarity Percentage Routine (species contributions assessment) |
| USP    | University of the South Pacific                                  |
| WWF    | World Wildlife Fund                                              |

## **2. ABSTRACT**

Coral reef management in the Mamanuca region of Fiji is practised within a paradigm of ecological thought that is largely determined by studies carried out in the Caribbean and Great Barrier Reef. This research aims to critically analyse the application of ecological principles to management in the Mamanucas. Dominant ecological theories within the coral reef literature are applied to data from 22 sites to in the study region. Perceptions among members of the scientific community with a working knowledge of the Mamanucas on the relevance of these theories are reviewed. Management priorities and strategies are identified by comparison of primary data analysis results and questionnaire responses.

**Keywords:** Conservation, management, scientific community, ecological theory, Mamanuca region



### **3.INTRODUCTION**

Coral reefs are the foundation and means of maintenance of many island communities. They protect coastal areas from oceanic waves and provide subsistence for coastal communities throughout the tropics. Tourism in reef areas represents a major source of economic development for host countries, such that fishing and tourism revenue from the Great Barrier Reef was valued at US\$912 million (Drimsl, 1998). In terms of biological diversity, coral reef ecosystems are the rainforests of the marine realm (Connell, 1978). Hotspots of global biodiversity, coral reefs are interesting habitats to study; of the 33 phyla that exist in marine habitats, 30 are found in coral reefs (Crosby, 2000). They have the highest diversity per unit area of any marine ecosystem and sustain fish yields of around 15 tonnes per km<sup>2</sup> (Talbot, 1995).

The health of the world's reefs is deteriorating as they are under increasing pressure from human interaction and natural stressors. The level of anthropogenic influence over reefs is widespread. A global survey of over 300 reefs in 31 countries indicated that few remain unaffected by man, even in very remote sites (Hodgson, 2000). Hard coral cover is significantly higher on reefs under no anthropogenic impact than those with high levels of such impacts. Mean hard coral cover globally was found to be 32%, with no reefs exceeding 85% cover (Hodgson and Liebeler, 2002).

The discipline of reef science has grown substantially across the last decade, in line with an increasing awareness of the important ecological status and services provided by reefs. International conferences have brought coral reefs to the forefront of the international environmental agenda. Management recommendations have stemmed principally from proceedings of The International Coral Reef Symposiums, held every three years. The Convention on Biological Diversity (1992) defined sustainable use of biological resources as:

“Use of components of biological diversity in a way and at a rate that does not lead to the long term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of future generations”. UNEP, 2001

To achieve the sustainable use of marine resources, particularly relating to coral reefs, policy and management decisions must be based on improved understanding of the

relationships between widely accepted natural resource management goals and those environmental factors influencing the achievement of these goals (Crosby, 1995).

Managers of reef resources face the challenge of balancing conservation and development objectives in the context of the inherent uncertainty of natural systems and the political and social pressure of human systems. Working together, scientists, managers and policy makers can make decisions with an increasingly comprehensive understanding of reef systems. A number of scientific principles commonly underpin approaches to reef conservation.

The aim of this project, namely to investigate the applicability of dominant theories in coral reef literature to the Mamanuca reefs and examine related perceptions among the scientific and management community, covers a number of different subject areas. At the time of writing, no existing bodies of literature relating these precise strands of research were found. Nevertheless, a number of writers tackle the different components of the project and this review aims to bring together various lines of investigation adopted by these authors to build an overall picture relevant to the main aims of this project.

### **3.2 CONSERVATION PRINCIPLES FOR MANAGEMENT**

One manifestation of the poor management of natural resources is the loss of biodiversity (Norse, 1993). Diversity measured as an individual attribute has a neutral value; but because high diversity usually has more interest to biologists than low diversity, the actual value measured can be used as a measure of quality in this respect (Ratcliffe, 1977). Diversity levels have consequently become analogous with conservation value and are common features of ecological evaluation (Magurran, 1983). Margules and Usher (1981) illustrated this point when they examined nine published schemes for the assessment of conservation potential. In each case they listed the criteria used to judge the suitability of a habitat for conservation and diversity emerged as the most widely used criterion.

Three key concepts provide guidelines for effective conservation strategies: irreplaceability, complementarity and rarity. Irreplaceability is an index of the potential contribution that a site will make to a defined conservation goal and the extent to which the options for conservation are lost if the site is lost (Pressey, 1993).

Managers frequently use the principle as a measure of the conservation value of reef sites across the Indo-Pacific (Zann & Lovell, 1992).

Complementarity assesses the content of candidate conservation areas and proceeds in a stepwise fashion, selecting at each step the site that is most complementary to the others in the features it contains (Begon *et al.*, 1996). The similarity in benthic composition of a number of reef systems is measured quantitatively using the Bray-Curtis similarity coefficient (Bray and Curtis, 1957). Faith *et al.* (1987) provide evidence that the Bray-Curtis similarity coefficient is a particularly robust measure of ecological distance when applied to coral reefs. Coral Cay have used this measurement of community semblance in Honduras, the Philippines and Fiji, in order to produce a habitat label for individual reefs and evaluate the diversity of particular classes (Mumby & Harborne, 1999; Harborne *et al.* 2001).

There are many different forms of rarity (Gaston, 1994). A species may be represented by very few individuals within any given community but be geographically widespread. Alternatively, a species may have a very restricted geographic range, throughout which it is abundant.

MacArthur and Wilson (1967) pioneered the species-area relationship when noting that more species exist on larger islands than small ones. Salm (1984) developed an objective procedure that applied species-area concept to corals. He based reef diversity assessment on the area they covered. This concept can be applied to any region suitable for a species surrounded by an area inhospitable to them, for example a barrier reef surrounded by deeper water where light is unable to penetrate.

To apply these principles to reef systems, the main parameters that need to be known include an indication of diversity, a measure of community composition and the similarity between communities of candidate conservation sites, and a measure of species richness in relation to the area surveyed.

### *Diversity indicators*

Species lists provide a quick and useful technique for measuring diversity at the community level, yet they overlook the fact that some species are rare and others common (Magurran, 1988). Indices that take into account abundance patterns and species adopt a more holistic approach. One such index is the Shannon-Weiner index, which accounts for both species proportionality and equitability. This is commonly employed to measure reef diversity globally (Riegl & Riegl, 1995; Hawkins *et al*, 1999; Walker *et al*, 2002). In addition, the Simpson's index determines for each species the proportion of individuals that it contributes to the total in the sample. Equitability, a measure of the evenness with which individuals are distributed among the species, expresses Simpson's index as a proportion of its maximum possible value if individuals were completely evenly distributed amongst the species (Paine, 1966).

### *Relationships between reef parameters*

In combination with traditional diversity indices, reef parameters frequently used to indicate health are percentage live coral cover and substratum complexity. The strength of linkages between diversity and habitat characteristics is important as they represent a useful management tool that enables the rapid assessment of reefs, with little requirement for scientific principles such as taxonomic classification (Zann, 1992).

Studies into the influence of live coral cover on community diversity have met with mixed outcomes. Bell & Galzin (1984) found a significant positive correlation between amount of live coral cover and fish diversity and abundance, while others found no correlation (Luckhurst & Luckhurst, 1978).

There has also been little consistency between studies examining relationships between substratum variables and the species richness or abundance of reef fish communities (Allan, 1975; Luckhurst & Luckhurst, 1978; Bell & Galzin, 1984; Roberts & Ormond, 1987). While positive correlations were found between substratum structural complexity and fish diversity for site attached species with relatively limited ranges of movement (Luckhurst & Luckhurst, 1978), past studies

suggest there is no significant correlation between overall fish abundance and substratum complexity (Risk, 1972).

### *Diversity modelling*

Diversity models provide a less direct approach to the measurement of diversity. Two models that have been applied to coral reefs with contrasting findings are the intermediate disturbance hypothesis and the use of coral morphology classification as an indicator of reef conservation value (Edinger & Risk, 2000).

According to the intermediate disturbance hypothesis (IDH), species diversity should be low at both low and high frequencies and intensities of disturbance, and maximal at intermediate levels of disturbance (Eggeling, 1947; Connell, 1978; Aronson & Precht, 1995). Disturbance can be defined as an event that damages or kills resident corals on a given site (Connell, 1997). Dominant competitors are thought to eliminate or severely limit most of the other species at low levels of disturbance, whereas at high levels of disturbance, only the most resistant species are able to survive. At intermediate levels of disturbance a balance is struck between the competitive exclusion of non-dominant species and the destruction of non-stress tolerant species by disturbance (Aronson & Precht, 1995). The result is a successional mosaic that supporting a higher diversity in the middle than at either extreme of the disturbance continuum, see figure 1.

Jackson (1991) found that the IDH did not hold for reef corals at a small scale. He concluded that reef dynamics are unpredictable at the quadrat scale, as coral colonies routinely covered several square meters of substratum, exceeding the scale of observation. At the landscape scale, reef spurs in Belize were found to have maximal coral diversity, in terms of increased evenness rather than species richness, at intermediate disturbance levels (Aronson & Precht, 1995). This landscape-scale analysis provided the first rigorous, quantitative support for the hypothesis in a reef coral assemblage.

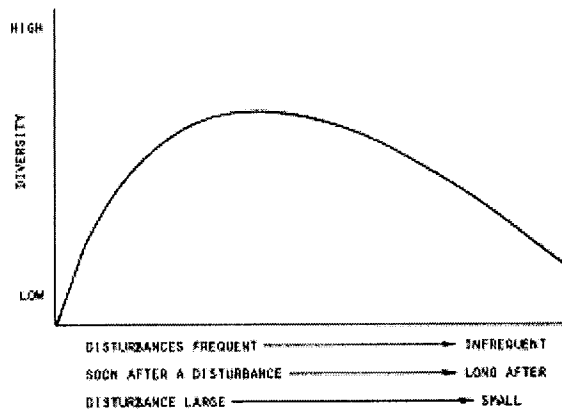


Figure 1. Patterns of diversity in accordance with the “intermediate disturbance hypothesis” proposed by Eggeling, (1947). Source: Connell, 1978.

In the past, reefs have tended to be evaluated in terms of health exclusively on live coral cover. Reefs with >75% live coral cover are considered to be in *excellent* condition, 50-75% live coral coverage is considered *good* condition, 25-50% live coral cover is *fair* condition; and reefs with <25% live coral cover are in *poor* condition (Gomez and Yap, 1988). However, sites with a high percentage of live coral cover are frequently composed of mono-specific communities, such that their biodiversity is low (Connell, 1978; Aronson & Precht, 1995, Edinger & Risk, 2000). In addition, the roles of disturbance, competition and stress in regulating coral species diversity are ignored (Huston, 1994).

Grime (1977) first outlined the three extreme types of life strategy in conjunction with habitat types for plant communities as; low stress with low disturbance (competitors), high stress with low disturbance (stress-tolerators) and low stress with high disturbance (ruderals). Competition was defined as “the tendency of neighbours to use the same quantum of light, the same ion of mineral nutrient, molecule of water or volume of space” and stresses were defined as “external constraints limiting the rate of production” (Grime, 1977). Different coral communities can be characterised by the relative importance of ruderals, competitors and stress-tolerators by displaying graphically using an r-K-S ternary diagram, see figure 8. Edinger and Risk (2000) categorised coral reef communities in this way and found conservation class to be a more reliable predictor of coral species richness and habitat complexity than live coral cover or coral mortality index (Edinger & Risk, 2000). This highlighted the

importance of coral morphology triangles as a management tool independent of coral taxonomic knowledge.

### *Scale*

Reef systems can be examined across a broad range of temporal and spatial scales (Hatcher, 1977). Coral reefs have received particular attention from ecologists working at the ecosystem level because of the apparent distinctness, in terms of isolation or enclosure, of their boundaries (Levin, 1992). Strong arguments exist for the study of reefs at a number of different scales. Differing opinion over the applicability of the intermediate disturbance hypothesis is thought to be a result of the different scale of studies. While Jackson (1991) found that the hypothesis did not hold at the quadrat scale, evidence in support of the theory was found at the landscape scale (Aronson & Precht, 1995).

Harper (1977) stresses the importance of taking an organism's eye-view of community and structural diversity. For instance, a quadrat that may appear species rich and structurally heterogeneous to the ecologist observing it may be perceived as homogenous by the plant or insect living within it. Conversely, an unvarying strip of reef may offer marine grazers considerably more variety than is at first apparent (Magurran, 1988).

One particular feature of the marine environment influential in determining population size and diversity is currents. As currents ensure larval dispersal over vast areas, both their strength and direction have implications for community distribution. As local extinctions are common events, particularly regarding immobile species on widely distributed reefs, recolonisation of habitat fragments is critical for the survival of divided populations (Newman, 1993). Particular attention should be paid to relationships amongst the landscape elements, including dispersal corridors of populations in question (Begon, *et al.*, 1996). As Gray (1997) states, a mosaic of marine habitats must be protected if complete protection of biodiversity is to be achieved. It has been argued however, that current understanding of the transfer of genetic materials by water currents does not provide a robust ecological basis for determining the minimum area necessary for reef conservation (Craik *et al.* 1990).

Done's 3-step decision making process (1995) for the assessment of proposed development sites provides a practical means for scientific and management communities to work together. Candidate development areas are valued depending upon uniqueness, or their worth in terms of bioconstruction (a measure longevity and size). An ecological risk assessment of the proposed site is then carried out, followed by a recovery time assessment. Decisions to permit activity are conditional upon establishing that recovery time is short enough. In Fiji, this strategy may be particularly applicable as a variety of different disturbance regimes exist, due to the occurrence of localised storms. The idea of equating age with value could potentially be applied across the age spectrum.

Volunteer collected data has also been used to a limited extent for management in the Mamanucas. Data is transferred to standard spreadsheets, which are then compiled and analysed by trained scientists. Statistical analyses are performed on relative areas of environmental health. These provide the basis for recommendations for protected areas within project locations. Results are compiled into technical reports and disseminated to all stakeholders within the project area. One such management recommendation is demonstrated by Coral Cay's Castaway Island Progress Report:

"If one part of the coastal environment of Castaway Island is to be designated as a marine reserve with restrictions on resource extraction then of the four sectors surveyed and reported here, it should be within the western sector. This area has all the prerequisites for a potential reserve; high cover of hard substrata (both living and dead), an even mix of defined habitats plus the greatest abundance of many coral lifeforms and fish families" (Walker *et al.*, 2002)

An alternative means of integrating scientific data into the management decision-making process is through the production of habitat maps from data collected by volunteers, see figure 2. Ordinal data collected by CCC volunteers has been used to classify reef habitats, describe species distributions and provide semi-quantitative analyses of biological communities, which have been used in management (Mumby *et al.* 1995).

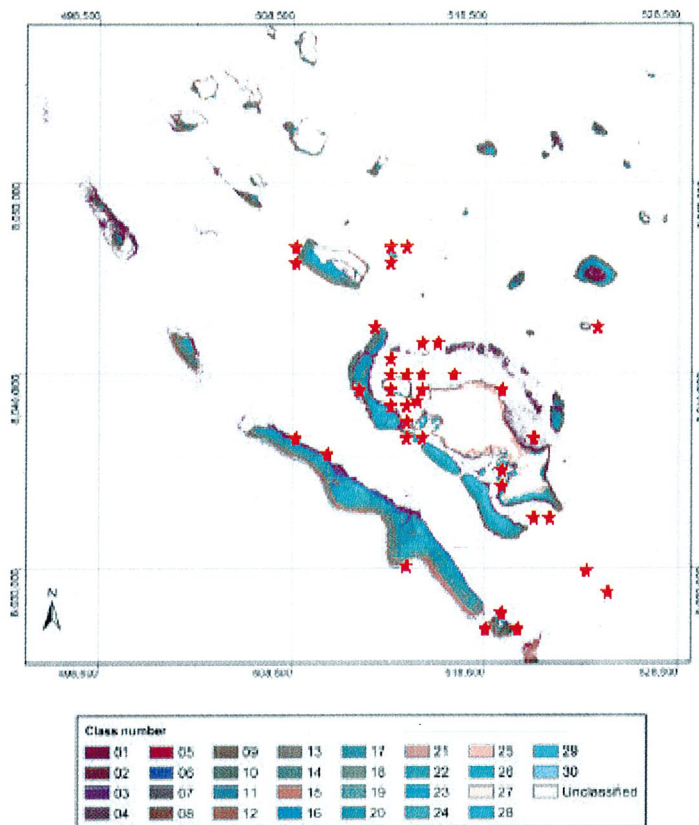


Figure 2. An unsupervised computer classification of Mamanuca habitat types into 30 classes based on spectral signatures & baseline data. Stars depict the location of baseline CCC transects. Source: MCRCP Fiji 2001 Pilot Project Final Report. Major habitat types include bedrock & mixed corals (light blue), sand with small coral patches (purple) and sand & algae (light brown).

One of the essential recommendations put forward by Ludwig *et al* (1993) for future marine resource management principles was to include human motivation and responses as part of the system to be studied and managed. A pioneering effort to include scientists in the management of the Red Sea Marine Peace Park has been made through their Research and Monitoring programme, Figure 3. The primary objective of the management team was to integrate data and analysis of the scientific community into their management decision making process. This was done through the delivery of relevant data to the management team via the joint discussion of trends and issues (Crosby *et al*. 2000)

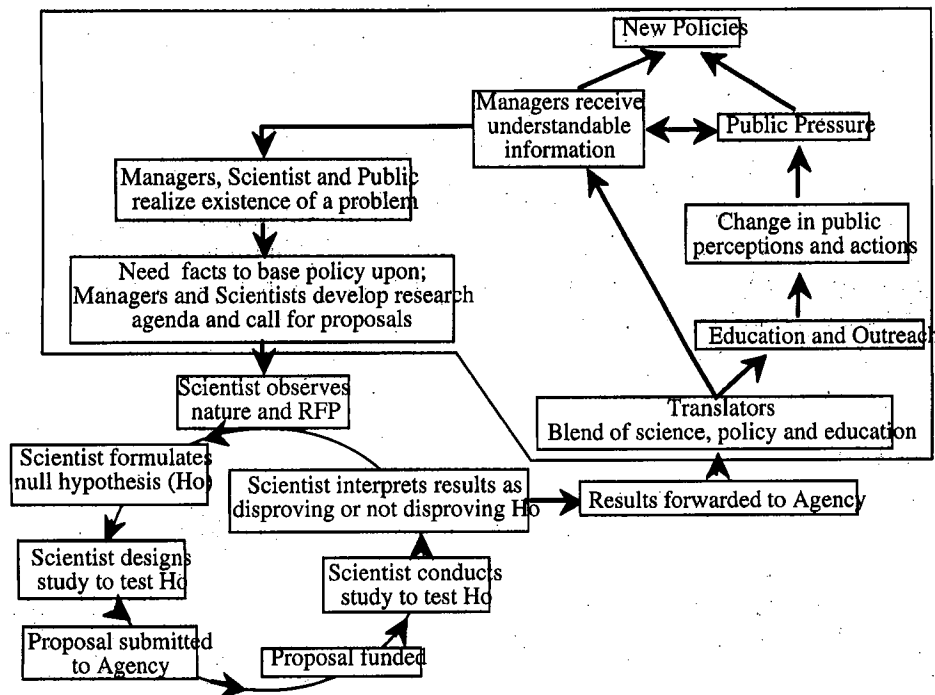


Figure 3. Paradigm for the interaction and role of integrated, multi-disciplinary science, management and education/ outreach efforts (Crosby, 2000).

Risk (1999) estimated that the realization of the problem stage occurred for most reefs in the late 1970s. The process of scientific study depicted by the bottom left circle of Crosby's paradigm is carried in a non-standardised way (Zann, 1992). Often results fail to reach the relevant management agency at all (Adams & Ledua, 1997), thus the link between the circle and main diagram body becomes tenuous and where received, information is not necessarily understandable to managers (Wolanski, 2002). To achieve sustainable management, the paradigm must shift from a fragmented to an integrated approach, from a site-specific to an ecosystem wide context, and from a reactive to a proactive mode (Risk, 1999). While Crosby's paradigm provides a blueprint for this, putting it into practice outside of the Red Sea may prove difficult.

### 3.3 THE MAMANUCA REEFS

This research focuses on the Mamanuca region of Fiji, an area of high coral diversity that provides a good basis for exploring these themes. The Mamanuca comprises a series of islands off the western coast of Fiji, near to the major city of Nadi, see figure 3. Fiji's moderate tropical climate has enabled reefs to become well developed around

all of the Mamanuca Islands, which consequently have been the focus of tourist development since the 1960s (Haycock *et al*, 2002). Although the coral reefs are of vital importance, both economically and ecologically, they are threatened because of rapid population growth. The Mamanuca coral reef systems are being threatened by a range of anthropogenic activities including overfishing, destructive fishing, sedimentation, eutrophication and pollution (table1).

Fiji currently holds 3-4% of the world's coral reefs, placing it in the top 10 of the 80 countries and geographical locations with reefs (Spalding *et al.*, 2001). There is a diverse range of reef types and sizes across the Mamanucas, from patch reefs, which are mostly less than 50m long, to the 370km long broken barrier reef chain of the Mamanucas/ Yasawas/ Great Sea Reef system (Vuki *et.al*, 2000).

Many authors find it difficult to describe Fiji's coral reefs because of the scattered and limited scientific data available and the shortage of technical in-country expertise in marine biodiversity. However, scientists have recognised Fiji's coral reefs as being of high ecological significance from a biodiversity standpoint (Zann, 1992).

The number of coral species in Fiji is low in comparison to elsewhere (e.g. the Great Barrier Reef), reflecting the general trend of lowered diversity eastward across the Pacific and Fiji's geographic isolation (Vuki *et.al*. 2000). MacArthur and Wilson's theory of island biogeography, whereby a balance between immigration and extinction onto an island determines the number of species present suggests that either immigration is low or emigration is high in the region. Fijian reefs are isolated on two accounts. They are habitats surrounded by deep water where light cannot penetrate and they are also isolated islands 1875miles from the nearest continent. Consequently, the immigration rate of species is low relative to other, less isolated reefs, such as the Great Barrier Reef and those in the Caribbean. Although the actual number of species is low, the large number of new species in Fiji is indicative of the poor state of knowledge of the region rather than a high degree of endemism in the group (Hodgson, 2000).

