REEF SURVEY FOR RAROTONGA

For the Cook Islands National Environment Service

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

EXECUTIVE SUMMARY

Comparative analysis between surveys of previous years and the present clearly indicated that the fore reefs (outer reef) around Rarotonga have been degraded and a phase shift in benthic community to a more algal-dominated reef has occurred. The shift was also noted in fish community assemblages between 1999 and 2006 with a general decrease in the abundance of planktivores and corallivores, an increase in herbivores, and a general increase in omnivores. While the phase shift was largely due to the recent outbreak of the crown-of-thorns starfish (COTS; lasting about 10 years), the impact of the five cyclones in 2005 may have been minimal due to the already degraded state of the fore reef.

Although, coral size data indicated that 86% of colonies on the fore reef were new recruits, 82% of these were hardy corals, suggesting that recovery is still in its early stages and less hardy corals are slowly colonizing. Furthermore, the establishment of soft coral and coralline algae at leeward sites as well as herbivore abundance at all sites may be indications that conditions are well set for recovery and recovery has begun. Based on the previous reef recovery from the COTS outbreak in the 1970's, at least 20 years is needed to reach pre-2000 conditions provided that the frequency of natural disturbances as well as anthropogenic disturbances do not increase.

Because conditions on Rarotonga are prime to favor top-down controls on algae (i.e. by herbivorous fish because of their abundance resulting from reduced fishing pressure due to the ciguatera scare), bottom-up controls (nutrient input) may now be the controlling factor of foremost concern and should be the focus of future monitoring to identify their sources.

Though natural events such as elevated temperatures, COTS predation and cyclones have impacted the reefs around Rarotonga, contributions from land may be dependent on factors such as site distance from land (width of lagoon), the size and land-usage and hydrogeology of watersheds, and accessibility for fishing. Differences noted between the exposures are fundamentally the result of differential environmental variables influencing reef development over time. In turn, the resultant geomorphology may be a primary control of present development, resulting in the noted differences between windward and leeward reefs. Our results suggest that the windward reefs of Rarotonga (i.e. Avarua) are more susceptible to land-based impacts. However, other studies would argue that the benthic community compositions found on the leeward side are more indicative of a continuous fresh water discharge. One of the goals of our future monitoring efforts will be to elucidate the relative influences of freshwater discharge and associated pollution.

Benthic communities within Rarotonga's lagoon back reefs have a high coverage of turf algae. Coral colonies were larger within the lagoon than on the fore reef, suggesting the impact of COTS may have been less there. Herbivores dominated most lagoon sites with benthic invertebrate predators dominating a few. Macro-algae and blue-green algae were observed in all areas of the lagoon, indicating that the lagoon may be experiencing elevated nutrient levels overall as a result of terrestrial runoff.

Data presented in this survey provides a snap-shot of present conditions around Rarotonga, however time series data obtained from continuous monitoring of all fore reef and lagoon sites may enable us to identify changes at the community level that may be related to land-based activities. Multi-Dimensional Scaling analyses of fore reef corals and fish (by trophic level) between windward and leeward exposures indicated differences between groups. It will be of value to monitor changes within these groups over time, as they may indicate direct or indirect impacts from land-based activities.

INTRODUCTION

Coral reefs play an essential role in protecting low-lying coastal areas from strong wave action and erosion. This delicate ecosystem provides many benefits, especially to island inhabitants whose lifestyle and culture have been reliant on ocean resources for centuries. Such benefits include food, recreational opportunities, medicinal products, and recently a major attraction for tourism industries, which is the foundation for the Cook Island economy. With the increase of human activities (anthropogenic influences) over the years, coral reefs and coastal ecosystems around the world have been degraded (Wilkinson, 2000). Since reef organisms are good indicators of anthropogenic stresses, monitoring these organisms can provide information on how these stresses can be prevented or minimized.

The goal of this survey was to examine and quantify the reef fauna and flora of Rarotonga for the purposes of determining changes in marine communities due to land-based activities over time as well as providing additional data to complement the existing monitoring program (see *Appendix A* for *Terms of Reference*). This is a continuation of previous studies performed by the Australian Institute of Marine Science (AIMS; Miller *et al.*1994) for the Cook Islands National Environment Service (CINES), Ponia *et al.* (1999) for the Ministry of Marine Resources (MMR), and Lyons (2000 and 2003) for CINES.

Prior to the most recent COTS outbreak beginning around 1995 and the five cyclones which hit Rarotonga in 2005, the fore reef and lagoon have been through one major cycles of disturbances (i.e. COTS outbreak in the 1970's) where minor disturbances have followed during the recovery period (notably the bleaching events reported in 1992-1993). Although the abundance of COTS from the recent outbreak have drastically dropped due to the scarcity of their food sources, the recovery of our reefs will depend on how well it copes with additional stresses. While impact on reef community changes may not be directly caused by land-based activities, a long-term monitoring program will provide a historical pattern reflecting these changes which may enable us to pinpoint the causes and their contributions to the degradation of our reefs.

MATERIALS AND METHODS

The survey revisited seven fore reef sites that were established in previous studies carried out in 2000 and 2003 (see Fig. 1). Four additional sites were established on the fore reef to look at impacts in their respective areas.

Twelve inner sites were established within Rarotonga's lagoon, six as possible control sites (C) and six to examine impacts (I) from development in their respective areas: Koromiri (Pacific Resort drain site), Titikaveka (Kent Hall), Vaimaanga (Captain Cook Resort Hotel), Kavera (Rarotongan Beach Resort), Arorangi (Manuia Beach Hotel), and Nikao (runway). Control sites were located up-current from respective impact sites.

The Moving Window Analysis (MWA) method was carried out at Vaimaanga to establish a baseline to examine present reef community changes along a gradient (see explanation of MWA under S*urvey methods*). The site is located between two river outlets.

All sites were marked with a rebar and a GPS reading taken (see *Appendix B*). The survey examined the following: 1) percent cover among corals and other benthos, 2) size distribution among corals, 3) density of corals, macro-invertebrates, and fish, 4) diversity of corals and fish, and 5) a species inventory for all fore reef and lagoon sites. The analysis carried out in this survey also tested for differences between exposures (i.e. windward vs. leeward) as well as lagoon width (narrow vs. wide).