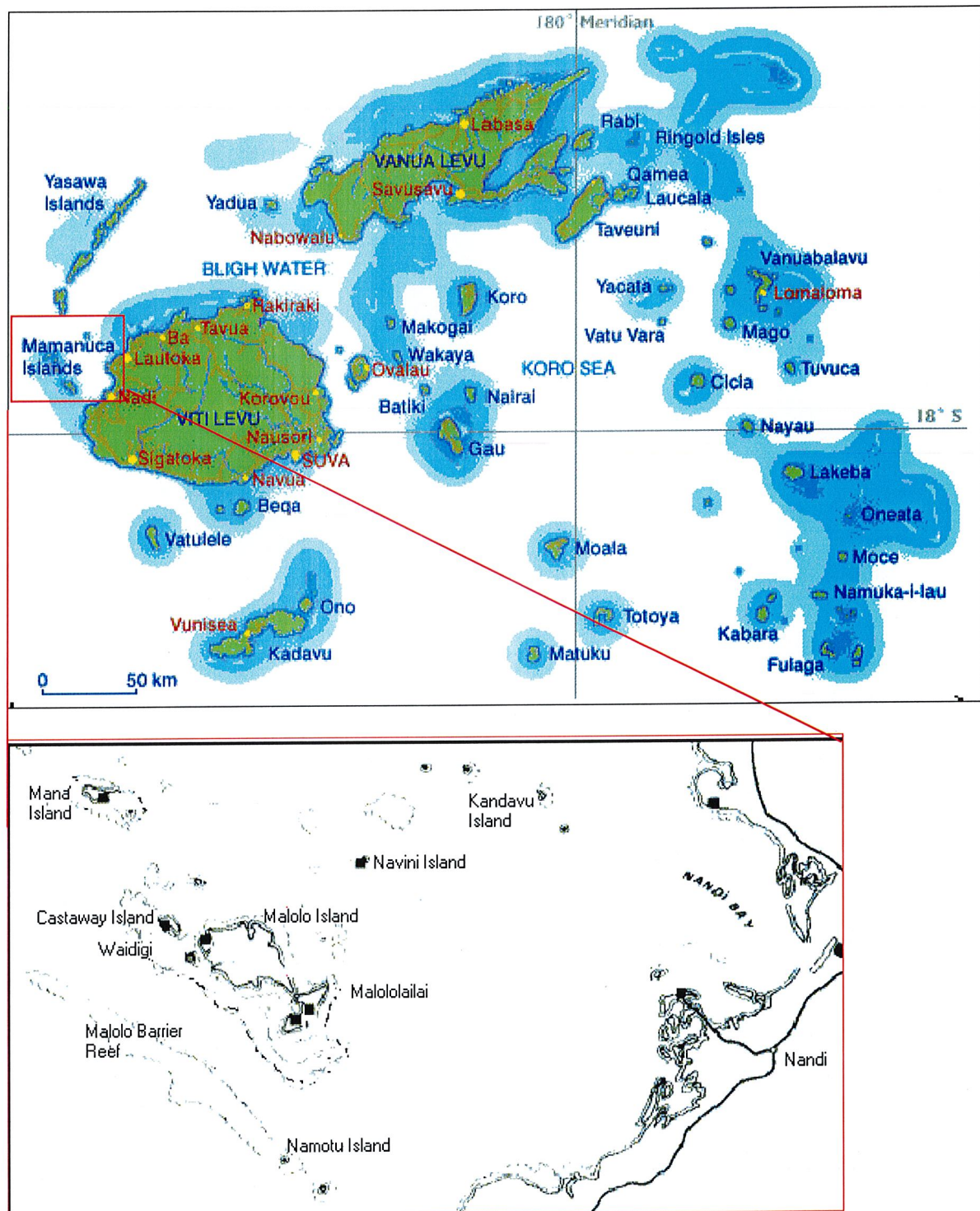


Figure 4. (a) The Fiji Islands showing the project area (dashed line) for the study, source: Fiji Visitors Bureau (b) Major Islands within the Mamanuca region, Source: Adapted from Coral Cay conservation

*Stresses to reef ecosystems within the study region*

| Influence                     | Description                                                                                                                                                                                 | Reference                           |
|-------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|
| Overfishing                   | Abnormally low abundances of high demand species such as groupers & emperors in the region.                                                                                                 | Jennings and Polunin (1996)         |
| Tourism                       | Fijian population 775,000<br>Tourist population 280,000 visitors pa                                                                                                                         | Clarke & Morrison (1987)            |
| Coral harvesting              | Coral specimen export permitted under license, impacts localized & regulated.<br>Limit on reef growth, erosion, threat to reef processes, coral extinction                                  | Zann (1992),<br>Lovell (2001)       |
| Invertebrate overharvesting   | Low populations of <i>Tridacna</i> clams & sea cucumbers close to urban areas                                                                                                               | Vuki <i>et.al</i> (2000)            |
| Agriculture                   | Erosion levels:<br>77t/ha/yr from sugar cane<br>71t/ha/yr from pineapple plots<br>4877t/ha/yr from pine seedlings. Vastly increased sediment loads in Fiji's marine environment as a result | Morrison (1990)<br>& Convard (1993) |
| Urban & industrial pollution  | Point sources identified: mining, shipyards, moorings, tourist developments, sugar & timber mills, cement factories, litter refuse disposal sites, pesticides & herbicides, sewage          | Cripps (1992)                       |
| Diving                        | Shift in dominance patterns, not overall coral cover                                                                                                                                        | Hawkins <i>et.al.</i> (1999)        |
| Habitat loss                  | Hundreds of hectares of reef reclaimed in urban areas for ports, sea walls & building sites                                                                                                 | Watling (1992)                      |
| Eutrophication                | Reefs within 100-500m of tourist resorts and villages were seagrass and algal dominated, equivalent reefs away from human habitation were coral dominated                                   | Zann & Lovell (1992)                |
| Destructive fishing practices | Dynamiting, use of poisons, domestic pesticides & bleach                                                                                                                                    | Zann (1992)                         |

Table 1. A summary of past studies into issues and threats in the Mamanuca marine environment

Population growth and tourism are increasing throughout the study region. Heavy souvenir collection has recently emerged as a serious problem across Fiji. Table 1 lists the evidence of past and present anthropogenic stresses on the coral reef systems of the Mamanucas.

The anthropogenic threats to reef health have been compounded by natural and semi-natural factors such as storm damage, coral bleaching events (Zann, 1992; Haycock *et al.* 2002), and outbreaks of the invasive reef eating crown-of-thorns starfish *Acanthaster planci* (Chesher, 1969; Harborne *et al.* 2001). Although these have a large and far-reaching influence on Fijian reefs, it is the purely human-induced impacts that are the focus of this study. Due to the close proximity of study sites (figure 6) water temperature rises as a result of climate change and large scale storm damage remained constant throughout all sites.

#### *Conservation measures present*

Although the recent National Environmental Management Plan (NEMP) has prioritised resource use control and the protection of coral reefs (Zann, 1992), coastal zone management in the Mamanuca islands is relatively nascent (Harborne *et al.*, 2001). In response to the NEMP, Fiji's draft Biodiversity Strategy Action Plan (1999) stated the need for a comprehensive system of marine protected areas. Two of the oldest private sanctuaries in Fiji, established by "Beachcomber Cruises" in 1970 are in the Mamanucas, around Tai (Beachcomber) and Lavuka (Treasure) Islands (Vuki *et al.*, 2000).

The Ulunikoro Marine Conservation Area was set up by the World Wildlife Fund (WWF) on the island of Ono on a fringing patch reef recognised as Fiji's premier reef complex. The customary right to fish in the 20 hectare conservation area belongs to 7 villages in the region. In order to establish the reserve, close collaboration with these stakeholders was needed and WWF have been working with the Ono communities since 1998 raising awareness about the health of their reef (Tabunakawai, 2002). This represents one of the biggest conservation measures adopted in Fiji. As it was set up so recently, there is little data to measure its effect on biodiversity levels.

Customary fishing rights present a barrier to, and tool for, the protection of local fish stocks among Fijian islands. The lack of support for the installation of protected areas stems largely from the reluctance of traditional land and sea owning groups to lose their traditional rights and uses. The reluctance of central governments to interfere in matters of customary law (Zann, 1994) combined with the complex nature of communal land and sea tenure systems can make negotiations for protected areas difficult. In spite of this, Crosby (2002) found that the strict enforcement of customary fishing rights by villagers is often effective in controlling exploitation of marine resources by outsiders. Most resorts in the Mamanucas have private arrangements with customary fishing right holders for the “lease” of waters adjacent to their resort (Vuki *et al*, 2000).

Hodgson (2000) found no significant difference when comparing the composite diversity index of Fijian sites located inside marine protected areas and non-protected sites. Either management is not effective, or insufficient time had elapsed for management to increase populations of indicator organisms. Emerging best practice for managing marine protected areas in Fiji has promoted the delegation of management responsibilities across a wide range of parties, including NGOs, user groups and local communities (Mascia *et al*, 2000). Conservation initiatives arising from communities themselves have been more successful than attempts to implement externally produced formal plans and an increasing emphasis on community led management will lead to the employment of more effective conservation measures (Adams, 2000).

All stony corals present in the Mamanucas are listed in Appendix II of CITES due to their importance in reef ecological processes, yet this does not prevent their trade. All coral products exported from Fiji require accompanied CITES documentation (Lovell, 2001). This enables monitoring of trade through the permit system. The listing was a response to the wholesale removal of coral from reefs in the Philippines and is primarily for the purpose of maintaining the habitat role that reef ecosystems play in the fisheries industry (Lovell, 2001).

The removal of unwanted species has been practised by the Crown of Thorns Starfish Monitoring Group. Large scale physical removal has been the primary control

mechanism for of past outbreaks of coral eating Crown-of Thorns starfish, *Acanthaster planci*, (Chesher, 1969; Endean, 1969; Harborne *et.al*, 2001).

Community rehabilitation or replacement has been practised to a limited extent within Fiji's coral harvesting trade to ensure sustainable supplies (Lovell, 2001).

Replacement is often necessary to maintain aesthetic value at sites used for recreational purposes (Bradshaw, 1984). This has been carried out at Sunflower Patch, a popular tourist dive site in the Mamanucas (Walker, 2002).

In the context of conserving reef diversity, habitat maps provide an inventory of habitat types and their statistics (Luczkovich *et al*, 1993), the location of environmentally sensitive areas (Bina, 1992), allow representative networks of habitats to be identified and detect hotspots of diversity (Loubersac *et al*, 1987). The production and use of habitat maps for conservation purposes has been used widely at both the global (Bryant *et al.*, 1998) and regional level (Harborne *et al*, 2001). Habitat maps are generally created by combining satellite imagery and field data in a cost effective manner (Green, 2000). An unsupervised classification of a Landsat 7 image taken in May 2001 of the Mamanuca area mapped the major habitats by combining computer generated pixels with the distribution of benthic classes delineated by overlaid field data, see figure 2 (Harborne *et al*, 2001). This located coral rich areas and patterns of zonation within the Mamanucas. Such analysis is vital, in terms of discussing the location of marine protected areas. However, this provided only a preliminary indication of the distribution of defined benthic classes, further data are required to improve the classification of the satellite image and more sophisticated processing would result in a better map (Harborne *et al*, 2001).

#### *Mamanuca reef management at present*

The economic value of Fiji's reefs is estimated to be around US\$196 million per annum; around 72% of this is derived from tourism (Lovell, 2001). It follows that as a major region of tourism, the Mamanuca reefs should be carefully managed. Current responsibility lies with a combination of stakeholders including traditional resource stewards, resort owners and the Mamanuca Fiji Hoteliers Association. Problems of biodiversity loss have occurred due to the ineffectual management of marine resources in the absence of a single management body for the area. This might be

attributable to the *ad hoc* nature of scientific studies (Zann, 1994), the absence of suitable GIS packages for translating technical information (Buddemeier, 2002), a failure to express management needs within the scientific forum (Crosby, 2002) or a lack of methodological consistency (Risk, 1999). In management decision-making, social and political factors often override recommendations made on the basis of scientific analysis (Hoffman, 2002). Decisions on conservation matters such as the siting of marine reserves tend not be founded on robust scientific principles as a result.

Conservation is defined as the sustainable use of natural resources and maintenance of processes that drive biological interactions that, in turn, maintain the diversity of organisms, communities and interactions (Nebel & Wright, 1999). Contrastingly, managers broadly aim to accommodate societal goals to achieve environmental, economic, social, cultural and recreational objectives. While the boundary between conservation and management is often unclear, it is thought that scientists can combine both aims by providing managers with the data needed to conserve. Traditional distinctions of scientific knowledge are objectivity, accuracy, impartiality and truthfulness (Andre, 2001) yet situations often arise where generalisations do not hold true.

As diversity is held to be synonymous with ecological quality, diversity indices are used extensively as management tools to gauge the adverse effects of pollution and environmental disturbance. Like most research, reef studies are designed to complement the existing and accepted body of knowledge. If findings are to aid management, there is a need for logical consistency & simplicity in methodologies employed. Diversity measures and models enable ecologists to ask questions and formulate hypotheses to help them understand, and sensibly manage, the natural world (Done, 1995). Contemporary discourse among the scientific community diversity measurement and its use is a major determinant in the success of conservation measures. There is considerable variation in the use of diversity indicators across Fiji. CCC have based management recommendations in the Mamanucas on total species records, total species abundance, Margalef species abundance, Pielou evenness and the Shannon-Weiner index (Walker *et al.*, 2001). Damage by bleaching has typically been assessed by virtue of mean coral cover (Lovell, 2001) while temporal health

variations have been monitored utilising invertebrate and fish species richness and abundance (Zann & Lovell, 1992). The ASEAN (Chou & Scura, 1984) and Gomez & Yap (1988) systems for describing the health of coral reefs utilise coverage parameters while at the data analysis level, Primer has been used facilitate habitat classification (Mumby & Harborne, 1999).

### **3.4 AIMS AND OBJECTIVES**

The objective of this study is to critically analyse scientific knowledge underpinning reef management in the Mamanucas. As ecologists dominate the reef science community, the applicability of a number of ecological theories to data collected at 22 sites in the Mamanucas is assessed. Interview data collected from experts working on these islands provides an insight into perceptions of scientists on the applicability of the aforementioned theories. The main aims of this study are therefore to:

- Review the magnitude, in terms of spatial extent and reductive effect on biodiversity, of a variety of anthropogenic influences in the study region
- Perform a cluster analysis of coral, fish and invertebrate populations to determine which factors influence community composition
- Test the robustness of relationships between habitat characteristics and fish populations
- Investigate the reliability of conservation class derived from coral morphology triangles as an indicator of reef health
- Test the applicability of the IDH at the landscape scale
- Assess current opinion within the scientific community on ecological theories investigated and draw comparisons between primary data analysis results and questionnaire responses.
- Briefly assess the level, scale and standardisation of scientific studies conducted, conservation measures present and awareness of them and the degree to which ecological theory is employed in management decision making.
- Review recommendations made by the scientific community for integrating scientific analysis into management decision-making

Management strategies and priorities are then highlighted as a result of implications arising from comparison of the two. While policy decisions and management are largely concerned with the activities of people, the focus of this paper is the ecological dimension of management.

## **4. METHODOLOGY**

### **2.1 DATA COLLECTION:**

#### *Survey Methodology*

Primary data collection employed a modified version of the standard ReefCheck survey, see appendix 1. All transects were carried out between 2 and 20m as the reef was of good quality at most sites in shallow water. Along each depth contour a 100m transect was deployed and four 20m replicate transects were surveyed, each interspersed with a 5m gap. Replicate transects followed the designated depth contour in sequence, with the start and end points separated by a 5m space, see figure 5. The distance between the start of the first transect and end of the last transect was 95m. Data collection from each of the four 20m sections yielded four replicates per site, allowing the calculation of a mean replicate value per site and more powerful statistical analysis.

Five types of data were recorded via three surveys along each transect line.

- 1) A site description sheet was completed which included locations, anecdotal, observational, historical, and other data. (See appendix, figure 17A)
- 2) Commercially important fish were surveyed along four 5m x 20m transects. Fish less than 5m above the transect line were counted, giving a survey area of 500m<sup>3</sup> for each replicate. More fish species were identified than specified by the standard ReefCheck protocol. Divers counting fish swam slowly along the transect and stopped to count target fish every 5m, waiting three minutes for target fish to come out of hiding before proceeding to the next stop point.
- 3) Transects were also sampled for invertebrate taxa typically targeted as food species or collected as curios. Quantitative counts were made of each species.
- 4) Transects were point sampled at 0.5m intervals to determine the substratum and benthic community type of the reef. Under the standard Reef Check protocol, categories recorded were hard coral, soft coral, recently killed coral, dead coral, fleshy seaweed, sponge, rock, rubble, sand, silt / clay and 'other'. Hard corals to were further subdivided to life form level and target species were identified
- 5) Substratum surveyors also recorded coral damage from anchors, dynamite, or the presence of other anthropogenic influences. Divers quantitatively rated the

damage caused by each factor (0 = none, 1 = low, 2 = medium, 3 = high). All data were transferred to specially designed recording forms (Appendix 1).

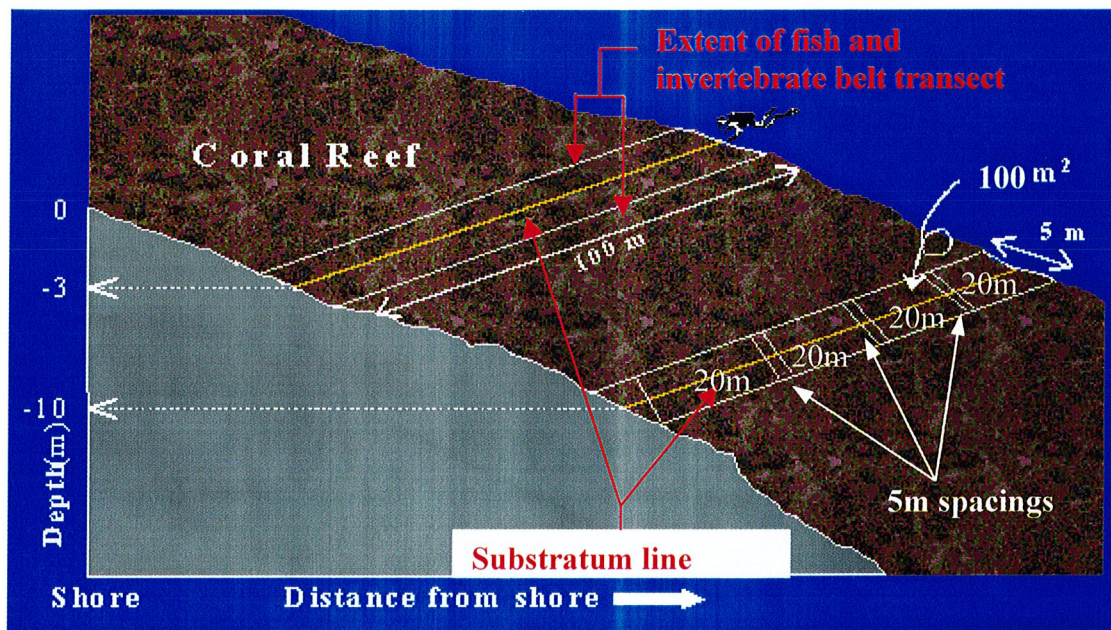


Figure 5. Schematic representation of the position of the transect lines during a Reef Check survey. Source: Haycock, *et al.* (2002) Fiji Reef Conservation Project: Reef Check Report (2001-2002), Unpublished.

#### *Survey Locations*

Between the 18th of June and 15th of August 2002, 23 surveys were completed by the author and a number of Coral Cay Conservation volunteers. Table 2 identifies transects and figure 6 show their locations. Table 3 and figure 7 describe and show the locations of the reef complexes respectively.

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

Table 2. Sites visited in June and July 2002. See figure 6 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.

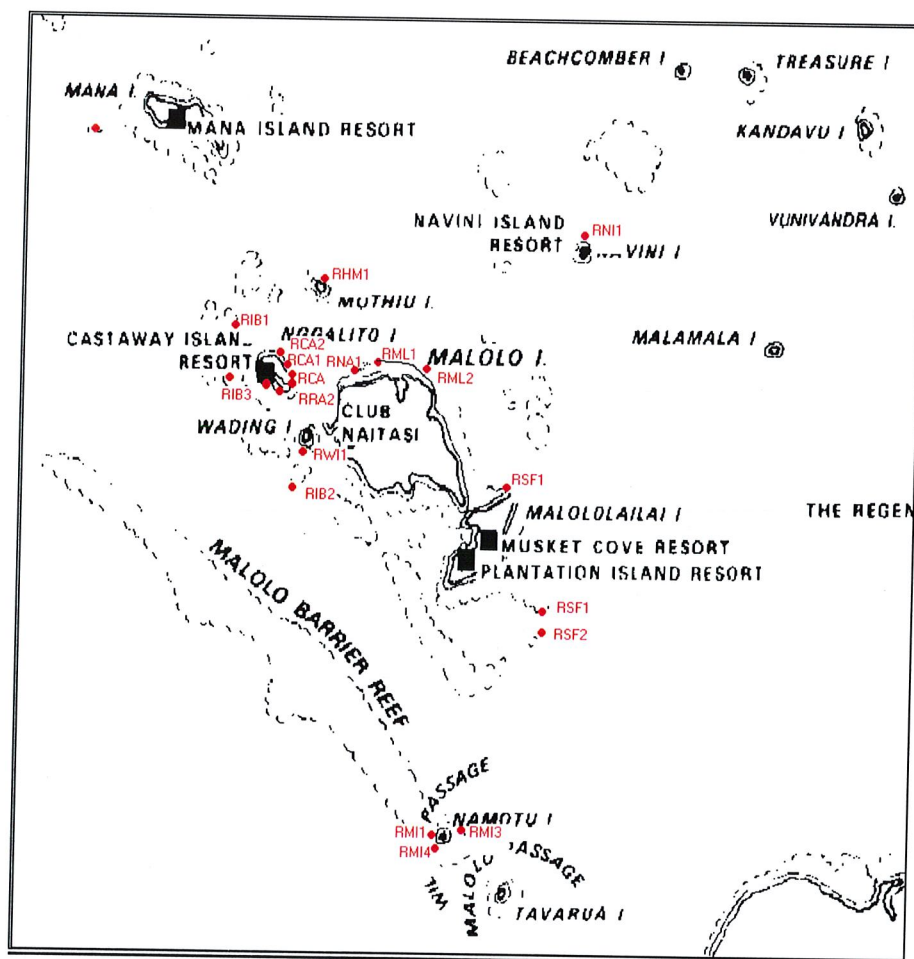


Figure 6. Transects studied between the 18th of June and 15th of August 2002.

Although sites were widespread, they could all be attributed to one of five major reef complexes identified in the Mamanucas. Four from five of these complexes were made up of fringing reefs.

| 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), Malolo, Mothiu (Honeymoon), Waidigi and Malololailai Islands |
| Outer Malolo Group | Platform reefs around the inner Malolo group                                                          |
| Navini Island      | Fringing reefs around Navini Island                                                                   |

Table 3. A description of the five reef complexes identified by Coral Cay during the pilot phase of the MCRCP

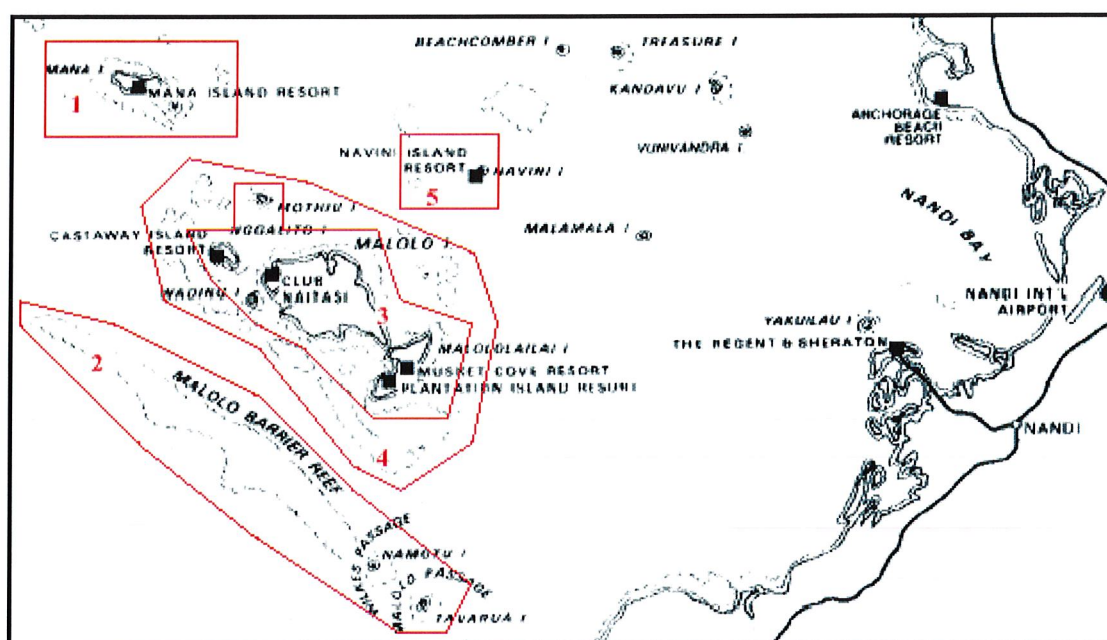


Figure 7. Diagrammatic representation of the five reef complexes (red boxes) delineated by CCC for the pilot phase of the MCRCP. 1= Mana Island, 2= Namotu Group, 3= Inner Malolo Group, 4= Outer Malolo Group, 5= Navini Island

## 4.2 DATA ANALYSIS

### *Anthropogenic impact analysis: Site pressure categorisation*

Surveyors were asked within the site assessment form (appendix, figures 17A & C) to record the extent and occurrence of a number of defined anthropogenic impacts. A combination of anecdotal evidence and eyewitness accounts of the impacts of different activities enabled a semi-quantitative assessment to be made. The presence of each pressure and converted into a point score on the basis of intensity (None=0, low=1, moderate=2, heavy=3).

Environmental properties such as value, resilience, ecosystem health & integrity and ecosystem services were assumed to be constant throughout all sites. Weighting factors were determined by combining evidence from studies on impacts in the region with the Reefs At Risk weighting framework (Bryant *et al*, 1998). Diving was found to have no significant effect on associated fish and invertebrate communities in the Mamanucas (Hawkins *et al*, 1998). Effects have been found to manifest themselves in

shifts in coral dominance patterns. As this associated shift would be present at all sites, it was impossible to quantify impact from this activity in the absence of a baseline comparison. Aquarium fish collection was found to be a prevalent problem in specific locations across the Mamanucas, similarly, sewage pollution was found to have low frequency, highly localised impacts near resorts (Hodgson, 1997). The harvest of invertebrates for curio sales does not have as large an impact as the harvest of invertebrates for food purposes, particularly in areas of high population (Raines, 2002). In order to integrate into the developing framework, Reefs at Risk variables were refined hierarchically to function at a higher scale to suit the study resolution and the impacts present in the Mamanucas were weighted (aquarium fish collection=3, harvest of invertebrates for food= 3, harvest of invertebrates for curio sales= 2, tourist diving= 1, sewage pollution= 4).

No evidence of dynamite fishing or industrial pollution was recorded. The impact with the highest score was taken to be the most prevalent pressure at each site and the site was categorised under that pressure accordingly. This scheme encompassed both occurrence and intensity of defined pressures

#### *Site impact comparison*

Average coral species richness, morphological diversity and conservation class were calculated for each site pressure class. Inter-site comparison of these diversity indicators enabled an assessment of the level of influence they have over reef diversity.

#### *Community composition analysis*

A number of diagrammatic representations were produced using the software PRIMER (Plymouth Routines in Multivariate Ecological Research). This enabled the visual analysis of coral, fish and invertebrate communities.

## Cluster Analyses

The Similarity in hard coral, fish and invertebrate communities between sites was measured objectively using the Bray-Curtis similarity coefficient:

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

Equation 1

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

The Bray-Curtis similarity coefficient was used because it has a number of biologically desirable properties and has been shown to be a particularly robust measure of ecological distance (Faith *et al*, 1987) especially when applied to coral communities (Mumby and Harborne, 1999) From the resulting similarity matrix, agglomerative hierarchical classification with group-average sorting was used to produce dendrograms for illustrating various clusters between communities at different sites. A co-variance based analysis was performed, where coral cover data was not normalised so that dominant species could exert an appropriately large influence on the classification.

## Multi-Dimensional Scaling

A multi-dimensional scaling ordination plot was constructed in order to visually assess the difference between the coral, fish and invertebrate communities of different sites. The relative distance apart of each point was examined alongside reef complex, reef depth, type of pressure present and conservation class for each site.

## Similarity Percentage Analysis

Sites were then grouped together depending on which reef complex they belonged to and the discriminating species between complexes were determined by similarity percentage analysis (SIMPER), a component of the software PRIMER. To identify discriminating species, the Bray-Curtis similarity between reef complexes was broken down into individual contributions from each species. By looking at the overall percentage contribution each species makes between two complexes, all species can

be listed in decreasing order of their importance in discriminating between the two sets of samples (Clarke & Gorley, 2001).

### *Bubble plots*

Following the SIMPER analysis, bubble plots were constructed for the three most discriminating coral species. The abundance of particularly influential species was superimposed onto the MDS plot. The larger the bubble, the greater the abundance of that particular species at each site. An assessment was made of the distributions of the top three discriminating coral species in relation to notable features of the MDS plot.

### *Testing relationships between reef parameters: Percentage live coral cover Vs Fish species richness and abundance*

The relationships between percentage live coral cover and fish species and abundance were explored via the method used by Bell & Galzin (1984). Percentage coral cover was visually assessed while fish surveys recorded counts for each species. Species richness was the number of different fish species at each transect and abundance was the total number of fish recorded for each transect. Linear regressions were calculated between these variables.

### *Substratum richness Vs fish species richness and abundance*

Relationships between substratum richness and fish species richness and abundance were explored in accordance with the method used by Roberts & Ormond (1987). Substratum richness was measured as the number of different substrate types recorded for each transect, fish species richness was the number of different species recorded at each site and fish abundance was the total number of fish recorded for each site. Putative causal relationships between variables were explored by calculating linear regressions.

### *Assignment of site conservation class*

Ternary diagrams of coral morphology were employed to assign a conservation class to each site in line with the scheme outlined by Edinger and Risk (2000), see figure 8. Conservation class was assigned by noting the percentage cover of each

morphological category present at each site and calculating the proportion of ruderal branching & tabular *Acropora* corals, competitor foliose & branching *non-Acropora* corals and stress-tolerant massive & sub-massive corals, summarized in table 4.

| Primary adaptive strategy                                       | Coral life-form                  | Conservation class |
|-----------------------------------------------------------------|----------------------------------|--------------------|
| >50% stress tolerators                                          | Massive & Submassive             | 1                  |
| >50% competitively dominated                                    | Foliose & branching non-Acropora | 2                  |
| >50% disturbance-adapted ruderal dominated                      | Branching & tabulate Acroporas   | 3                  |
| All 3 morphological groups present in roughly equal proportions | Mixed morphology                 | 4                  |

Table 4. Edinger and Risk (2000) scheme for assigning conservation class on the basis of life-forms present

#### *Conservation class reliability assessment*

Following classification, conservation class was compared with coral mortality index (Gomez & Yapp, 1988) and live coral cover as a predictor of coral species richness and habitat complexity. Coral species richness was taken as a count of the number of different hard coral species recorded at each site. The habitat complexity of each site was estimated as the Shannon Weiner diversity of coral morphologies,  $mH'$ , where  $mH' = \sum -(p_i)(\log_2 p_i)$  for all morphological categories. Coral mortality index for each site was calculated as the ratio of standing dead coral cover to both live and dead corals,  $MI = \text{dead corals} / (\text{live corals} + \text{dead corals})$

Mean coral species richness and habitat complexity ( $mH$ ) of sites with conservation scores 1, 2 3 or 4 were compared using a 1-way ANOVA test. Ability of aggregate conservation class to predict coral species richness and habitat complexity was assessed using linear regression. Conservation class was then compared with live coral cover and mortality index as a predictor of coral species richness and habitat complexity, using linear regression.

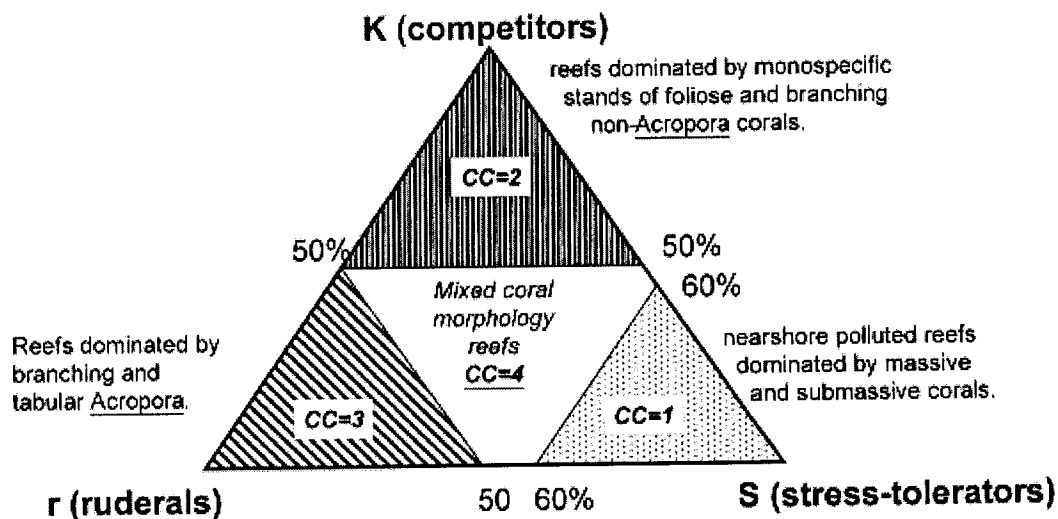


Figure 8. r-K-S Ternary triangle for reef conservation classes. Source: Edinger & Risk, 2001

#### *Application of the intermediate disturbance hypothesis*

Historical records of disturbance did exist at each study site (Haycock *et al*, 2002), yet as there was no way to sum the different disturbances and reflect the total disturbance regime. Disturbance was measured via habitat complexity (Edinger & Risk, 2000). Habitat complexity was taken to be the number of different substrate types recorded for each transect (Magurran, 1983). Substratum richness has proven a good surrogate variable for disturbance in the absence of topographic complexity measurements. The two are closely linked and have both been used as a measure of disturbance in the past (Roberts and Ormond, 1987). Species richness was assessed by recording all coral species within 5m on either side of the transect. Shannon-Wiener diversity, which takes into account both species richness and evenness, was calculated for the hard coral community. Causal relationships were explored by computing linear and second-order polynomial regressions. All second-order relationships were expected to be concave downward, reflecting high diversity values at intermediate disturbance levels, see figure 1.

### 2.3 QUESTIONNAIRES

Well informed members of the scientific or management community were selected as interviewees, where possible with survey experience in the locality of study sites. Information was elicited via a questionnaire (see appendix, figure 18). Specific factual

information was extracted via the use of closed questions for direct comparison with results from the analysis of primary data. Topics included anthropogenic influences, relationships between various reef parameters, the use of coral morphology as an indicator of conservation value and the relevance of the intermediate disturbance hypothesis in determining coral diversity. To gain a more detailed understanding of managerial and scientific perceptions relating to these issues, respondents were asked a series of open-ended questions. Topics included the role of scientists in management decision-making, the use of diversity indicators and perceived barriers to the successful implementation of conservation measures in the Mamanucas. The nature of the sample population commanded a "judgement sampling" approach as some members were more knowledgeable than others to interview (Salandt & Dillman, 1994). Informants included the scientists employed by conservation organisations with operations in the Mamanucas, Members of the Fiji Locally Managed Marine Area Network, researchers at the University of the South Pacific, biological consultants and the head of the Fiji Crown of Thorns starfish monitoring group.

### *Response comparison*

In general, small population sizes are surveyed via open-ended questions (Nicholls, 1991). However, the range of informants in this study are thought to provide a sample statistic (O'Muircheartaigh & Payne, 1977) that is large enough for the inclusion of closed questions, provided that statistical analyses were not carried out on responses. General trends were therefore highlighted and the consistency of answers was assessed. Results from primary analyses were taken to be the anticipated response to survey questions. A comparison was made of actual responses with anticipated responses. Open questions were designed to provide an explanatory framework within which the closed questions could be considered.

## 5. RESULTS

### *Site Classification*

| Site | Primary pressure                                |
|------|-------------------------------------------------|
| RCA1 | Sewage pollution                                |
| RCA2 | Aquarium fish collection                        |
| RCA3 | Tourist diving                                  |
| RCA4 | Tourist diving                                  |
| RHM1 | Harvest of invertebrates for food / curio sales |
| RIB1 | Aquarium fish collection                        |
| RIB2 | Tourist diving                                  |
| RIB3 | Aquarium fish collection                        |
| RMI1 | Tourist diving                                  |
| RMI3 | Tourist diving                                  |
| RMI4 | Spear fishing                                   |
| RML1 | Aquarium fish collection                        |
| RML2 | Harvest of invertebrates for food / curio sales |
| RML3 | Sewage pollution                                |
| RNA1 | Harvest of invertebrates for food / curio sales |
| RNI1 | Tourist diving                                  |
| RRA1 | Harvest of invertebrates for food / curio sales |
| RRA2 | Tourist diving                                  |
| RSF1 | Harvest of invertebrates for food / curio sales |
| RSF2 | Harvest of invertebrates for food / curio sales |
| RSM1 | Tourist diving                                  |
| RWI1 | Harvest of invertebrates for food / curio sales |

Table 5. Predominant anthropogenic pressure at each site.

No evidence of dynamite fishing or industrial pollution was recorded. Tourist diving was the most widespread pressure, present at 90% of the sites, (see appendix, table 14) and was the dominant pressure at 8 of the sites. The harvest of invertebrates for food or curio sales was also a prominent pressure that dominated 7 sites, while aquarium fish collection was less widespread. Evidence of sewage pollution was very localised; it was recorded at two surveys on the Inner Malolo complex, by the “Castaway” resort and at the Malololailai location downstream of Solevu Village. All sites where the prevalent pressure was the harvest of invertebrates for food were a part of the Malolo complex, with the exception of the Sunflower site they were all on the inner reef crest. Aquarium fish were collected from sites mainly off the northern coasts off Castaway and Malolo Islands.

*Impact of different pressures*

| <b>Anthropogenic Pressure</b>                  | <b>Mean Conservation class</b> | <b>Mean Coral Species Richness</b> | <b>Coral Morphological diversity</b> | <b>Percentage live coral cover</b> |
|------------------------------------------------|--------------------------------|------------------------------------|--------------------------------------|------------------------------------|
| Aquarium fish collection                       | 1.8                            | 6.0                                | 1.44                                 | 38.45                              |
| Harvest of invertebrates for food/ curio sales | 2.8                            | 9.9                                | 2.38                                 | 24.11                              |
| Sewage pollution                               | 1.5                            | 5.5                                | 1.21                                 | 35.94                              |
| Tourist diving                                 | 2.4                            | 5.9                                | 1.27                                 | 22.43                              |

Table 6. Mean conservation class, species richness, morphological diversity and percentage live coral cover of classed sites.

Sites polluted by sewage had a mean conservation class of 1.5 (table 6) and were dominated by stress tolerators and competitors. They also had the lowest mean coral species and morphological diversity but a relatively high live coral coverage. Figure 9 illustrates that of all the different pressures, sewage pollution caused the biggest overall reduction in mean conservation class, coral species richness and morphological diversity. Sites where the predominant pressure was harvesting invertebrates for either food or curio sales were the most species rich and morphologically, their corals were the most diverse. However, they had the lowest percentage live coral cover. In terms of diversity, sites where aquarium fish collection and tourist diving were prevalent had similar levels that were intermediate between the sewage polluted reefs and those harvested for invertebrates. Although the coral diversity of these sites was similar, reefs exploited by aquarium fish collectors had a substantially higher mean percentage live coral cover (38.45%) than those where tourists regularly dive (22.43%).

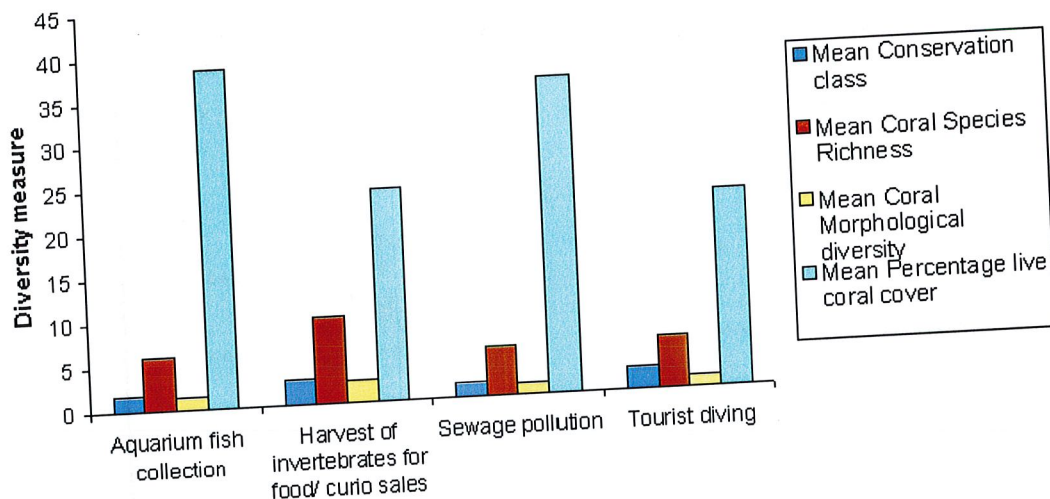


Figure 9. Mean conservation class, coral species richness, coral morphological diversity and percentage live coral cover for sites classed in terms of predominant anthropogenic pressure. Impact data collected by physical diver of Coral Cay Conservation survey team, Mamanucas, July 2002.

## 5.1 COMMUNITY COMPOSITION ANALYSIS

### *Cluster analyses*

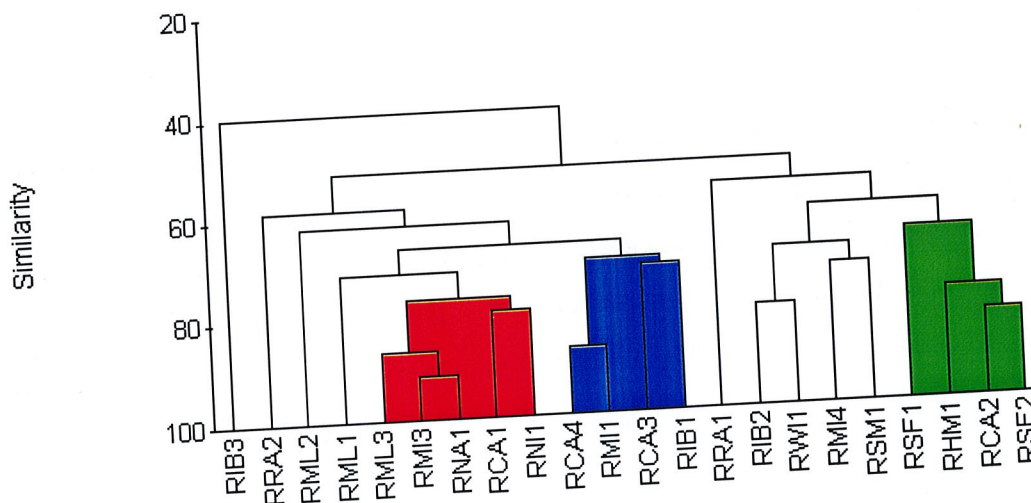


Figure 10. Cluster analysis of fish communities at study sites in the Mamanucas. Characteristics causing the most distinctive dichotomies among fish communities are thought to be the type of anthropogenic pressure present at each study site, and to a lesser extent, percentage live coral coverage. No clusters were apparent that were determined by reef complex or conservation class. The subcluster incorporating sites

RML3, RMI3, RNA1, RCA1 and RNI1 of 78% similarity is a particularly high similarity relative to the other clusters. None of the sites belong to the same reef complex and the only distinguishing feature that links them is that they all have between 30 and 40% live coral coverage. Two notable clusters, both at the 70% level of similarity appear to be subjected to common pressures, these are tourist diving and the harvest of invertebrates for food.

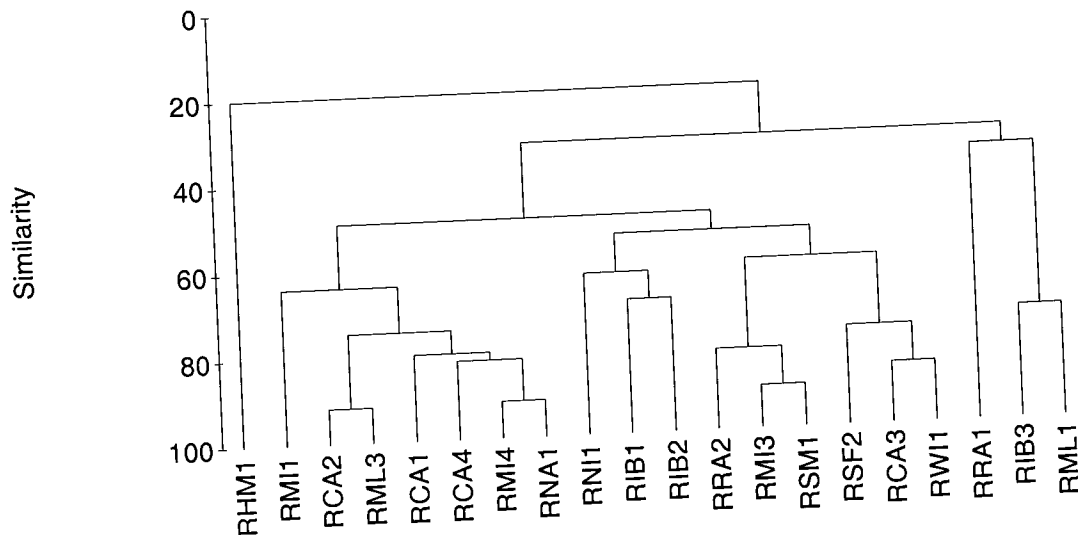


Figure 11. Cluster analysis of invertebrate data

Similarities were generally higher among the invertebrate communities yet these tended to form smaller sub-clusters, consisting of two or three sites only at levels above 80%. Larger clusters appeared at the coarser level of 65% similarity, yet these were not synchronised with the type of anthropogenic pressure present, reef depth, reef complex, conservation class or substrate complexity, see table 11.

Multi-dimensional scaling (MDS) analyses were performed on the fish and invertebrate communities, yet little could be inferred from the ordinations produced. The MDS plots yielded little additional information for fish and invertebrate communities as there were no particularly distant groupings and the subclusters were evenly spaced.

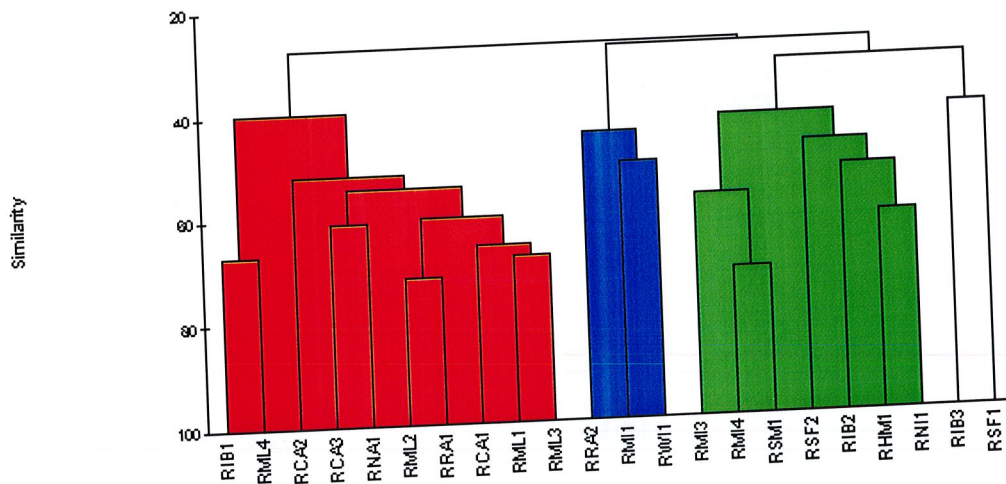


Figure 12. Cluster analysis of coral species data collected in the Mamanucas

Similarity between sites for the coral community was low in comparison to the fish and invertebrate communities. Communities split into three major groups at the 40% level of similarity, see figure 12. The distinction between these clusters is dependant on which complex the reef belongs to. With the exception of RIB1 and RNA1, all sites within the red cluster were a part of the Inner Malolo complex. Two sites from within the smaller cluster were from the Inner Malolo complex while the remaining site was from Navini. The third cluster was made up of sites from the Outer Malolo, Mana and Navini complexes in roughly equal proportions. In terms of coral community, the characteristic causing the major dichotomy appears to be which complex the reef belongs to. A noteworthy distinction can be drawn on the basis of whether the site is a part of the Inner Malolo complex.

### Multi-Dimensional scaling

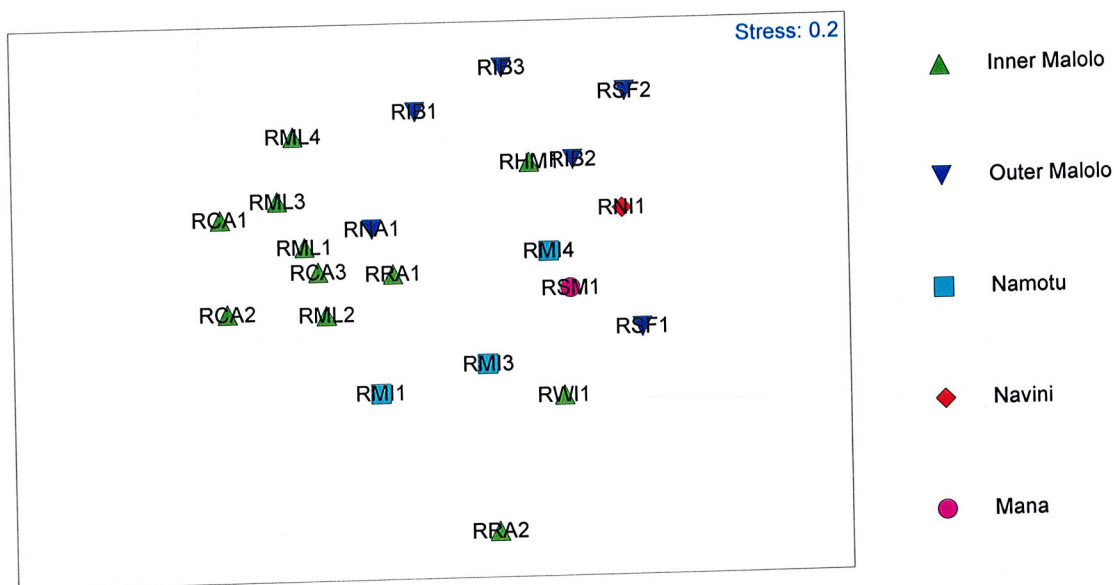


Figure 13. A non-metric multi-dimensional scale ordination plot of the coral communities at study sites, (10 restarts).

The close proximity of Inner Malolo sites toward the left hand side of the plot matches up with the subcluster of 65% similarity on the dendrogram comprising sites RML2, RRA1, RCA1, RML1 and RML3. All sites within this cluster are part of the Inner Malolo complex. Remaining sites were relatively evenly spaced with no distinctive clusters. The Ravinyake site (RRA2) had a comparatively low similarity (30%) with other sites from the Inner Malolo complex. This could be a result of its close proximity to the CCC base and consequent intense pressure from diving changing the community structure.

### Similarity Percentage Analysis

The average dissimilarity of all pairwise coefficients between Inner Malolo and Outer Malolo sites was calculated to be 77.06% (See appendix, figure 19). Of this, 10.33% was contributed by *Massive porites*, 9.56% by *Porites rus* and a further 9.47% by *Porites cylindrica*. This represents 13.41%, 12.41% and 12.29% respectively of the overall 77.06%, cumulating to 38%. A total of three species account for just over half of the dissimilarity between the coral communities of the two main reef complexes studied. Major distinguishing features between the complexes are that there was less *Massive Porites* on outer Malolo than Inner Malolo, no *Porites rus* was found on the

outer Malolo complex and other than a small amount at sunflower reef patch (study site RSF2), no *Porites cylindrica* was found on the Outer Malolo complex (see appendix, table 14). With the exception of the dissimilarity between Outer Malolo and Navini, *Massive porites* featured as one of the top two most influential species on the coral community (see appendix, figure 19). Less commonly occurring species included *Millepora platyphylla*, *Halometra pileus* and *Herpolitha limax*. These did not make a big enough contribution to the average dissimilarity to appear on the SIMPER analysis. Species were listed in decreasing order of their contribution to the average dissimilarity between two groups, until 90% of the dissimilarity was accounted for.

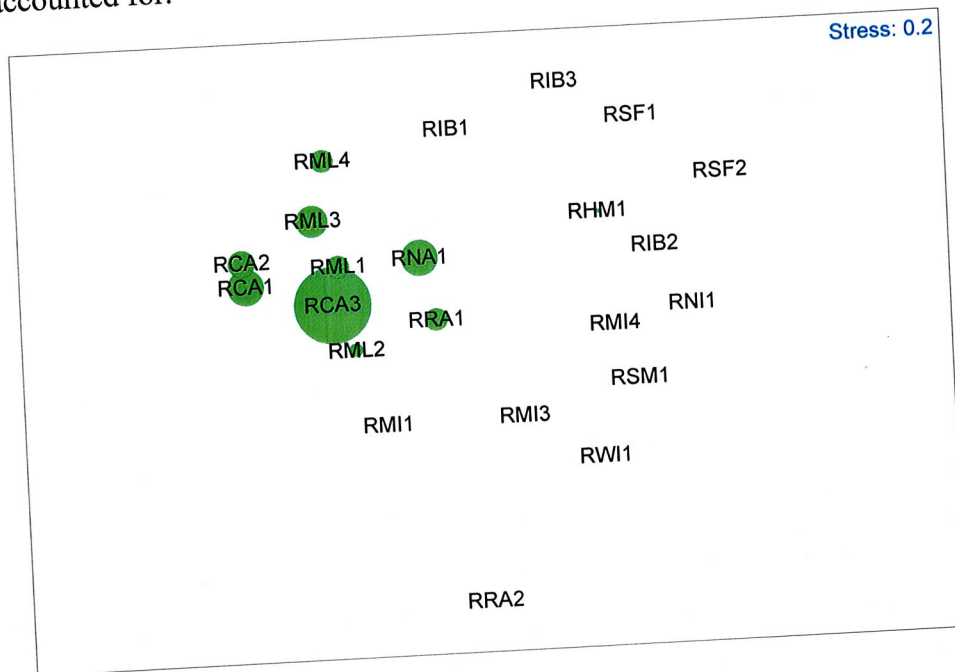


Figure 14. Bubble plot superimposing the percentage coverage of *Porites rus* at each study site.

The influence of *Porites rus*, which contributes 9.47% toward the total dissimilarity between the inner and outer Malolo reef complexes, is illustrated by figure 14. Plots for *Porites cylindrica* and *Massive Porites* revealed the same pattern of a relative abundance within the Inner Malolo cluster.

*Relationships between reef and fish parameters*

| Relationship tested                                  | $r^2$ | F-value | p-value |
|------------------------------------------------------|-------|---------|---------|
| Percentage live coral cover Vs Fish species richness | 0.13  | 0.300   | 0.588   |
| Percentage live coral cover Vs Fish abundance        | 0.34  | 2.636   | 0.12    |
| Substratum richness Vs fish species richness         | 0.25  | 1.253   | 0.277   |
| Substratum richness Vs fish abundance                | 0.21  | 0.878   | 0.360   |

Table 7. ANOVA linear regression results for the four relationships investigated

No significant relationships were found between any of the habitat variables investigated and fish species richness or abundance, see table 7.

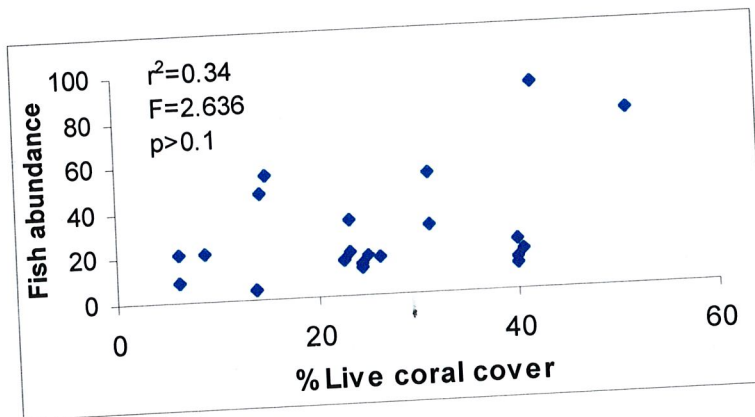


Figure 15. Percentage live coral cover Vs fish abundance

A linear relationship between percentage live coral cover and fish species richness was not significant and accounted for little variance ( $r^2=0.13$ ,  $p>0.5$ ), whereas the relationship between live coral cover and fish abundance was stronger but still not significant ( $r^2=0.34$ ,  $p=0.12$ ).

The substratum richness did not correlate significantly with abundance or species richness of the fish at any of the study sites, in both cases  $p>0.25$ , see table 6. No causal relationship between substratum richness and either measure of fish diversity was apparent.

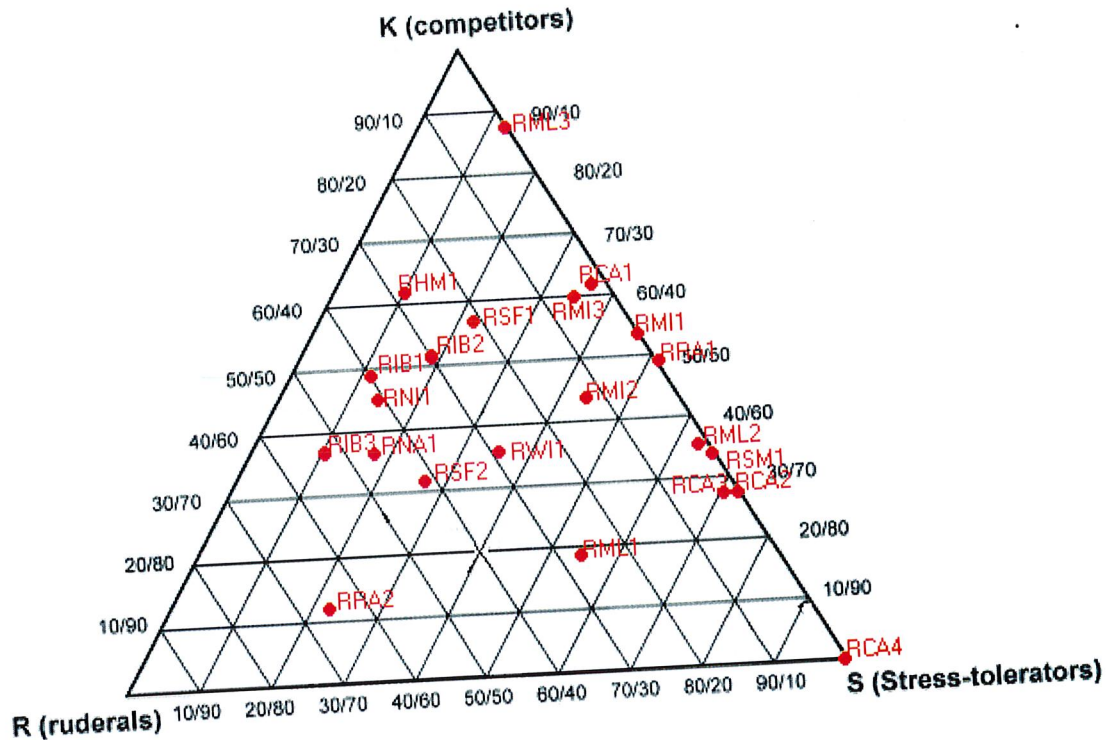


Figure 16. All study sites plotted on an r-K-S ternary diagram, (n=22).

As can be seen by the even spreading of sites across the right hand side of the ternary triangle, the sites were distributed evenly between conservation classes 1, 2 and 4 (figure 16). Forty percent of the sites were of conservation class 2, although dominated by competitors, the majority also comprised a substantial proportion of stress tolerant and ruderal adapted corals. Only two sites were of conservation class 3, the presence of ruderal adapted corals was not commonly recorded. Nine sites had less than 2% representation by ruderal adapted corals. Conservation classes 1 and 4 had an intermediate level representation of five and six sites respectively. It would appear that reef complex, depth or percentage of live coral cover did not influence life strategy, as no groupings were apparent in terms of these characteristics.

### *Predictors of conservation value*

| Conservation class | Coral species richness | Coral morphological diversity |
|--------------------|------------------------|-------------------------------|
| 1                  | 6.4                    | 1.21                          |
| 2                  | 6.7                    | 1.53                          |
| 3                  | 1.5                    | 1.65                          |
| 4                  | 9.0                    | 1.74                          |

Table 8. Mean coral species richness and morphological diversity for each conservation class

Aggregate reef conservation class interpreted from ternary diagrams accurately and significantly predicted coral morphological diversity ( $r^2=0.96$ ,  $p<0.05$ ,  $n=22$ ; Table 9), yet no causal relationship was apparent between conservation class and coral species richness (table 8). Total live coral cover accurately predicted both coral species richness ( $r^2=0.74$ ,  $p<0.05$ ,  $n=22$ ) and habitat complexity ( $r^2=0.60$ ,  $p<0.005$ ,  $n=22$ ), see table 9. Conservation class was the most reliable predictor of habitat complexity, although live coral cover and habitat complexity were also significantly positively correlated. Live coral cover was the most reliable predictor of coral species richness.

| Relationship tested                          | $r^2$ | F-value | p-value |
|----------------------------------------------|-------|---------|---------|
| Conservation class Vs coral species richness | 0.52  | 0.357   | 0.657   |
| Conservation class Vs habitat complexity     | 0.96  | 9.787   | 0.018   |
| Mortality index Vs coral species richness    | 0.09  | 0.186   | 0.617   |
| Mortality index Vs habitat complexity        | 0.03  | 0.018   | 0.894   |
| Live coral cover Vs coral species richness   | 0.74  | 23.829  | 0.039   |
| Live coral cover Vs habitat complexity       | 0.6   | 11.040  | 0.003   |

Table 9. Linear regression values assessing the reliability of conservation class, mortality index and live coral cover as predictors of conservation value.

### *The intermediate disturbance hypothesis*

A linear relationship between habitat complexity and coral shannon-wiener diversity was not significant ( $r^2=0.112$ ,  $F=2.513$ ,  $p>0.1$ ). Likewise, a second-order polynomial relationship accounted for little variance and was not significant ( $r^2=0.41$ ,  $F=0.907$ ,

$p>0.3$ ). Diversity remained unaffected by disturbance, as measured by habitat complexity.

A significant linear relationship between habitat complexity and percentage coral cover existed ( $r^2=0.48$ ,  $F=5.914$ ,  $p<0.025$ ), whereas a second-order polynomial regression was not significant and accounted for almost none of the variance ( $r^2=0.004$ ,  $F=0.116$ ,  $p>0.1$ ). These results suggest that habitat complexity does affect percentage coral cover, yet the relationship is of the first order so as disturbance increases, percentage live coral cover decreases. There was no optimum coverage at an intermediate disturbance level.

No relationships were found between coral Shannon evenness and habitat complexity. The distribution of individuals between families was therefore constant throughout all disturbance levels.

## **5.2 QUESTIONNAIRES**

Response rate was high; of the ten questionnaires sent out, seven were returned. With the exception of Dr. David Obura, all respondents had worked in the Mamanucas for a substantial time period, i.e. more than 6 months and were therefore able to relate answers well to the study region. All respondents had scientific qualifications, primarily in the ecological field. With the exception of Annette Muehlig-Hoffmann and Professor Leon Zann, all respondents had worked in a capacity related to conservation in the Mamanucas.

Table 10. Responses to closed questions; see appendix table 12 for responses to open questions.

|                                       | Sangeeta Mangubhai | Professor Leon Zann   | Dr. David Obura | Etika Rupeni | Annette Muehlig-Hoffmann | Saki Patrick Fong | James Comley |
|---------------------------------------|--------------------|-----------------------|-----------------|--------------|--------------------------|-------------------|--------------|
| 2. Length of time working in Fiji     | 4 years            | 23 years              | 2 weeks         | 4 years      | 2 years                  | 2 years           | 4 months     |
| Dynamite fishing                      | None               | Low                   | -               | Medium       | Very low                 | Very low          | None         |
| Poison fishing                        | Low                | Medium                | -               | Low          | Very Low                 | Low               | Very low     |
| Aquarium fish collection              | Low                | Very low              | -               | Medium       | High                     | High              | Very low     |
| Harvest of invertebrates- food        | Medium             | Very High             | -               | Low          | High                     | Medium            | Very low     |
| Harvest of invertebrates- curio sales | Medium             | Medium                | -               | Medium       | High                     | Medium            | Very low     |
| Tourist diving                        | Medium             | No impact             | -               | High         | Medium                   | High              | Medium       |
| Sewage pollution                      | High               | Very High (localised) | -               | Medium       | Very high                | Very high         | Medium       |
| Industrial pollution                  | None               | Low                   | -               | Very low     | Very low                 | High              | Low          |
| 4. Influence on coral community       |                    |                       |                 |              |                          |                   |              |
| Anthropogenic influence               |                    | -                     | -               | Medium       | Medium                   | High              | High         |
| Reef complex                          | High               | High                  | -               | Medium       | None                     | High              | High         |
| Coral morphology                      | High               | -                     | -               | Medium       | Low                      | High              | High         |
| Reef depth                            | High               | High                  | -               | Medium       | Medium                   | High              | Medium       |
| Influence on fish community           |                    |                       |                 |              |                          |                   |              |
| Anthropogenic influence               |                    | -                     | -               | Medium       | High                     | Medium            | High         |
| Reef complex                          | High               | High                  | -               | Medium       | None                     | High              | Medium       |
| Coral morphology                      | Medium             | -                     | -               | Medium       | Low                      | Medium            | High         |
| Reef depth                            | High               | -                     | -               | Medium       | Medium                   | High              | Medium       |
| Influence on invertebrate community   |                    |                       |                 |              |                          |                   |              |
| Anthropogenic influence               |                    | -                     | -               | High         | Medium                   | High              | Medium       |
| Reef complex                          | High               | High                  | -               | High         | High                     | Medium            | Medium       |
| Coral morphology                      | High               | -                     | -               | Medium       | None                     | High              | Medium       |
| Reef depth                            | Medium             | -                     | -               | Medium       | Low                      | Medium            | High         |



|                                                                | Sangeeta Mangubhai | Professor Leon Zann     | Dr. David Obura   | Etika Rupeni      | Annette Muehlig-Hoffmann | Saki Patrick Fong | James Comley       |
|----------------------------------------------------------------|--------------------|-------------------------|-------------------|-------------------|--------------------------|-------------------|--------------------|
| 5. Influence causing biggest overall reduction in biodiversity | Sewage pollution   | Invertebrate harvesting | Sewage pollution  | Sewage pollution  | Sewage pollution         | Sewage pollution  | Tourist diving     |
| 6. Is % live coral cover a good or poor indicator of           | Poor               | Good                    | Neither           | Good              | Good                     | Good              | Good               |
|                                                                | Poor               | Good                    | Poor              | Good              | Neither                  | Neither           | Good               |
|                                                                | Poor               | Good                    | Poor              | Good              | Neither                  | Good              | Poor               |
|                                                                | Poor               | Good                    | Poor              | Good              | Neither                  | Good              | Poor               |
| 8. Performed ReefCheck survey                                  | No                 | Yes                     | Yes               | Yes               | Yes                      | Yes               | Yes                |
| 9. Performed ReefCheck survey in Fiji                          | No                 | Yes                     | Yes               | Yes               | Yes                      | Yes               | Yes                |
| 10. Studied reefs at different scales                          | No                 | Yes                     | Yes               | Yes               | No                       | Yes               | Yes                |
| 11. Employed primary adaptive strategy classification          | No                 | No                      | Yes               | Yes               | Yes                      | No                | Yes                |
| 12. Is primary adaptive strategy a reliable indicator of       | -                  | -                       | Neither           | Yes               | Yes                      | -                 | Yes                |
| 13. Reliability as a predictor of coral diversity              | -                  | -                       | Neither           | Yes               | Yes                      | -                 | Yes                |
|                                                                | -                  | -                       | Very reliable     | Very reliable     | Very reliable            | -                 | Very reliable      |
|                                                                | -                  | -                       | Very reliable     | Not very reliable | Not very reliable        | -                 | Medium reliability |
|                                                                | -                  | -                       | Not very reliable | Very reliable     | Medium reliability       | -                 | Not very reliable  |
| 14. Awareness of IDH application to coral reefs                | Yes                | Yes                     | Yes               | Yes               | Yes                      | Yes               | Yes                |

|                                                                    | Sangeeta Mangubhai                | Professor Leon Zann | Dr. David Obura | Etika Rupeni | Annette Muehlig-Hoffmann | Saki Patrick Fong | James Comley |
|--------------------------------------------------------------------|-----------------------------------|---------------------|-----------------|--------------|--------------------------|-------------------|--------------|
| 15. Relevance                                                      | High                              | High                | High            | Medium       | Medium                   | High              | High         |
| 16. Disturbance level prioritised in conservation value assessment | Intermediate                      | High                | Intermediate    | Low          | Intermediate             | Intermediate      | Intermediate |
| 17. Investigative techniques employed                              | No                                | No                  | No              | No           | No                       | No                | No           |
|                                                                    | Fine chain link measurement       |                     |                 |              |                          |                   |              |
|                                                                    | <i>Ex situ</i> coral study        | Yes                 | Yes             | Yes          | Yes                      | No                | No           |
|                                                                    | Satellite imagery habitat mapping | Yes                 | No              | No           | No                       | No                | Yes          |
| 18. Awareness of conservation measure employment                   | Genetic diversity assessment      | Yes                 | No              | No           | No                       | No                | No           |
|                                                                    | Marine protected area             | Yes                 | Yes             | Yes          | Yes                      | Yes               | Yes          |
|                                                                    | Captive propagation               | Yes                 | Yes             | Yes          | Yes                      | No                | Yes          |
|                                                                    | Removal of unwanted species       | Yes                 | Yes             | Yes          | Yes                      | Yes               | Yes          |
|                                                                    | Habitat restoration               | Yes                 | Yes             | Yes          | Yes                      | Yes               | Yes          |
|                                                                    | Community rehabilitation          | Yes                 | No              | Yes          | Yes                      | Yes               | Yes          |
|                                                                    | Limiting fishing effort           | Yes                 | Yes             | Yes          | Yes                      | Yes               | Yes          |
| 21. Influence on reef management decisions                         | Endangered species protection     | Yes                 | Yes             | Yes          | Yes                      | Yes               | Yes          |
|                                                                    | Social                            | Very strong         | Very strong     | Medium       | Very strong              | Very strong       | Very strong  |
|                                                                    | Financial                         | Very strong         | Strong          | -            | Strong                   | Very strong       | Very strong  |
|                                                                    | Political                         | Very strong         | Very strong     | -            | Very strong              | Strong            | Strong       |
|                                                                    | Scientific                        | Medium              | Strong          | -            | Weak                     | Weak              | Medium       |

### *Anthropogenic Influence*

Four out of seven respondents rated sewage pollution as having a very high influence on biodiversity, with the remaining two rating it medium. Aquarium fish collection, tourist diving and the harvest of invertebrates for food or curio sales received a mixed response ranging from very high to very low and yielding little consistency. Sewage pollution was thought to cause the biggest overall reduction in biodiversity in the Mamanucas. No respondents rated impacts from dynamite fishing, poison fishing or industrial pollution impacts above a medium level.

Reef complex was consistently cited as having a high influence on coral community composition and four from five respondents also rated reef complex as also having a high influence over fish and invertebrate community composition. Perceptions of the influence of anthropogenic pressures, coral morphology or reef depth on coral, fish or invertebrate communities were not consistent.

### *Relationships between reef and fish parameters*

Opinion on the reliability of percentage coral cover as an indicator of fish, invertebrate or coral diversity varied considerably. It was thought that percentage coral cover was best as an indicator of fish (as opposed to coral or invertebrate) diversity, with five out of seven respondents rating it good.

### *The application of principles outlined in coral reef literature*

Four out of seven respondents were aware of the classification of reefs by virtue of their primary adaptive strategy, three rated conservation class a good indicator of both coral species richness and morphological diversity. Opinion on reliability of mortality index and percentage live coral cover as predictors of these parameters varied considerably, neither was reputed as dependable.

Awareness of the intermediate disturbance hypothesis and its application to coral reefs was widespread; all respondents said they were aware of it and would prioritise



areas with intermediate levels of disturbance for conservation. Five from seven respondents rated the relevance of the IDH in the Mamanuca region as high.

*The level of scientific study, conservation measures and ecological theory*

Assessment of reef diversity at the genetic level in Fiji was low; only one respondent had attempted to carry out analyses at this level of detail. None of the respondents had attempted to measure substratum rugosity via fine chain link measurement. However, four out of seven respondents had engaged in the *ex situ* study of Fijian corals and two respondents had attempted larger scale habitat mapping employing satellite imagery.

Six from seven respondents has performed surveys in line with the standard ReefCheck protocol on Fijian reefs and five had conducted studies at more than one scale.

Respondents were aware of the implementation of all of the measures outlined; marine protected areas, *ex situ* conservation/ captive propagation, the removal of unwanted species, habitat restoration, community rehabilitation, limiting fishing effort, the protection of endangered species.

Captive propagation was less widely known, only 70% were aware of this, while all respondents were aware of the formation of MPAs, removal of unwanted species, habitat restoration, limits placed on fishing effort and the protection of endangered species.

*A summary of responses to open questions, (appendix, table 12)*

- Reliable indicators of fish diversity split clearly into two categories: demographic factors and the use of indicator species. Principally, distance from Fijian villages or the presence of Mooray eels were cited as reliable indicators of fish species richness or abundance.
- Other conservation measures cited include species restocking and species specific harvesting ban.

- Measures commonly cited as effective for conservation in Fiji included the involvement of a wide range of stakeholders. All respondents noted that community participation plays a key part in the process. The most prevalent factor recommended for consideration in employing measures to conserve coral diversity was the integration of all stakeholders, with a particular emphasis on local communities, fishermen and resource owners.
- A wide range of diversity indicators was known by respondents to be considered in management decision-making. These included coral cover, the presence of particular fish and invertebrate species and coral diversity. James Comley further broke down the measurement of coral diversity into species richness, Shannon-wiener, Pielous & Margalef species evenness and primary adaptive strategy
- Reasons cited for the low influence of science in management:
  - Decision makers are unaware of scientific principles when making decisions,
  - Low capacity and small number of qualified scientists limiting collaboration
  - Failure to pass the Sustainable Development Bill through parliament (a bill which will empower scientists far more in the management planning process)
- Lack of community involvement was identified as a barrier to the successful implementation of conservation measures. Where communities have been engaged, lack of consensus from chiefs or conflict between chiefs and resort owners have hindered success
- A tendency to prioritise tourism activities over conservation the promotion of cosmetic conservation measures for the purpose of the tourist industry over substantive action
- Lack of funds to support in depth scientific analysis
- A tendency to model management approaches on well established regimes such as the Great Barrier Reef that are less appropriate to Fijian culture.

| Management Aspect/ question number             | Question number | Data analysis result                                                                                                                                                                                                                               | Anticipated questionnaire output                                                                                                                                                                                                                                                    | References                                    |
|------------------------------------------------|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|
| Level of impact from anthropogenic influences  | 3,5             | Sewage pollution had the highest impact, aquarium fish collection and the harvest of invertebrates for food had a medium level impact, tourist diving had a low impact, dynamite fishing & poison fishing had no impact                            | Sewage pollution to be identified as the biggest overall cause of biodiversity reduction.                                                                                                                                                                                           | Harborne <i>et al.</i> 2001                   |
| Community analysis                             | 4               | Fish communities possibly effected by percentage live coral cover and type of anthropogenic pressure present. No obvious influences on invertebrate communities. Coral community composition mostly dependent on which reef complex it belongs to. | Reef complex to be rated as having the biggest influence on coral communities, anthropogenic influence and percentage coral cover also influential on fish communities.                                                                                                             | Ormond <i>et al.</i> , 1997                   |
| Relationships between reef and fish parameters | 6,7,22          | No causal relationships found between percentage live coral cover or substratum richness and fish species richness or abundance                                                                                                                    | Percentage live coral cover a poor indicator of fish, invertebrate and coral diversity.                                                                                                                                                                                             | Bell & Galzin, 1984<br>Roberts & Ormond, 1997 |
| Coral morphology as a predictor of reef health | 11,12,13        | Conservation class a reliable predictor of coral morphological diversity, mortality index a poor predictor of coral species richness and morphological diversity                                                                                   | Where scientists are aware of the classification, it is a reliable indicator of coral morphological diversity<br>As predictors of coral diversity,<br>Conservation class is very reliable (3), mortality index is not very reliable (1), Percentage live coral cover is neither (2) | Edinger & Risk, 2000                          |
| Intermediate disturbance hypothesis            | 14,15,16        | No second-order polynomial regressions were found, no evidence to support the intermediate disturbance hypothesis                                                                                                                                  | If aware of the application of the intermediate disturbance hypothesis to reef diversity, not relevant to diversity patterns in the Mamanucas                                                                                                                                       | Aronson & Precht, 1995                        |

Table 11. Anticipated output of questions on ecological management aspects of predicted from data analysis results

## **6. DISCUSSION**

### *Anthropogenic impact*

Surveys were completed at a range of geographic locations, providing a good assessment of health parameters in the shallow reef areas. Reefs comprising a range of diversities, coral coverage and community structures were recorded. Ranges of reef coral species richness measured during July 2002 surveys compared closely to those reported a year previously for the same region (Harborne *et al.*, 2001) and fall within ranges reported for other reef systems (South & Skelton, 2000). A temporal comparison of mean 2001 and 2002 data reveals an overall growth in live coral cover, moving it above the Gomez & Yap (1988) criteria threshold from “poor” to “fair” condition. As would be expected in the Mamanucas where resorts are prevalent, tourist diving was the most widespread pressure. The harvest of invertebrates for food or curio sales and aquarium fish collection were present at a medium level. Evidence of sewage pollution was only recorded at two sites, reflecting the relatively advanced standard of resort sanitation systems (Hoffmann, 2002)

Following classification on the basis of the pressures endured, sites ranked consistently in terms of mean conservation class, coral species richness and morphological diversity. Most diverse coral communities were recorded at sites where the dominant pressure was the harvesting of invertebrates, followed by those where tourist diving was prevalent, then those where aquarium fish were collected, and sewage polluted reefs were the least diverse.

Different stresses act synergistically to cause greater damage to reefs (Harborne *et al.*, 2001). Hawkins *et al.* (1999) found the impact of background stresses on massive corals to be greater in the presence of tourist diving. While this had no effect on the overall percentage cover, it allowed the branching coral community to increase at the expense of large, massive colonies. Consequently, a shift in community structure should occur with coral cover remaining constant. In contrast, this study found tourist diving to be the most prevalent pressure, yet sites where it was dominant consistently displayed a low percentage coral cover, with little effect on diversity.

Invertebrate harvesting had the least reductive effect on biodiversity. This may be attributable to the reduction in competition that results from low level invertebrate removal, particularly in high-density areas where invertebrates compete for space (Lovell, 2001).

Aquarium fish collection is permitted under license, but these are regulated and impacts are localised (Zann, 1994). Intermediate diversity levels at fish collection sites were indicative of the continued regulation of collectors. The rapid growth and re-establishment of many aquarium fish species provides encouragement that their removal at present levels is sustainable (Lovell, 2001). While aquarium fish collection was not regarded a major cause of biodiversity reduction in the Mamanucas, there was little consistency between respondents on the level of impact from this activity.

It was strongly agreed by all respondents that sewage pollution was the biggest cause of biodiversity loss in localised areas. This was supported by the fact that these areas had the lowest mean conservation class, coral species richness and morphological diversity. Laboratory experiments have identified a shift in coral community species composition due to enhanced nutrient input (Muehlig-Hoffmann, 2001). Field studies have also indicated that temporal variations in environmental factors such as temperature and nutrient load relate closely to reef health (Harborne *et al.* 2001). Effects of sewage pollution are known to be highly localised and powerful predominantly around populated areas such as island villages (Vuki *et al.* 2000). Sites where sewage pollution prevailed were downcurrent of a major resort or village community, possibly because 90% of rural households lack adequate sanitation (Watling, 1992). While comparatively low diversity measures were recorded here, live coral coverage was not low in comparison. Sewage pollution reduced biodiversity but not overall coverage of corals.

Impacts from industrial pollution, dynamite and poison fishing were thought to be low level in the Mamanucas, this was supported by the fact that no evidence of damage from these sources was recorded at any of the study sites. Although Nadi Bay is an area of intense industrial development, the mangroves lining this section of coastline act as a barrier to industrial compounds that might otherwise be transported further off coast (Vuki *et al.* 2000).

At the regional scale, with or without human impact, a proportion of reefs and sites are expected to be in “degraded”, “recovering” and “healthy” states as a result of previous disturbances (Done, 1995). Scientists can play an important role in defining how these states are recognised and assessing how certain and fast their recovery may be under specific pressures. This may facilitate management decision-making regarding development issues. Results suggest that categorisation of Mamanuca reefs by virtue of the anthropogenic pressure present gives an indication of the biodiversity levels they play host to. Survey responses did not recognise this as only two respondents deemed the type of anthropogenic influence present to have a high influence on coral community.

Severely degraded reefs have less chance of recovery and remediation efforts may be more effectively placed on reefs in better health where efforts are more likely to be rewarding (Risk, 1972). Areas subject to pressures other than sewage pollution, where diversity levels were not reduced to such an extent, are more likely to respond well to conservation measures. That is not to say that all sites where sewage pollution prevails are beyond recovery.

#### *Community composition analysis*

As might be expected for species that have the ability to move between islands of suitable habitat, fish dendrograms produced clusters that were not determined by reef complex. The overall dispersal ability of fish species was high, rendering evolutionary factors at the local level irrelevant to fish community composition. Consequently, overall population composition remained independent of the reef complex surveyed. Site attached fish species such as damselfishes often display preferred microhabitats, particularly for smaller branched coral growth forms (Ormond *et al.*, 1997) thus clusters may be more directly influenced by the life form present. Individual families were not analysed as a part of this study, hence a family level distribution would not be identifiable.

A large cluster incorporating five sites of 78% similarity, all with comparable percentage live coral coverage indicated that reefs with between 30-40% coverage

provide habitat for a distinct fish community. Anthropogenic pressure had less of an influence on fish communities although sites of invertebrate harvesting and tourist diving did display similarities.

Reef complex was more influential over coral communities due to their static nature. Should a “complementarity” approach be adopted for conserving corals in the Mamanucas, areas could be divided up on the basis of the main distinction apparent in the dendrograms; whether or not the candidate community was part of the Inner Malolo complex. A strategy seeking to maintain complementary coral communities would aim to preserve sites both on and off this complex. Likewise, a similar strategy adopted for fish populations would aim to conserve sites with a range of coral coverage so that not just the communities associated with reefs exhibiting 30-40% cover are prioritised.

An alternative assessment of complementarity might compare species composition directly. To promote efficiency in terms of time and man power, assessments could be restricted to those species that have a high influence on coral community composition. Indications from SIMPER analyses are that *Porites rus*, *Porites cylindrica* and Massive *porites* would be the species to investigate in this scenario. *Non-Acroporas* are robust, in particular *Porites* which are renowned for being tolerant to both natural and anthropogenic threats such as typhoons, low level sedimentation and pollution (Walker et al, 2002). Species were influential due to their frequent occurrence, resulting, in turn, from their tolerance. The abundance of influential species on the Inner Malolo complex, as illustrated by the bubble plots, suggests that a strategy to maintain a diverse community range should incorporate sites from Inner Malolo and other complexes.

In contrast, an approach based on principles of rarity would place value on reefs hosting rare species. As the majority of species are present in low abundance at numerous sites, a “rarity” approach would likely focus on species classed as rare due to their endemic restriction to a particular area. Consequently, areas where species such as *Millepora platyphylla*, *Herpolitha limax* and *Halometra pileus* are abundant would be targeted for conservation.

When asked to rate the influence of type of anthropogenic pressure present reef complex, coral morphology and reef depth community composition, responses were in broad agreement with study findings. Reef complex rated the strongest influence over coral, as opposed to fish or invertebrate communities. Reef complex was also rated as having a high influence over fish diversity, while cluster analyses did not support this view. This could be attributable to variation in interpretation of data portrayal. A mean similarity index of 0.7 has been interpreted by some workers as confirming a relatively high degree of similarity, and by others as indicating a surprising degree of variability (Sale, 1981). Opinion over influential factors for invertebrate communities varied widely. Coral management based on a strong community dependence upon which complex the reef forms a part of, would be more robust than invertebrate and fish population management based on the same assumptions.

#### *Relationships between reef and fish parameters*

Fishes are important to many different processes on reefs, such as control of algal populations, bioerosion, sediment production and nutrient cycling (Cripps, 1992). It is therefore important to take measures to conserve their diversity and prevent pressures such as overfishing driving populations into extinction. Fish population management is facilitated by generalisations based on robust ecological relationships that avoid large-scale measurement of population statistics (Bell & Galzin, 1984).

Past studies have revealed a striking relationship between fish species richness and habitat heterogeneity (Risk, 1972; Luckhurst & Luckhurst, 1978; Roberts & Ormond, 1987). This could be attributable to differential adaptation of larvae to different pelagic habitats (Roberts, 1991), with increased surface area providing a greater diversity of shelter and feeding sites, resulting in an increased species richness (Bell & Galzin, 1984). No such relationship was uncovered between substratum richness and fish abundance in this study.

Reef fish diversity is not strongly linked to coral cover, except for at very low coverage values where fish diversity tends to be low (Ormond & Roberts, 1997).

Despite a low coverage throughout the region, fish populations were largely independent of coral coverage.

The failure to find trends relating both coral coverage and substratum richness to fish diversity may result from the stronger influence of other factors masking weak relationships. It is likely ecological processes such as competition, resource limitation, predation and mutualism determine the species present within a particular habitat (Grime, 1977). Risk (1972) found that oceanographical processes result in a significant element of chance affecting the composition of the assemblage, whereas Gorman and Karr (1978) concluded depth, current and bottom type need to be taken into account.

The lack of causal relationships revealed in this study may be due to the differential adaptation of fish families to the same substrate characteristic. The relative abundance of dead coral with algae provides food, shelter and an egg laying surface for benthic herbivorous families (Walker *et al.* 2002). However, it is generally accepted that dead corals are not a good substrate for abundance and diversity of other reef fish (Riegl & Riegl, 1995). Observations of overall diversity across a number of families hide this inconsistency. A study of individual family abundance with substrate characteristics may therefore yield more causal relationships. Indeed, past studies have highlighted correlations between coral cover and Snappers, Groupers, Parrotfish and Surgeonfish off the north and eastern coasts of Castaway Island (Walker *et al.* 2000)

While no correlation between substratum structural complexity and fish species richness was revealed, reef fish elsewhere have shown subregional patterns in distribution and diversity. Systematic changes in abundance of butterfly fishes across the width of the Great Barrier Reef have been noted (Anderson, 1981). Changes of this nature may not have been noted in this study as the reefs were much smaller than the GBR, which covers a distance comparable to that of a continental shelf. Dramatic changes over comparatively short distances would be necessary for the detection of such relationships at this scale.

On the whole, reef fish assemblages were found to be unpredictable from both habitat characteristics. Observations of fish abundance and species richness must therefore be made directly.

The consensus among respondents was that live coral cover was best as an indicator of fish (as opposed to coral or invertebrate) diversity. This reflects the abundance of literature on relationships between coral and fish populations. As the questionnaire did not specify whether the association was pertaining to the overall fish population or individual families, answers could refer to relationships established within particular families.

Distance from Fijian villages was recommended by numerous respondents for inclusion in a scheme to predict fish diversity. This has been employed effectively at a much coarser resolution to map impacts on global coral reefs (Bryant *et al*, 1998). A more accurate measure of distance is required to adequately assess the level of influence that the nearest population has on fish diversity.

Invertebrates were generally uncommon during baseline surveys, because many of them blend well into their surroundings or are nocturnal (Harborne *et al*, 2001). This study did not measure direct causal relationships between invertebrate diversity and habitat characteristics, even though substrate richness has been shown to be a good predictor of invertebrate diversity in the past (Allan, 1975). Cluster analyses produced groupings that were largely independent of substrate characteristics. There was little consensus on which factors influence invertebrate communities. Past research has tended to prioritise relationships between coral and fish populations, while invertebrate studies have traditionally been carried out in freshwater environments (Linduska, 1942; Coleman & Hynes, 1970; Allan, 1975)

#### *Conservation class assignment*

Sites were evenly distributed between conservation classes 1, 2 and 4, indicating that reef health in the Mamanucas was variable. Inferences drawn from reef coverage data are in agreement with these findings. Mean coral coverage across all the study sites

was 25.7%, under ASEAN coral coverage reef health criteria, this would rate the reef condition as “fair”.

The majority of sites came under conservation class 2, revealing that the most abundant coral life strategists in the Mamanucas were the competitors. A prevalence of competitive corals suggests that in the Mamanuca marine environment, habitats are subject to low stress and disturbance levels (Grime, 1977). Evidence to support this lies with the lack of sites in the bottom left corner of the ternary diagram, indicating a low abundance of ruderal adapted corals. A ruderal strategy is appropriate when disturbance levels are high but conditions are benign and resources abundant (Grime, 1977). This is therefore indicative of the low occurrence of large disturbance events such as storms. Nonetheless, anecdotal evidence and past status reports have documented the occurrence of storms in the region (Lovell, pers comm., South & Skelton, 2000). Both reefs that were dominated by ruderals (conservation class 3) had a lower than expected live coral coverage, accompanied by comparatively low fish and invertebrate diversities. This may be attributable to a major disturbance event, shortly after which the reefs were surveyed. The primary pressure on both reefs was found to be tourist diving. As surveys were conducted at the end of the tourist season, it is likely that recent damage from tourist diving amounted to a high magnitude disturbance, thus explaining the lower than expected coverage at these sites.

#### *Conservation class reliability assessment*

Coral morphologies were grouped into conservation class. Comparisons drawn were semi-quantitative as the relative proportions of the different life strategists present were the basis of classification for each site. Regressions used whole-reef averages of conservation class, the comparison of discrete value averages with continuous data is an approach that has been widely employed in reef science by Gomez & Yap (1988) who classified reef condition based on coral cover. While the classification system masked the exact proportion of coral morphologies, comparisons were drawn on the basis of where each site fell in relation to the classification system. The semi-quantitative nature of this classification provides adequate basis for demonstration of conservation class as a practical, taxonomy independent means of estimating reef conservation value.

Reefs are primarily recognised as a basis for the economic advancement of Fiji through tourism (Lovell, 2001). Managers and tourism operators are keen to preserve the beauty of the reefscape, including corals, fish and other biota, in order to maintain the quality of the visitor experience and in turn, the viability of individual tourism operations (Done, 1995). Of the three measures of reef condition compared here, conservation class was the best predictor of habitat complexity, while live coral cover proved the best predictor of coral species richness. Habitat complexity, or morphological diversity (the term is interchangeable), is taken in this study to mean coral life-form diversity. It is likely that life-form diversity has greater aesthetic appeal than species diversity due to the more dramatic change in physical coral characteristics. A conservation approach prioritising sites of conservation class 4 would therefore contribute more to aesthetic appeal than simply prioritising sites with a high coverage. This provides a good argument for the suitability of conservation class above coral cover for a management tool in the Mamanucas. At the regional scale, most coral species only occur in one life-form (Haycock *et al.*, 2002), hence a high habitat complexity will in most cases equate to high species diversity.

The use of live coral cover as an indicator of reef condition is based on the underlying assumption that greater coverage equates a healthy system. In spite of this, sites with a very high percentage coral cover are frequently composed of mono-specific stands of corals, such that their biodiversity is low (Connell, 1978; Aronson & Precht, 1995). Results are indicative of this scenario as sewage polluted sites have the lowest diversity accompanied by a relatively high percentage coral cover (figure 9). Although live coral cover was found in this study to be useful, the reef condition index (Gomez & Yap, 1988) does not facilitate the adequate judgement of reef health as in many cases, polluted reefs are comprised of large homogenous coral strands. Consequently, published data and the results of the present study suggest that conservation class derived from ternary diagrams is a reliable indicator of coral morphological diversity.

The current study found conservation class to be a significant and accurate predictor of habitat complexity and responses broadly agreed with this finding. Those who were aware of conservation class as an indicator of reef health rated it a good indicator of

both coral species richness and habitat complexity. While conservation class was unanimously rated a very reliable predictor of coral diversity, both mortality index and percentage live coral cover were considered less reliable. Evidence from the study supported this opinion, yielding no correlation between mortality index and either health parameter. A significant relationship was detected between percentage live coral cover and species richness. Opinion over the use of live coral cover as a predictor of coral diversity failed to reach a consensus, ranging from not very reliable to very reliable. Although the use of conservation class was not widely known, it was considered an accurate predictor of reef health among respondents who had heard of it and consistently rated more accurate than mortality index and live coral cover. While opinion over the use of percentage live coral cover as a biodiversity indicator varied, it did prove accurate for coral species richness. A strategy of optimum biodiversity conservation involves giving maximum protection to a number of reefs incorporating different conservation classes because reefs of different conservation class differ in species composition. (Gray, 1997). Nevertheless, where financial or temporal constraints occur and the aim is to conserve habitat complexity, reefs of conservation class 4 should be prioritised.

Conservation values can be particularly useful since they incorporate a range of important parameters and can be used for coastal resources management by aiding, for example, the siting of marine reserves. However, it is important to recognise that this technique alone does not provide a comprehensive measure of reef health. A more holistic approach should take into account factors such as live coral coverage. This would ensure that sites assigned a conservation class of 4, such as Waidigi (RWI1), even though they have comparatively low coverage (8.75%), are afforded the right level of protection. While a reef may incorporate colonies of each coral morphology in roughly equal proportions, this does not equate to overall reef health, as both coral species richness and coverage might still be low.

#### *Intermediate disturbance hypothesis*

A widespread knowledge and clear understanding of the intermediate disturbance hypothesis was illustrated as all participants said they were aware of it and would prioritise areas of intermediate disturbance for conservation. Sixty six percent also

said that this was very relevant to management decision making in the Mamanuca region. A second-order polynomial regression was weak and insignificant, providing no evidence in support of the IDH at the landscape scale in the Mamanucas. Many authors have stressed the need to determine that patterns consistent with particular models are in fact due to the proposed mechanisms (Elner & Vadas, 1990). The use of habitat complexity (Roberts & Ormond, 1987; Edinger & Risk, 2000) as a surrogate measure of disturbance as opposed to substratum rugosity (Aronson & Precht, 1995) may deter causal relationships from being detected. The less direct measurement of disturbance makes it harder to link disturbance levels with diversity measures and hence, attributing diversity patterns to the IDH is made difficult.

Past studies have tested the IDH at a number of different scales with varying results, suggesting that relationships may be scale dependent. While observations made at the landscape (Aronson & Precht, 1995) and on a temporal (Rogers, 1993) scale have yielded evidence of high biodiversity at intermediate disturbance levels, a higher resolution study found no significant relationship at the quadrat level (Jackson, 1991).

As well as demonstrating a clear understanding of the IDH, respondents deemed it very relevant in the Mamanucas, which was not in line with the data analysis results. This study has shown biodiversity to be maximal at low disturbance levels, hence these areas should be afforded a high degree of protection. Results indicate that diversity levels are highest in the absence of disturbance and continually decrease as disturbance levels increase, yet 5 of the 7 scientists were of the opinion that diversity reaches a maximum at intermediate disturbance levels. This variation in perceptions may result from the focus of conservation efforts at intermediate disturbance levels where diversity is judged to be higher than it actually is. That is not to say that the IDH cannot be used to good effect as a management model in conjunction with other indicators.

A weak and significant linear relationship between habitat complexity and percentage coral cover was calculated, indicated that biodiversity continually reduces as disturbance levels increase. This would suggest that either competitive exclusion was not reduced to a level low enough to override the destruction of non-stress tolerant species. No balance was reached whereby diversity levels increased. To this end,

areas of low disturbance should be prioritised if the conservation aim is to maintain a high percentage of coral cover. Chances of recovery depend on the nature of the disturbance. An Indo-Pacific study incorporating a range of Fijian reefs found coral cover recovered after 69% of acute, short term disturbances, while only 27% recovered after long-term chronic disturbances (Connell, 1997). A range of disturbance regimes, from one-off storm events to continued anthropogenic pressures prevail in the Mamanucas. Consequently, the failure to detect intermediate biodiversity levels resulting from one single disturbance is likely to be attributable to the masking effect of such a combination of pressures.

#### *The level of scientific study, conservation measures and ecological theory*

An overall picture of the level of reef study in Fiji emerged whereby habitat mapping and *ex situ* studies had been carried out extensively, with less attention being paid to studying reef at the genetic level. This may result from the nature of the population sample- five from seven of the respondents were employed by conservation organisations whose primary role of reef study was that of surveying with a view to reviewing status. Contemporary conservation is widespread both geographically and methodologically. All measures identified in the questionnaire were adopted in Fiji.

Five respondents had studied reefs at more than one scale. This was not surprising as most of them were employed by conservation organisations. Conservation studies can be aimed at numerous levels: genetic (Holling, 1992), species (Smithe, 2001), population (Walker *et al*, 2002) or biosphere (Bryant *et al*, 1998) whereas other disciplines restrict studies to finer resolutions (Muehlig-Hofmann, 2001).

The majority of respondents had conducted a survey in line with the standard ReefCheck methodology. The prevalence of ReefCheck has facilitated a shift away from the tendency of reef scientists to conduct isolated studies that do not lend themselves well to comparison. ReefCheck methodologies are primarily used to survey health on a large geographical scale. The simplicity of the methodology has proved advantageous as ReefCheck surveys are widely carried out by volunteers with eco-tourism operations in Fiji such as CCC, WWF and GreenForce. It goes some way toward standardising reef studies, facilitating simplistic site comparisons, both within Fiji and internationally.

While coral diversity was identified on a number of occasions as a factor in management decision-making, there was little consistency in its measurement. Past recommendations on potential marine reserve locations around Castaway have been made on the basis of fish and coral population abundance. Scientific studies on Fijian reefs have historically been *ad hoc* in nature, conducted by visiting researchers with a primarily taxonomic interest (Zann, 1994). Indicators employed in management decision making were wide ranging. This is in line with the lack of consistency among scientific reports written for management applications (See §3.3).

Around villages, reefs are treated as resource systems for sustained extractive use by human communities who may regard the appearance of the reef as irrelevant. Factors that influence the reef's capacity to produce protein for human consumption are managed (Done, 1995). A high value is traditionally placed on old benthic organisms and pristine communities to ensure "sustainable bioconstruction" (Buddemeier & Hopley, 1988). An alternative approach of "sustainable biodiversity" manages the diversity responsible for maintaining ecosystem processes. Conservation on this level is not being practised in the Mamanucas, as aims have historically been tourism-orientated. However, the use of MPAs, due to their all-encompassing nature, goes some way toward this ecological aim.

A wide range of conservation measures was known to be currently in place in Fiji. Survey responses illustrated a wide awareness and appreciation of the conservative effect of MPAs among the scientific community. An example of a conservative measure that is both biologically effective and accepted in most social systems around

the world is the protected area, intuitively grasped by almost everyone as being conservative in effect. (Adams and Ledua, 1997). National conservation measures that have historically met with success have all been centred around the introduction of MPAs. Reserves have been sited at Kadavu (WWF), Tai (Beachcomber) and Lavuka (Treasure) Islands.

### *Social and Political Factors*

Interest in marine protected areas has grown because customary fishing rights owners are becoming aware of the value of marine eco-tourism, habitat protection and fisheries conservation (Vuki *et al*, 2000). While MPAs are seemingly the most suitable conservation measure in the Mamanucas, management of these reserves has varied considerably depending on location, which uses are integrated into management and who is involved as stakeholders.

While the primary focus of this paper has been scientific restraints on the use of ecological theory in management, several important non-scientific influences have emerged that impede the integration of science into management decision making. Public participation emerged as a key element of conservation, with a particular emphasis on local communities. A global priority need has been identified as the establishment of multi-stakeholder partnerships involving the public and private sectors, NGOs, the scientific community, and in particular, local communities (Dight & Scherl, 1997). There is a clear mandate for community involvement as the general consensus between respondents was that the success of conservation measures depends on dialogue and the development of a consensus between local and national stakeholders. Community chiefs are key stakeholders as a result of traditional marine tenure systems.

The intense human use and obvious boundaries of reef ecosystems in the Mamanucas make the region a prime candidate for management by zoning (Mangubhai, 2000). Ideally, in a reserve, there should be open areas for visitors as well as specially protected restocking areas, which can serve as “larval reservoirs” (Riegl & Riegl, 1995). The latter should be located upstream of open areas, which will likely require larval imports in the face of user degradation. While generic principles can be applied,

ecological theory underpinning management decisions is far from consensual. Any objective or accurate view that the scientific community may provide to enhance understanding of natural systems on management aspects such as larval reservoirs and their implications for zoning tends to be overridden by social and political factors. Such a scenario might determine whether an MPA is set up at all.

Although one of the key aims of tropical marine conservation is to maintain biodiversity, it is also important to address the fact that coastal communities rely on the environment for both their food and livelihood. Careful management to avoid over-exploitation must therefore become a priority.

The lack of support for protected areas stems largely from the reluctance of traditional resource owning groups to lose their traditional rights. The reluctance of governments to interfere in matters of customary law compounds this (Zann, 1992)

Where fishing areas are finely subdivided between villages, clans or families, it may be difficult for one or more of these units to give up their holdings for the greater good, particularly if that sacrifice is made permanent by legislation (Adams, 2000). However, recent experience in Kadavu and elsewhere has shown that fishing rights owners can be unexpectedly willing to sacrifice a great deal of production, in the form of extended (5-10 year) moratoria on fishing for certain species, if they retain ownership of the area under moratorium and if they are allowed to retain control over the disposition of any resultant harvest (Mangubhai, 2000).

## **7. CONCLUSION**

A number of different approaches to conservation have been outlined and management decisions will largely depend on the conservation aims in specific cases, which may not remain constant. To this end, it is hard to relate the findings of this paper to implications for reef management, as they can be applied to a range of situations in different ways.

While overall, health was found to be fair, one of the major findings of this study was that sewage pollution caused the biggest overall reduction in biodiversity in the Mamanuca region. If areas were to be prioritised for community rehabilitation, those downcurrent of point sources of sewage pollution would be important. Encouraging results from survey responses indicated that scientists are aware of the detrimental effect of enhancing nutrient load, particularly on coral diversity.

Clear discriminations were apparent between coral communities by virtue of which reef complex communities belonged to while factors influencing fish and invertebrate communities were less detectable.

Univariate techniques did not reveal relationships between habitat characteristics and fish populations. While no statistically significant relationships were found, cluster analyses did infer that live coral cover has a degree of influence over fish populations. An analysis of individual fish families may reveal more robust relationships. Possible constraints of the survey methodology and inability to take into account additional factors such as ecological pressures and depth, currents etc. simultaneously should be borne in mind.

Conservation class distribution revealed a dominance of competitors, inferring that stresses are low-level and constant. The low biodiversity coupled with comparatively high live coverage of polluted reefs provided a strong argument for the use of a parameter other than live coverage as an indicator of reef health. For an environmental manager, model predictions must be easy to obtain, customisable and easy to interpret (Wolanski, 2002). In addition, they must be founded on robust relationships that consistently provide an accurate assessment of reef health.

Both survey responses and the analysis of primary data revealed conservation class as a reliable indicator of reef health in terms of coral morphological diversity.

Conservation class derived from ternary diagrams both meets criteria for a management-friendly means of analysis and has proven to be based on robust ecological relationships. Additionally, the incorporation of life-form diversity as opposed to coral species richness makes the classification more suited to the locality, whereas tourism is widespread. This provides a strong argument for increasing its use among both the scientific and management communities in the Mamanucas.

Furthermore, conservation values could be tailored for each geographical area to take into account conservation priorities and the major threats to reef health (Edinger & Risk, 2000; Harborne *et al*, 2001). For this study region, the major threat has proven to be sewage pollution, while the conservation would likely prioritise the maintenance of aesthetic value for tourism.

The majority of respondents stated that the IDH was very relevant to reefs in the Mamanucas, yet this study did not yield evidence in support of the hypothesis.

Popular opinion would suggest it is a useful form of guidance in alliance with other methods. Supportive evidence for the IDH may be elicited from studies carried out at a different scale to that of the landscape. Alternatively, a parameter other than habitat complexity as a measure of disturbance could be employed.

Research among respondents was largely carried out for conservation purposes, thus a range of scales had been studied. Furthermore, standardisation has been achieved through adoption of the ReefCheck methodology.

Conservation measures were widespread both methodologically and geographically across Fiji. Additional recommendations include, increased grassroots participation at decision making levels for people with a close interdependency on reef resources. A clear preference among the scientific community has emerged for bottom-up management. Marine protected areas appear to be both popular and effective conservation approaches.

Scientific research clearly needs careful consideration so that it can be understood and employed effectively by the management community. The lack of a standardised approach to reef assessment, or consensus on generic ecological principles within the scientific community, presents a barrier to the effective integration of scientists and managers. Answers across the sample of scientists surveyed reflected a knowledge base in line with dominant themes in coral reef literature. Knowledge pertaining to the application of theories within the specific study region lacked consensus, despite the fact that all candidates had a working knowledge of the Mamanucas. Literature-based knowledge may be restrictive on both a temporal and spatial scale (Andre, 2001). Reef management in the Mamanucas would benefit from the widespread and in-depth investigation of how ecological theories apply so that management assumptions can be based on robust principles.

There is a clear mandate for a framework to provide methodological and conceptual guidelines that ecologists can follow. This, in turn, will assist the conduction of studies with applications for the management community across the board. Basic reef assessment tools that have proved effective include live coral cover and conservation class from coral morphology triangles. Furthermore, questionnaire responses have identified the possible use of indicator species and distance from Fijian villages as measures of reef health.

This study has highlighted that the application of ecological theory to coral reefs is a discursive practice, rooted in paradigms that are primarily controlled by the existing literature body. Further detailed study into the application and function of ecological theory will go a long way toward reaching consensus among scientists based in the Mamanuca region, which in turn will lead to sustainable reef management based on an increasingly comprehensive view.

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## 10. APPENDICES

Figure 17A. Physical survey form

|                                                                     |                                              |
|---------------------------------------------------------------------|----------------------------------------------|
| 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                                                      |                                              |
|                                                                     |                                              |
|                                                                     |                                              |
|                                                                     |                                              |
|                                                                     |                                              |
|                                                                     |                                              |
|                                                                     |                                              |

Figure 17B. Coral record form

[illegible]

Figure 17C. Fish and invertebrate record form

**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 ( <i>Cromileptes</i> )            |       |        |        |         |
| 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                                        |       |        |        |         |

**Indo-Pacific Belt Transect : Invertebrates**

Data recorded by:

|                                                     | 0-20m | 25-45m | 50-70m | 75-100m |
|-----------------------------------------------------|-------|--------|--------|---------|
| Banded coral shrimp ( <i>Stenopus hispidus</i> )    |       |        |        |         |
| Diadema urchins                                     |       |        |        |         |
| Pencil urchin ( <i>Heterocentrotus mamillatus</i> ) |       |        |        |         |
| Sea cucumber (edible only)                          |       |        |        |         |
| Crown-of-thorns star ( <i>Acanthaster</i> )         |       |        |        |         |
| Giant clam ( <i>Tridacna</i> )                      |       |        |        |         |
| Triton shell ( <i>Charonia tritonis</i> )           |       |        |        |         |
| <i>Drupella</i> 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:                            |  |  |  |  |

"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

Figure 18. Survey Questionnaire

**ADDRESSING STRATEGIES AND PRIORITIES FOR REEF MANAGEMENT IN  
THE MAMANUCAS**

Where relevant, please indicate your answer by placing a cross in the selected box or next to the word that represents your answer.

1. In what capacity do you work with Fijian reefs?

---



---

2. How long have you been studying Fijian reefs?

---

**ANTHROPOGENIC INFLUENCES**

3. In terms of the loss of reef biodiversity, how do you rate the level of impact from the following activities in the Mamanucas?

|                                          | <u>Very high</u> | <u>High</u> | <u>Medium</u> | <u>Low</u> | <u>Very low</u> |
|------------------------------------------|------------------|-------------|---------------|------------|-----------------|
| Dynamite fishing                         |                  |             |               |            |                 |
| Poison fishing                           |                  |             |               |            |                 |
| Aquarium fish collection                 |                  |             |               |            |                 |
| Harvest of invertebrates for food        |                  |             |               |            |                 |
| Harvest of invertebrates for curio sales |                  |             |               |            |                 |
| Tourist Diving                           |                  |             |               |            |                 |
| Sewage pollution                         |                  |             |               |            |                 |
| Industrial pollution                     |                  |             |               |            |                 |

4. Do you believe the following factors to have a high, medium or low level influence on coral, fish and invertebrate community composition of different reefs in the Mamanucas?

|                                  | Coral community<br>High    Medium    Low |  |  | Fish community<br>High    Medium    Low |  |  | Invertebrate community<br>High    Medium    Low |  |  |
|----------------------------------|------------------------------------------|--|--|-----------------------------------------|--|--|-------------------------------------------------|--|--|
| Type of anthropogenic influence  |                                          |  |  |                                         |  |  |                                                 |  |  |
| Reef complex                     |                                          |  |  |                                         |  |  |                                                 |  |  |
| Coral morphology (life strategy) |                                          |  |  |                                         |  |  |                                                 |  |  |
| Reef depth                       |                                          |  |  |                                         |  |  |                                                 |  |  |

5. Which of the following influences do you believe causes the biggest reduction in overall reef biodiversity?

Aquarium fish collection

Sewage pollution

Tourist diving

Harvest of invertebrates for food

Spear Fishing

#### **RELATIONSHIPS BETWEEN REEF PARAMETERS**

6. Have you found percentage live coral cover to be a good or bad indicator of any of the following?

|                               |      |         |     |
|-------------------------------|------|---------|-----|
| Fish diversity                | Good | Neither | Bad |
| Invertebrate diversity        | Good | Neither | Bad |
| Coral morphological diversity | Good | Neither | Bad |

7. Have you found any reliable predictors of fish species richness or overall abundance in the Mamanucas?

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#### **THE APPLICATION OF PRINCIPLES OUTLINED IN THE LITERATURE**

8. Have you ever performed a reef survey in line with the standard ReefCheck protocol?

Yes                      No

9. Have you performed a ReefCheck survey on a Fijian reef?

Yes                      No

10. Population dynamics can be open to large-scale processes, e.g the passage of larvae between reefs through currents. Diversity indicators can also vary depending upon what scale a reef is measured at. Do you study reefs at a number of different scales?

Yes No

11. Have you ever used a reef classification system based on primary adaptive strategy? Reefs can be assigned a conservation class based on the predominant life strategy of the corals present, i.e. the ratio of competitors to ruderals to stress-tolerators (Edinger & Risk, 2000). If no, go to *question 14*.

Yes No

12. Have you found primary adaptive strategy to be a reliable indicator of the following?

Coral species richness Yes Neither No

Coral morphological diversity Yes Neither No

13. Please rank the following predictors of coral diversity in order of increasing reliability (1=not very reliable, 3= very reliable)

Conservation class (Edinger & Risk)

Mortality index,  $MI = \text{dead corals} / (\text{live corals} + \text{dead corals})$

Percentage live coral cover

14. Are you aware of the intermediate disturbance hypothesis in relation to coral diversity? According to the non-equilibrium intermediate disturbance hypothesis, species diversity should be low at both low and high frequencies and intensities of disturbance. At intermediate levels of disturbance, a higher level of species diversity should be present. (Aronson & Precht, 1995) If no, go to *question 16*.

Yes No

15. How influential do you believe the intermediate disturbance hypothesis to be on patterns of reef diversity around the Mamanucas?

| Very High | High | Medium | Low | Very low |
|-----------|------|--------|-----|----------|
|           |      |        |     |          |

16. Would you typically prioritise areas of high, intermediate, or low disturbance when locating potential reserve sites?

High   Intermediate   Low

17. Have you employed any of the following investigative techniques on Fijian reefs?

|                                                       |     |    |
|-------------------------------------------------------|-----|----|
| Fine chain link measurement of topographic complexity | Yes | No |
| Any form of <i>ex situ</i> study of corals            | Yes | No |
| Habitat mapping using satellite imagery               | Yes | No |
| Assessed reef diversity at the genetic level          | Yes | No |

#### **CONSERVATION**

18. Please indicate whether you are aware of any of the following conservation measures being currently employed in Fiji.

|                                                  |     |    |
|--------------------------------------------------|-----|----|
| Marine protected area                            | Yes | No |
| <i>Ex situ</i> conservation/ captive propagation | Yes | No |
| The removal of unwanted species                  | Yes | No |
| Habitat restoration                              | Yes | No |
| Community rehabilitation                         | Yes | No |
| Limiting fishing effort                          | Yes | No |
| The protection of endangered species             | Yes | No |

Others

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19. Taking into account financial, political and social constraints, what conservation measures do you think can be employed most effectively in Fiji to maintain high levels of biodiversity for coral reef and their associated species?

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20. In a series of key points, please outline what you deem to be the major factors to be considered in successfully employing measures to conserve high levels of coral diversity.

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### **MANAGEMENT**

21. How influential would you say the following factors are in determining the outcome of reef management decisions in the Mamanucas?

| <b>Factor</b> | <b>Very Strong</b> | <b>Strong</b> | <b>Medium</b> | <b>Weak</b> | <b>Very weak</b> |
|---------------|--------------------|---------------|---------------|-------------|------------------|
| Social        |                    |               |               |             |                  |
| Financial     |                    |               |               |             |                  |
| Political     |                    |               |               |             |                  |
| Scientific    |                    |               |               |             |                  |

22. What diversity indicators do you commonly use, or know to be used in management decision making in Fiji?

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23. How influential would you say scientists are in decision-making at the managerial / policy making level in Fiji?

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24. What do you think are the major barriers to the successful implementation of conservation measures in the Mamanucas today?

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Additional Comments

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Table 12. Responses to open ended questions

| Question                                                                             | Responses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|--------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>1. Work capacity on Fijian reefs</b></p>                                       | <p><b>Sangeeta Mangubhai</b> WWF South Pacific regional coordinator for the marine programme<br/> <b>Professor Leon Zann</b> Staff, Uni South Pacific, 1979-85. Consultant National Environment Management Program (1992-3). Crown of thorns starfish monitoring (group database, annual Suva reef) 1982-2001. Ono-I-Lau management 2000-present.<br/> <b>Dr. David Obura</b> I conducted surveys of two reef areas as a consultant to WWF.<br/> <b>Etika Rupeni</b> I work as marine conservation officer establishing marine protected areas in Fiji.<br/> <b>Annette Muehlig-Hoffmann</b> I conducted my PhD on Fijian reefs, including the Mamanucas- studied localised elevated nitrogen levels near island populations<br/> <b>Patrick Saki Fong</b> Community-based marine resources management program. (Environment Unit of the Institute of Applied Science, The University of the South Pacific)<br/> <b>James Comley</b> Senior Field Scientist with Coral Cay Conservation; currently analysing data towards the production of thematic habitat maps for the end of year-one report</p> |
| <p><b>7. Alternative reliable indicator of fish diversity</b></p>                    | <p><b>Leon Zann</b> Distance from Fijian villages<br/> <b>Etika Rupeni</b> Demography<br/> <b>James Comley</b> From the work that CCC has done, not just in the Mamanucas, fish population structure and demography are not closely linked to habitat complexity and structure. In fact, in most data sets we analyse, there is no multivariate statistical link between fish populations and habitat characteristics. Observations of fish species richness and abundance must therefore be made directly.<br/> <b>Patrick Saki Fong</b> The presence of some rare and endangered species, for instance, the Maori wrasse is a Good indicator of fish species richness in the Mamanucas.</p>                                                                                                                                                                                                                                                                                                                                                                                                        |
| <p><b>18. Are you aware of any other conservation measures employed in Fiji?</b></p> | <p><b>Anette Muehlig-Hoffmann</b> Community managed marine areas, fisheries reserves<br/> <b>Patrick Saki Fong</b> Species restocking and species specific ban</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

| 19. Effective measures for maintaining high levels of biodiversity in the study region | <p><b>Sangeeta Mangubhai.</b> Networks of marine protected areas in each of the island groups would be a good way to work, given the political divisions/legal divisions in the country. In addition, more efforts need to make on good fisheries management, as a means of protecting habitats, species and biodiversity.</p> <p>1. Involvement of key stakeholders in management – looking at appropriate levels/options for co-management. 2. Bleaching threats, and the need to better design MPAs to protect those areas more resistant and resilient to bleaching. 3. Education and awareness on coral reefs with local communities, and tourism operators. Government action in developing a national plan for the management of Fiji's reefs, and putting in place policies that support MPAs – this includes the need to implement and give more legal backing to the NBSAP as well as the Sustainability Generally, not very influential as there is a large gap between scientists, communities and decision makers. Low capacity and small numbers of qualified local scientists is a large problem, especially in the marine/fisheries sector.</p> <p><b>Professor Leon Zann</b> Community based, rather than national PAs, with compensation (financial or alternative industries) for loss of fishing or other usage rights. PAs with restrictions on reef gleaning, use of poisons and dynamite, control of crown of thorns starfish outbreaks in strategic areas etc.</p> <p><b>Etika Rupeni</b> Identifying high biologically significant areas and placing protective measures through the collaboration of stakeholders</p> <p><b>Anette Muehlig-Hoffmann</b> MPAs involving local communities in management</p> <p><b>Patrick Saki Fong</b> Using the “bottom up” approach. Utilising the knowledge and skills of fishers and fishing ground owners in Fiji is proven effective because this is the level where most of the fishing activities taking place. Therefore, any management actions (MPA, effort/gear restrictions etc....) employed should filter down or be heard at this level Good and strong leadership in the area, The dependence of people in the area on marine resources</p> <p>Degree of consensus from stakeholders, Density and diversity of people on site</p> <p><b>James Comley</b> Multi-stakeholder, Integrated Coastal Zone Management employing some form of zoning strategy that enables use of the marine resource by all stakeholders is the only way it can work in Fiji. However, as I am sure you appreciate mediation between all stakeholder groups is a long and difficult process. Short term measures include the establishment of top-down management planning including no-take areas and recreational use areas. The problem of these within the context of Fiji is the native land law and stewardship regulations that exist there. These make any such ‘top-down’ management initiatives difficult to implement. Stakeholder interactions. Stewardship of the resource- resort owners vs resource owners in the case of the Mamanucas. Education</p> |
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|-----------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>22. Diversity indicators commonly employed in management decision making</b></p>              | <p><b>Professor Leon Zann</b> Quantitative estimates of coral cover and diversity</p> <p><b>Dr. David Obura</b> Species and taxon diversity in a selection of different groups.</p> <p>Coral cover and diversity</p> <p><b>Etika Rupeni</b> Community catch data, scientific surveys</p> <p><b>James Comley</b> If you are referring to individual indicator species, then <i>Trochus nobilis</i> (Tritons Trumpet), <i>Acanthaster planci</i> (COT), Butterfly fish sp., <i>Tridacna</i> sp. (Giant clams) If referring to analytical indicators then; Univariate community measures; Total species, Shannon-Weiner, Pielous evenness, Marglef species eveness.</p> <p>Multivariate; ANOSIM (analysis of similarity within PRIMER software), primary adaptive strategy</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <p><b>23. Influence of scientists in decision-making at the managerial/ policy-making level</b></p> | <p><b>Sangeeta Mangubhai</b> Generally, not very influential as there is a large gap between scientists, communities and decision makers. Low capacity and small numbers of qualified local scientists is a large problem, especially in the marine/fisheries sector.</p> <p><b>Professor Leon Zann</b> Minimal influence in the past, but agencies such as WWF becoming more influential</p> <p><b>David Obura</b> Primary decisions are always political, social and economic</p> <p><b>Etika Rupeni</b> WE are still yet to see a more collaborative effort between scientists and reef managers</p> <p><b>Anette Muehlig-Hoffmann</b> Volunteer-led organisations are becoming more influential, yet currently social (ease of harvesting ground use for invertebrates &amp; willingness to change and political factors (chief systems) prevail.</p> <p><b>Patrick Saki Fong</b> Surveys and research results done by most scientists in Fiji do not have much influence in decision making, mainly because most policy/decision makers are unaware of them.</p> <p><b>James Comley</b> Not as influential as would be liked. Fiji is struggling at the moment because of the delay in passing the sustainable development bill through parliament. This bill will empower scientists far more in the management planning process- for example making environmental impact assessments mandatory for larger developments in the foreshore and coastal zone. The bill however spans the jurisdiction of many departments and passing it will be complicated. As far as I am aware, the bill has been in draft format since 1998 and still looks no nearer completion. Without the bill, the Ministry of the Environment is pretty toothless</p> |



|                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>24. Barriers to the successful implementation of conservation measures in the Mamanucas</b></p> | <p><b>Sangeeta Mangubhai</b> Previous attempts at implementing a Marine Park in the group have not produced any tangible results after &gt;11 years of work – design of the Marine Park concept too much like those established in Australia, and are not necessarily appropriate from a cultural/social aspect. The management structure that was proposed was far too complex, and likely to be unnecessarily expensive, and hence not sustainable in Fiji. Lack of government support and leadership in supporting the establishment of MPAs has been a large barrier in designating MPAs. Also until recently, the involvement of communities in management has been non-existent.</p> <p><b>Leon Zann</b> Conventional conservation strategies, MPAs have had limited implementation in the past (eg National Environmental management program) because of attempts to impose western national park models. Several tourist resorts (eg Treasure Island) have PAs through agreement with customary Fijian owners (ie owners have been financially compensated through loans of fishing opportunities)</p> <p>Important to develop culturally appropriate conservation measures, co-management and self-management (through community education etc)</p> <p><b>David Obura</b> Excessive tourism development and financial interests that will promote cosmetic conservation to market to tourists over substantive actions.</p> <p><b>Etika Rupeni</b> Lack of community involvement</p> <p><b>Anette Muehlig-Hoffmann</b> Lack of funding for in-depth studies such as the impact from sewage on reefs by looking at the 15-N content</p> <p><b>Patrick Saki Fong</b> Tourism industry- most conservation measures conflict with tourism activities Since there is division among chiefs, getting consensus from communities would be very hard to achieve.</p> <p><b>James Comley</b> The community stakeholder situation in Fiji is complex, especially in areas reliant on the tourism industry for their primary income- like the Mamanucas. Resource owners ultimately have the final say in management initiatives because of the native land laws. It strikes me there is often a conflict between political agendas, those of the feudal hierarchy (chiefs etc) and the resort owners in the tourism dominated areas.</p> |
|-------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|



| Additional comments | <p><b>Sangeeta Mangubhai</b> Organisations such as USP, WWF and FSP have substantial knowledge working with local communities developing management systems for marine resources that have been relatively successful and can be built upon. There is substantial literature in the Pacific too on mechanisms for co-management and protecting biodiversity.</p> <p>The Mamanuca group, because of importance for tourism and government revenue, needs to be approached in the different manner than other island groups – however the lessons learned from above will be applicable and useful for future directions for this island group. In terms of investment from a biodiversity point of view, there are far more areas outside the Mamanuca group that need to be protected from a straight biodiversity perspective. However, from the tourism, income for local community point of view, the area would benefit greatly from the development of a system of management to rehabilitate the reefs in the area, and minimise any further degradation.</p> <p><b>Leon Zann</b> My experience in ten years in the Great barrier Reef marine park, 8 yrs in Fiji etc is that the application of ecological theory to coral reef management (even on the well researched and managed GBR) has been very limited. Management decisions are generally based on political and social factors. In Fiji where there is customary marine tenure, it means working with the sea-holding groups, and conservation of whatever areas are possible rather than the optimal sites.</p> <p><b>Patrick Saki Fong</b> To have a successful conservation project in the Mamanucas, all stakeholders in the area should approach it as a team and not individually. The main two issues in the Mamanucas are sewerage pollution from hotels and the use of the fishing ground for tourist activities, therefore, fishing ground owner and hotel owners should find solutions to the two problems.</p> |
|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
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Table 13 Pressure categorisation codes: SP= sewage pollution, AFC= Aquarium fish collection, TD= Tourist diving, HIF= Harvest of invertebrates for food, SF= Spear fishing

| Site | Primary pressure | Conservation class | % live coral cover | Substrate richness | SW fish | Fish abundance | Fish species richness | Invertebrate species richness | Distance to nearest population centre/ km | Mortality index | Reef complex | Depth | Coral species richness | Shannon Equitability | Coral morphological diversity |
|------|------------------|--------------------|--------------------|--------------------|---------|----------------|-----------------------|-------------------------------|-------------------------------------------|-----------------|--------------|-------|------------------------|----------------------|-------------------------------|
| RCA1 | SP               | 2                  | 31.25              | 7                  | 1.3     | 30.25          | 6                     | 4                             | 0.6                                       | 0               | IM           | 5     | 4                      | 1.89                 | 1.24                          |
| RCA2 | AFC              | 2                  | 14.38              | 7.5                | 1.11    | 47.25          | 5                     | 3                             | 0.6                                       | 1               | IM           | 5     | 6                      | 2.06                 | 1.22                          |
| RCA3 | TD               | 1                  | 22.5               | 5.5                | 1.19    | 16             | 6                     | 3                             | 0.3                                       | 0               | IM           | 3     | 3                      | 1.86                 | 1.32                          |
| RCA4 | TD               | 3                  | 5                  | 7.5                | 1.15    | 21             | 5                     | 4                             | 0.5                                       | 0.1             | IM           | 4     | 0                      | 1.96                 | 0                             |
| RHM1 | HIF              | 2                  | 37.5               | 6.5                | 0.7     | 90.75          | 5                     | 2                             | 1                                         | 0               | IM           | 5     | 12                     | 1.92                 | 1.83                          |
| RIB1 | AFC              | 4                  | 20.63              | 7.5                | 1.38    | 14             | 6                     | 4                             | 0.5                                       | 0.1             | OM           | 3     | 6                      | 1.57                 | 1.67                          |
| RIB2 | TD               | 2                  | 39.38              | 5.5                | 1       | 17.5           | 4                     | 2                             | 0.5                                       | 0.3             | OM           | 1     | 10                     | 2.05                 | 1.74                          |
| RIB3 | AFC              | 2                  | 11.88              | 7                  | 0.58    | 4.25           | 3                     | 2                             | 0.8                                       | 0.8             | OM           | 3     | 6                      | 2.04                 | 1.78                          |
| RM11 | TD               | 2                  | 22.5               | 8                  | 1.31    | 17             | 6                     | 3                             | 0.2                                       | 1               | NO           | 20    | 4                      | 1.59                 | 1.65                          |
| RM13 | TD               | 4                  | 36.63              | 7.5                | 1.08    | 12             | 4                     | 2                             | 0.5                                       | 0               | NO           | 6     | 7                      | 2.11                 | 1.59                          |
| RM14 | SF               | 2                  | 31.25              | 6.5                | 1.16    | 19.75          | 6                     | 3                             | 0.3                                       | 0.7             | NO           | 13.5  | 8                      | 1.40                 | 1.22                          |
| RM11 | AFC              | 1                  | 40.01              | 7                  | 1.12    | 11.75          | 5                     | 1                             | 0.25                                      | 0               | IM           | 7     | 6                      | 1.69                 | 1.09                          |
| RM12 | HIF              | 1                  | 23.13              | 6                  | 1.3     | 53.5           | 8                     | 0                             | 0.3                                       | 0.7             | IM           | 4     | 6                      | 2.14                 | 1.3                           |
| RM13 | SP               | 2                  | 14.38              | 7                  | 1.33    | 17.5           | 4                     | 3                             | 2                                         | 0               | IM           | 6     | 7                      | 2.14                 | 1.18                          |
| RNA1 | HIF              | 4                  | 38.75              | 6.5                | 1.22    | 14.5           | 5                     | 3                             | 0.4                                       | 0.2             | OM           | 3     | 10                     | 2.03                 | 1.85                          |
| RN11 | TD               | 4                  | 32.5               | 8                  | 1.08    | 22             | 3                     | 4                             | 0.5                                       | 0.2             | NA           | 5     | 11                     | 0.00                 | 1.65                          |
| RRA1 | HIF              | 1                  | 14.38              | 7.5                | 1.78    | 55.25          | 10                    | 3                             | 0.5                                       | 0.5             | IM           | 3     | 8                      | 2.15                 | 1.3                           |
| RRA2 | TD               | 3                  | 5.63               | 8                  | 0.56    | 9              | 3                     | 1                             | 0.2                                       | 0.3             | IM           | 4     | 3                      | 1.88                 | 1.15                          |
| RSF1 | HIF              | 2                  | 46.25              | 6.5                | 0.89    | 208            | 11                    | 0                             | 0.8                                       | 0               | OM           | 14    | 13                     | 2.16                 | 1.95                          |
| RSF2 | HIF              | 4                  | 45                 | 6                  | 1.13    | 78.25          | 7                     | 4                             | 0.8                                       | 0               | OM           | 4     | 13                     | 2.74                 | 1.87                          |
| RSM1 | TD               | 1                  | 23.13              | 7                  | 1.55    | 33.25          | 7                     | 2                             | 0.8                                       | 0               | MA           | 8     | 9                      | 2.12                 | 1.02                          |
| RW11 | HIF              | 4                  | 8.75               | 7                  | 0.99    | 21.5           | 5                     | 3                             | 0.3                                       | 0.2             | IM           | 6     | 7                      | 1.91                 | 1.81                          |



Table 14. Mean coral abundance on each transect for each site

|                           | RCA1 | RCA2 | RCA3 | RCA4 | RHM1 | RIB1 | RIB2 | RIB3 | RMI1 | RMI3 | RMI4 | RML1 | RML2 | RML3 | RML4 | RNA1 | RNI1 | RRA1 | RRA2 | RSF1 | RSF2 | RSM1 | RWI1 |
|---------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| <i>Pocillopora small</i>  | 0    | 0    | 0.25 |      | 1.25 | 1.5  | 0.25 | 1    | 0.25 | 0.25 | 0.25 | 0.5  | 0.25 | 0.25 | 0    | 0.25 | 0.5  | 0.25 | 0.25 | 1.5  | 0.75 | 0    | 0.25 |
| <i>Pocillopora medium</i> | 0    | 0    |      |      | 0.25 |      |      | 0    | 0    | 0.75 | 1.5  | 0    | 0    | 0    | 0    | 0.25 | 0.25 | 0    | 0    | 0    | 0    | 1.25 | 0    |
| <i>Pocillopora large</i>  | 0    | 0    |      |      |      |      |      | 0    | 0    | 1    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| <i>S. hystrix</i>         | 0    | 0    |      |      | 0.25 | 0.25 | 6    | 0.25 | 0    | 0    | 0    | 0    | 0    | 0    | 0.25 | 0.75 | 0    | 0    | 0    | 0    | 0.25 | 0    | 0    |
| <i>Stylophora</i>         | 0    | 1.25 |      |      |      |      |      | 0    | 0.25 | 0    | 0    | 0.25 | 0    | 0    | 0    | 0    | 0    | 0    | 0.25 | 0.25 | 0    | 0    | 0    |
| <i>M. digitata</i>        | 0    | 0    |      |      | 0.25 | 0.5  |      | 0    | 0    | 0    | 0    | 0    | 0    | 0.25 | 0.5  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| <i>B. Acropora</i>        | 0    | 0    |      |      | 0.25 |      | 3    | 0.25 | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.25 | 1.5  | 0    | 0.25 |
| <i>Massive Porites</i>    | 1.5  | 1.5  | 2    |      | 0.25 | 1.25 | 1.25 | 0.5  | 2    | 1.75 | 1.25 | 5.75 | 4.75 | 1    | 1.75 | 1.75 | 0.25 | 0.5  | 0    | 0.5  | 0    | 3.5  | 0.25 |
| <i>P. cylindrica</i>      | 7    | 0.5  |      |      |      |      |      | 0    | 0    | 0    | 0    | 1    | 4    | 1.25 | 0    | 1.25 | 0    | 2    | 0    | 0    | 0.5  | 0    | 0    |
| <i>P. nigrescens</i>      | 0    | 0    |      |      |      |      |      | 0    | 0    | 0    | 0    | 0    | 0    | 0.5  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| <i>P. rus</i>             | 2    | 1.5  | 4.25 |      | 0.25 |      |      | 0    | 0    | 0    | 0    | 1.25 | 0.75 | 1.75 | 1.25 | 2    | 0    | 1.25 | 0    | 0    | 0    | 0    | 0    |
| <i>Goniopora</i>          | 0    | 0    |      |      |      |      |      | 0    | 0    | 0    | 0    | 0    | 0.25 | 0    | 0    | 0    | 0.5  | 0.25 | 0    | 0    | 0    | 0    | 0    |
| <i>P. speciosa</i>        | 0    | 0    |      |      |      |      |      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.25 | 0    | 0    | 0    | 0.25 | 0.75 | 0    | 0    |
| <i>P. rugosa</i>          | 0    | 0.25 |      |      |      |      |      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 2.5  | 0.25 | 0    | 0    |
| <i>C. echinata</i>        | 0    | 0    |      |      |      |      |      | 0.5  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.25 | 0    | 0    | 0    |
| <i>H. linax</i>           | 0    | 0    |      |      |      |      |      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.25 | 0    | 0    | 0    |
| <i>P. talpina</i>         | 0    | 0.5  |      |      |      |      |      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.25 | 0    | 0    | 0    | 0.5  | 0    | 0    | 0    |
| <i>H. pileus</i>          | 0    | 0    |      |      |      |      |      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.25 | 0    | 0    | 0    |
| <i>Galaxea</i>            | 0    | 0    | 0.25 |      | 1    |      | 1.25 | 0    | 0    | 0    | 0.75 | 0    | 0    | 0    | 0    | 0.25 | 1.25 | 0    | 0    | 0.25 | 0.75 | 0.25 | 0    |
| <i>P. lactuca</i>         | 0    | 0    |      |      |      |      |      | 0    | 0    | 0    | 0.25 | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.25 | 0    | 0    |
| <i>M. elephantotus</i>    | 0    | 0    |      |      |      |      |      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.5  | 0    | 0    | 0    | 1.25 | 0    | 0    |
| <i>Lobophyllia</i>        | 0    | 0    |      |      | 0.25 |      |      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.25 | 0    | 0    | 0    | 0    | 0.25 | 0.25 |
| <i>Favia</i>              | 0    | 0    |      |      | 0.75 |      | 0.5  | 0    | 0    | 0.25 | 0.75 | 0    | 0    | 0    | 0    | 0    | 0.25 | 0.5  | 0    | 0    | 0.5  | 1.25 | 0    |
| <i>Favites</i>            | 0    | 0    |      |      | 0.75 |      | 1.3  | 0    | 0    | 0.25 | 0.75 | 0    | 0.25 | 0    | 0    | 0.25 | 0.75 | 0.25 | 0.25 | 1    | 0.25 | 1.25 | 0.25 |
| <i>D. heliopora</i>       | 0    | 0    |      |      |      |      | 2.5  | 0.75 | 0    | 0    | 0.25 | 0    | 0    | 0    | 0    | 0    | 1.75 | 0.25 | 0    | 0    | 0    | 0.5  | 0    |
| <i>Pterogyra</i>          | 0    | 0    |      |      |      |      |      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| <i>M. platyphylla</i>     | 0    | 0    |      |      |      |      |      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.25 | 0    | 0    |
| <i>M. intricata</i>       | 0    | 0    |      |      |      |      |      | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| <i>T. reniformis</i>      | 0.25 | 0    |      |      | 1.25 | 0.25 | 0.25 | 0    | 0    | 0    | 0    | 0.25 | 0    | 0.5  | 1.5  | 0    | 0.25 | 0    | 0    | 0    | 0.25 | 0    | 0    |
| <i>Brain small</i>        | 0    | 0    |      |      |      | 0.25 | 0.5  | 0    | 0.25 | 0    | 0    | 0    | 0    | 0    | 0.25 | 0    | 0    | 0    | 0    | 0    | 0    | 0.25 | 0.25 |
| <i>Brain medium</i>       | 0    | 0    |      |      |      |      |      | 0    | 0    | 0.25 | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.25 | 0    | 0.25 | 0.5  |

Table 15. Occurrence and extent of different impacts on the Mamanuca reefs. (1=low intensity, low weighting, 6= high intensity, high weighting, see §2.2). No evidence of industrial pollution, dynamite or poison fishing was recorded, these impacts have been omitted for clarity.

| Site | Aquarium fish collection | Harvest of invertebrates for food | Harvest of invertebrates for curio sales | Tourist diving | Sewage pollution | Pressure classification |
|------|--------------------------|-----------------------------------|------------------------------------------|----------------|------------------|-------------------------|
| RCA1 | 0                        | 3                                 | 3                                        | 2              | 4                | SP                      |
| RCA2 | 6                        | 3                                 | 3                                        | 2              | 0                | AFC                     |
| RCA3 | 0                        | 0                                 | 0                                        | 1              | 0                | TD                      |
| RCA4 | 0                        | 0                                 | 0                                        | 1              | 0                | TD                      |
| RHM1 | 0                        | 3                                 | 3                                        | 2              | 0                | HIF                     |
| RIB1 | 6                        | 0                                 | 0                                        | 1              | 0                | AFC                     |
| RIB2 | 0                        | 0                                 | 0                                        | 1              | 0                | TD                      |
| RIB3 | 6                        | 3                                 | 3                                        | 2              | 0                | AFC                     |
| RM11 | 6                        | 0                                 | 0                                        | 2              | 0                | AFC                     |
| RM13 | 0                        | 0                                 | 0                                        | 2              | 0                | TD                      |
| RM14 | 6                        | 6                                 | 6                                        | 2              | 0                | HIF                     |
| RML1 | 0                        | 0                                 | 0                                        | 1              | 0                | TD                      |
| RML2 | 0                        | 0                                 | 0                                        | 0              | 0                | Fishing                 |
| RML3 | 6                        | 6                                 | 3                                        | 1              | 4                | SP                      |
| RNA1 | 0                        | 6                                 | 0                                        | 0              | 0                | HIF                     |
| RNI1 | 0                        | 0                                 | 0                                        | 1              | 0                | TD                      |
| RRA1 | 0                        | 3                                 | 0                                        | 1              | 0                | HIF                     |
| RRA2 | 0                        | 0                                 | 0                                        | 1              | 0                | TD                      |
| RSF1 | 3                        | 6                                 | 3                                        | 3              | 0                | HIF                     |
| RSF2 | 3                        | 6                                 | 3                                        | 3              | 0                | HIF                     |
| RSM1 | 0                        | 0                                 | 0                                        | 3              | 0                | TD                      |
| RWI1 | 0                        | 6                                 | 0                                        | 1              | 4                | HIF                     |



Figure 19. Similarity percentage analysis of coral data

PRIMER 02/04/03

## SIMPER

Similarity Percentages - species contributions

### Worksheet

File: A:\CORAL DATA.pri  
Sample selection: All  
Variable selection: All

### Parameters

Standardise data: No  
Transform: None  
Cut off for low contributions: 90.00%  
Factor name: Reef complex

### Factor groups

IM  
OM  
NO  
NA  
MA

#### Group IM

Average similarity: 30.23

| Species            | Av.Abund | Av.Sim | Sim/SD | Contrib% |
|--------------------|----------|--------|--------|----------|
| Cum.%              |          |        |        |          |
| Massive Porites    | 1.75     | 10.47  | 1.05   | 34.62    |
| 34.62              |          |        |        |          |
| Porites rus        | 1.30     | 9.45   | 1.00   | 31.24    |
| 65.86              |          |        |        |          |
| Porites cylindrica | 1.43     | 4.17   | 0.50   | 13.80    |
| 79.67              |          |        |        |          |
| Pocillopora small  | 0.30     | 2.68   | 0.79   | 8.86     |
| 88.53              |          |        |        |          |
| Favites            | 0.16     | 1.18   | 0.38   | 3.89     |
| 92.42              |          |        |        |          |

#### Group OM

Average similarity: 26.55

| Species           | Av.Abund | Av.Sim | Sim/SD | Contrib% |
|-------------------|----------|--------|--------|----------|
| Cum.%             |          |        |        |          |
| Pocillopora small | 0.88     | 8.93   | 1.03   | 33.64    |
| 33.64             |          |        |        |          |
| Massive Porites   | 0.88     | 6.72   | 1.04   | 25.30    |
| 58.93             |          |        |        |          |

|                       |      |      |      |       |
|-----------------------|------|------|------|-------|
| Seriatopora hystrix   | 1.25 | 2.78 | 1.15 | 10.47 |
| 69.40                 |      |      |      |       |
| Bottlebrush Acropora  | 0.83 | 1.95 | 0.58 | 7.33  |
| 76.73                 |      |      |      |       |
| Favites               | 0.47 | 1.47 | 0.64 | 5.55  |
| 82.27                 |      |      |      |       |
| Galaxea               | 0.42 | 1.34 | 0.70 | 5.06  |
| 87.34                 |      |      |      |       |
| Pachyseris speciosa   | 0.21 | 0.66 | 0.48 | 2.48  |
| 89.82                 |      |      |      |       |
| Turbinaria reniformis | 0.13 | 0.59 | 0.45 | 2.21  |
| 92.03                 |      |      |      |       |

*Group NO*

Average similarity: 48.04

| Species            | Av.Abund | Av.Sim | Sim/SD | Contrib% |
|--------------------|----------|--------|--------|----------|
| Cum. %             |          |        |        |          |
| Massive Porites    | 1.67     | 34.03  | 2.70   | 70.83    |
| 70.83              |          |        |        |          |
| Pocillopora small  | 0.25     | 5.89   | 5.83   | 12.25    |
| 83.08              |          |        |        |          |
| Pocillopora medium | 0.75     | 4.88   | 0.58   | 10.15    |
| 93.23              |          |        |        |          |

*Group NA*

Less than 2 samples in group

*Group MA*

Less than 2 samples in group

*Groups IM & OM*

Average dissimilarity = 77.06

| Species               |          | Group IM | Group OM |         |
|-----------------------|----------|----------|----------|---------|
| Diss/SD               | Contrib% | Av.Abund | Av.Abund | Av.Diss |
|                       | Cum. %   |          |          |         |
| Massive Porites       |          | 1.75     | 0.88     | 10.33   |
| 1.03                  | 13.41    |          |          | 13.41   |
| Porites rus           |          | 1.30     | 0.33     | 9.56    |
| 1.05                  | 12.41    |          |          | 25.82   |
| Porites cylindrica    |          | 1.43     | 0.29     | 9.47    |
| 0.79                  | 12.28    |          |          | 38.10   |
| Seriatopora hystrix   |          | 0.05     | 1.25     | 6.44    |
| 0.69                  | 8.36     |          |          | 46.46   |
| Pocillopora small     |          | 0.30     | 0.88     | 6.26    |
| 1.07                  | 8.12     |          |          | 54.58   |
| Bottlebrush Acropora  |          | 0.05     | 0.83     | 4.84    |
| 0.88                  | 6.28     |          |          | 60.86   |
| Pachyseris rugosa     |          | 0.02     | 0.46     | 3.48    |
| 0.50                  | 4.51     |          |          | 65.38   |
| Diploastrea heliopora |          | 0.02     | 0.54     | 3.42    |
| 0.69                  | 4.44     |          |          | 69.82   |

|                       |      |       |      |      |      |
|-----------------------|------|-------|------|------|------|
| Favites               |      |       | 0.16 | 0.47 | 2.96 |
| 1.11                  | 3.84 | 73.66 |      |      |      |
| Turbinaria reniformis |      |       | 0.34 | 0.13 | 2.82 |
| 0.72                  | 3.66 | 77.32 |      |      |      |
| Galaxea               |      |       | 0.11 | 0.42 | 2.78 |
| 1.03                  | 3.61 | 80.92 |      |      |      |
| Mycedium elephantotus |      |       | 0.00 | 0.21 | 1.61 |
| 0.43                  | 2.08 | 83.01 |      |      |      |
| Pachyseris speciosa   |      |       | 0.00 | 0.21 | 1.60 |
| 0.74                  | 2.08 | 85.08 |      |      |      |
| Favia                 |      |       | 0.11 | 0.17 | 1.54 |
| 0.73                  | 2.00 | 87.08 |      |      |      |
| Stylophora            |      |       | 0.16 | 0.04 | 1.53 |
| 0.49                  | 1.99 | 89.07 |      |      |      |
| Montipora digitata    |      |       | 0.09 | 0.08 | 1.33 |
| 0.61                  | 1.73 | 90.80 |      |      |      |

Groups IM & NO

Average dissimilarity = 71.91

| Species               |          |       | Group IM<br>Av.Abund | Group NO<br>Av.Abund | Av.Diss |
|-----------------------|----------|-------|----------------------|----------------------|---------|
| Diss/SD               | Contrib% | Cum.% |                      |                      |         |
| Massive Porites       |          |       | 1.75                 | 1.67                 | 14.28   |
| 1.07                  | 19.86    | 19.86 |                      |                      |         |
| Porites rus           |          |       | 1.30                 | 0.00                 | 11.72   |
| 1.08                  | 16.30    | 36.16 |                      |                      |         |
| Porites cylindrica    |          |       | 1.43                 | 0.00                 | 11.02   |
| 0.74                  | 15.33    | 51.48 |                      |                      |         |
| Pocillopora medium    |          |       | 0.02                 | 0.75                 | 7.03    |
| 1.13                  | 9.78     | 61.26 |                      |                      |         |
| Pocillopora large     |          |       | 0.00                 | 0.33                 | 3.43    |
| 0.64                  | 4.77     | 66.03 |                      |                      |         |
| Favia                 |          |       | 0.11                 | 0.33                 | 3.29    |
| 1.05                  | 4.57     | 70.60 |                      |                      |         |
| Turbinaria reniformis |          |       | 0.34                 | 0.00                 | 3.24    |
| 0.62                  | 4.51     | 75.11 |                      |                      |         |
| Favites               |          |       | 0.16                 | 0.33                 | 3.04    |
| 1.10                  | 4.23     | 79.34 |                      |                      |         |
| Galaxea               |          |       | 0.11                 | 0.25                 | 2.81    |
| 0.76                  | 3.90     | 83.25 |                      |                      |         |
| Stylophora            |          |       | 0.16                 | 0.08                 | 2.16    |
| 0.62                  | 3.01     | 86.26 |                      |                      |         |
| Pocillopora small     |          |       | 0.30                 | 0.25                 | 1.62    |
| 0.61                  | 2.26     | 88.51 |                      |                      |         |
| Brain medium          |          |       | 0.05                 | 0.08                 | 1.37    |
| 0.59                  | 1.91     | 90.42 |                      |                      |         |

Groups OM & NO

Average dissimilarity = 73.15

| Species |          |       | Group OM<br>Av.Abund | Group NO<br>Av.Abund | Av.Diss |
|---------|----------|-------|----------------------|----------------------|---------|
| Diss/SD | Contrib% | Cum.% |                      |                      |         |

|                       |      |      |      |
|-----------------------|------|------|------|
| Massive Porites       | 0.88 | 1.67 | 8.44 |
| 1.17 11.54 11.54      |      |      |      |
| Seriatopora hystrix   | 1.25 | 0.00 | 7.27 |
| 0.73 9.94 21.48       |      |      |      |
| Pocillopora small     | 0.88 | 0.25 | 6.67 |
| 1.11 9.12 30.60       |      |      |      |
| Pocillopora medium    | 0.04 | 0.75 | 6.20 |
| 1.15 8.47 39.07       |      |      |      |
| Bottlebrush Acropora  | 0.83 | 0.00 | 5.42 |
| 0.89 7.40 46.48       |      |      |      |
| Diploastrea heliopora | 0.54 | 0.08 | 3.91 |
| 0.78 5.35 51.83       |      |      |      |
| Pachyseris rugosa     | 0.46 | 0.00 | 3.77 |
| 0.48 5.15 56.98       |      |      |      |
| Favites               | 0.47 | 0.33 | 3.66 |
| 1.24 5.00 61.98       |      |      |      |
| Galaxea               | 0.42 | 0.25 | 3.36 |
| 1.15 4.60 66.58       |      |      |      |
| Pocillopora large     | 0.00 | 0.33 | 3.01 |
| 0.65 4.12 70.69       |      |      |      |
| Porites rus           | 0.33 | 0.00 | 2.91 |
| 0.43 3.98 74.67       |      |      |      |
| Favia                 | 0.17 | 0.33 | 2.85 |
| 1.10 3.89 78.56       |      |      |      |
| Porites cylindrica    | 0.29 | 0.00 | 2.53 |
| 0.60 3.46 82.03       |      |      |      |
| Mycedium elephantotus | 0.21 | 0.00 | 1.78 |
| 0.43 2.43 84.46       |      |      |      |
| Pachyseris speciosa   | 0.21 | 0.00 | 1.77 |
| 0.75 2.42 86.88       |      |      |      |
| Ctenactis echinata    | 0.13 | 0.00 | 1.47 |
| 0.56 2.01 88.89       |      |      |      |
| Brain small           | 0.13 | 0.08 | 1.27 |
| 0.90 1.73 90.62       |      |      |      |

Groups IM & NA

Average dissimilarity = 83.40

| Species                | Group IM<br>Av.Abund | Group NA<br>Av.Abund | Av.Diss |
|------------------------|----------------------|----------------------|---------|
| Diss/SD Contrib% Cum.% |                      |                      |         |
| Diploastrea heliopora  | 0.02                 | 1.75                 | 14.50   |
| 3.40 17.39 17.39       |                      |                      |         |
| Massive Porites        | 1.75                 | 0.25                 | 10.69   |
| 0.95 12.81 30.20       |                      |                      |         |
| Porites rus            | 1.30                 | 0.00                 | 9.66    |
| 1.07 11.58 41.79       |                      |                      |         |
| Galaxea                | 0.11                 | 1.25                 | 9.64    |
| 2.38 11.56 53.35       |                      |                      |         |
| Porites cylindrica     | 1.43                 | 0.00                 | 9.32    |
| 0.71 11.18 64.52       |                      |                      |         |
| Favites                | 0.16                 | 0.75                 | 4.87    |
| 2.46 5.84 70.37        |                      |                      |         |
| Mycedium elephantotus  | 0.00                 | 0.50                 | 4.20    |
| 3.48 5.04 75.40        |                      |                      |         |

|                         |      |      |      |
|-------------------------|------|------|------|
| Goniopora / Alveopora   | 0.05 | 0.50 | 3.87 |
| 2.52      4.64    80.04 |      |      |      |
| Turbinaria reniformis   | 0.34 | 0.25 | 3.09 |
| 0.98      3.71    83.75 |      |      |      |
| Pocillopora small       | 0.30 | 0.50 | 2.81 |
| 1.82      3.37    87.12 |      |      |      |
| Favia                   | 0.11 | 0.25 | 2.27 |
| 2.91      2.72    89.84 |      |      |      |
| Pocillopora medium      | 0.02 | 0.25 | 1.93 |
| 2.20      2.31    92.15 |      |      |      |

Groups OM & NA

Average dissimilarity = 71.90

| Species                      | Group OM<br>Av.Abund | Group NA<br>Av.Abund | Av.Diss |
|------------------------------|----------------------|----------------------|---------|
| Diss/SD    Contrib%    Cum.% |                      |                      |         |
| Diploastrea heliopora        | 0.54                 | 1.75                 | 11.24   |
| 2.52      15.63    15.63     |                      |                      |         |
| Galaxea                      | 0.42                 | 1.25                 | 7.08    |
| 1.45      9.84    25.48      |                      |                      |         |
| Seriatopora hystrix          | 1.25                 | 0.00                 | 6.32    |
| 0.65      8.79    34.27      |                      |                      |         |
| Massive Porites              | 0.88                 | 0.25                 | 5.13    |
| 1.26      7.14    41.41      |                      |                      |         |
| Bottlebrush Acropora         | 0.83                 | 0.00                 | 4.65    |
| 0.82      6.46    47.87      |                      |                      |         |
| Pocillopora small            | 0.88                 | 0.50                 | 4.37    |
| 1.29      6.08    53.95      |                      |                      |         |
| Favites                      | 0.47                 | 0.75                 | 4.35    |
| 1.75      6.06    60.01      |                      |                      |         |
| Mycedium elephantotus        | 0.21                 | 0.50                 | 4.08    |
| 3.32      5.67    65.68      |                      |                      |         |
| Goniopora / Alveopora        | 0.00                 | 0.50                 | 3.78    |
| 3.57      5.26    70.95      |                      |                      |         |
| Pachyseris rugosa            | 0.46                 | 0.00                 | 3.17    |
| 0.46      4.41    75.36      |                      |                      |         |
| Porites rus                  | 0.33                 | 0.00                 | 2.42    |
| 0.41      3.37    78.73      |                      |                      |         |
| Porites cylindrica           | 0.29                 | 0.00                 | 2.11    |
| 0.57      2.94    81.66      |                      |                      |         |
| Lobophyllia                  | 0.00                 | 0.25                 | 1.89    |
| 3.57      2.63    84.29      |                      |                      |         |
| Favia                        | 0.17                 | 0.25                 | 1.89    |
| 3.57      2.63    86.92      |                      |                      |         |
| Pocillopora medium           | 0.04                 | 0.25                 | 1.59    |
| 1.69      2.21    89.13      |                      |                      |         |
| Pachyseris speciosa          | 0.21                 | 0.00                 | 1.48    |
| 0.71      2.06    91.20      |                      |                      |         |

Groups NO & NA

Average dissimilarity = 73.85

Group NO    Group NA

| Species                | Av.Abund | Av.Abund | Av.Diss |
|------------------------|----------|----------|---------|
| Diss/SD Contrib% Cum.% |          |          |         |
| Diploastrea heliopora  | 0.08     | 1.75     | 15.69   |
| 4.69 21.25 21.25       |          |          |         |
| Massive Porites        | 1.67     | 0.25     | 13.57   |
| 2.52 18.38 39.62       |          |          |         |
| Galaxea                | 0.25     | 1.25     | 9.65    |
| 1.95 13.07 52.69       |          |          |         |
| Pocillopora medium     | 0.75     | 0.25     | 5.82    |
| 1.49 7.88 60.57        |          |          |         |
| Mycedium elephantotus  | 0.00     | 0.50     | 4.68    |
| 6.96 6.33 66.90        |          |          |         |
| Goniopora / Alveopora  | 0.00     | 0.50     | 4.68    |
| 6.96 6.33 73.24        |          |          |         |
| Favites                | 0.33     | 0.75     | 4.22    |
| 1.04 5.71 78.95        |          |          |         |
| Pocillopora large      | 0.33     | 0.00     | 3.03    |
| 0.58 4.10 83.05        |          |          |         |
| Lobophyllia            | 0.00     | 0.25     | 2.34    |
| 6.96 3.17 86.22        |          |          |         |
| Turbinaria reniformis  | 0.00     | 0.25     | 2.34    |
| 6.96 3.17 89.38        |          |          |         |
| Pocillopora small      | 0.25     | 0.50     | 2.34    |
| 6.96 3.17 92.55        |          |          |         |

*Groups IM & MA*

Average dissimilarity = 75.57

| Species                | Group IM<br>Av.Abund | Group MA<br>Av.Abund | Av.Diss |
|------------------------|----------------------|----------------------|---------|
| Diss/SD Contrib% Cum.% |                      |                      |         |
| Massive Porites        | 1.75                 | 3.50                 | 17.50   |
| 1.89 23.16 23.16       |                      |                      |         |
| Pocillopora medium     | 0.02                 | 1.25                 | 8.60    |
| 3.99 11.38 34.54       |                      |                      |         |
| Porites rus            | 1.30                 | 0.00                 | 8.25    |
| 1.07 10.92 45.46       |                      |                      |         |
| Porites cylindrica     | 1.43                 | 0.00                 | 8.10    |
| 0.70 10.72 56.18       |                      |                      |         |
| Favia                  | 0.11                 | 1.25                 | 7.98    |
| 2.88 10.56 66.74       |                      |                      |         |
| Favites                | 0.16                 | 1.25                 | 7.57    |
| 3.68 10.02 76.76       |                      |                      |         |
| Diploastrea heliopora  | 0.02                 | 0.50                 | 3.34    |
| 3.45 4.41 81.17        |                      |                      |         |
| Turbinaria reniformis  | 0.34                 | 0.00                 | 2.25    |
| 0.61 2.98 84.15        |                      |                      |         |
| Pocillopora small      | 0.30                 | 0.00                 | 2.03    |
| 0.90 2.68 86.84        |                      |                      |         |
| Galaxea                | 0.11                 | 0.25                 | 1.90    |
| 1.60 2.51 89.35        |                      |                      |         |
| Brain medium           | 0.05                 | 0.25                 | 1.75    |
| 4.28 2.31 91.66        |                      |                      |         |

*Groups OM & MA*

Average dissimilarity = 76.84

| Species               |          |       | Group OM | Group MA |         |
|-----------------------|----------|-------|----------|----------|---------|
| Diss/SD               | Contrib% | Cum.% | Av.Abund | Av.Abund | Av.Diss |
| Massive Porites       |          |       | 0.88     | 3.50     | 16.97   |
| 2.76                  | 22.09    | 22.09 |          |          |         |
| Pocillopora medium    |          |       | 0.04     | 1.25     | 7.75    |
| 3.71                  | 10.09    | 32.18 |          |          |         |
| Favia                 |          |       | 0.17     | 1.25     | 7.17    |
| 2.46                  | 9.34     | 41.51 |          |          |         |
| Pocillopora small     |          |       | 0.88     | 0.00     | 6.03    |
| 1.39                  | 7.85     | 49.37 |          |          |         |
| Favites               |          |       | 0.47     | 1.25     | 5.72    |
| 1.37                  | 7.44     | 56.81 |          |          |         |
| Seriatopora hystrix   |          |       | 1.25     | 0.00     | 5.63    |
| 0.63                  | 7.32     | 64.13 |          |          |         |
| Bottlebrush Acropora  |          |       | 0.83     | 0.00     | 4.09    |
| 0.80                  | 5.32     | 69.46 |          |          |         |
| Diploastrea heliopora |          |       | 0.54     | 0.50     | 3.84    |
| 1.88                  | 4.99     | 74.45 |          |          |         |
| Pachyseris rugosa     |          |       | 0.46     | 0.00     | 2.74    |
| 0.46                  | 3.57     | 78.02 |          |          |         |
| Porites rus           |          |       | 0.33     | 0.00     | 2.08    |
| 0.41                  | 2.71     | 80.73 |          |          |         |
| Galaxea               |          |       | 0.42     | 0.25     | 1.84    |
| 1.16                  | 2.39     | 83.12 |          |          |         |
| Porites cylindrica    |          |       | 0.29     | 0.00     | 1.81    |
| 0.57                  | 2.36     | 85.49 |          |          |         |
| Lobophyllia           |          |       | 0.00     | 0.25     | 1.60    |
| 4.09                  | 2.09     | 87.57 |          |          |         |
| Brain medium          |          |       | 0.04     | 0.25     | 1.35    |
| 1.76                  | 1.76     | 89.33 |          |          |         |
| Mycedium elephantotus |          |       | 0.21     | 0.00     | 1.28    |
| 0.41                  | 1.67     | 91.00 |          |          |         |

Groups NO & MA

Average dissimilarity = 49.91

| Species               |          |       | Group NO | Group MA |         |
|-----------------------|----------|-------|----------|----------|---------|
| Diss/SD               | Contrib% | Cum.% | Av.Abund | Av.Abund | Av.Diss |
| Massive Porites       |          |       | 1.67     | 3.50     | 13.92   |
| 10.06                 | 27.89    | 27.89 |          |          |         |
| Favia                 |          |       | 0.33     | 1.25     | 7.29    |
| 1.96                  | 14.60    | 42.49 |          |          |         |
| Favites               |          |       | 0.33     | 1.25     | 7.29    |
| 1.96                  | 14.60    | 57.10 |          |          |         |
| Pocillopora medium    |          |       | 0.75     | 1.25     | 5.46    |
| 1.14                  | 10.93    | 68.03 |          |          |         |
| Diploastrea heliopora |          |       | 0.08     | 0.50     | 3.28    |
| 2.38                  | 6.57     | 74.60 |          |          |         |
| Pocillopora large     |          |       | 0.33     | 0.00     | 2.52    |
| 0.58                  | 5.04     | 79.64 |          |          |         |
| Galaxea               |          |       | 0.25     | 0.25     | 2.50    |
| 3.01                  | 5.01     | 84.66 |          |          |         |

|                   |      |       |      |           |
|-------------------|------|-------|------|-----------|
| Lobophyllia       |      |       |      |           |
| 8.47              | 3.86 | 88.52 | 0.00 | 0.25 1.93 |
| Pocillopora small |      |       |      |           |
| 8.47              | 3.86 | 92.38 | 0.25 | 0.00 1.93 |

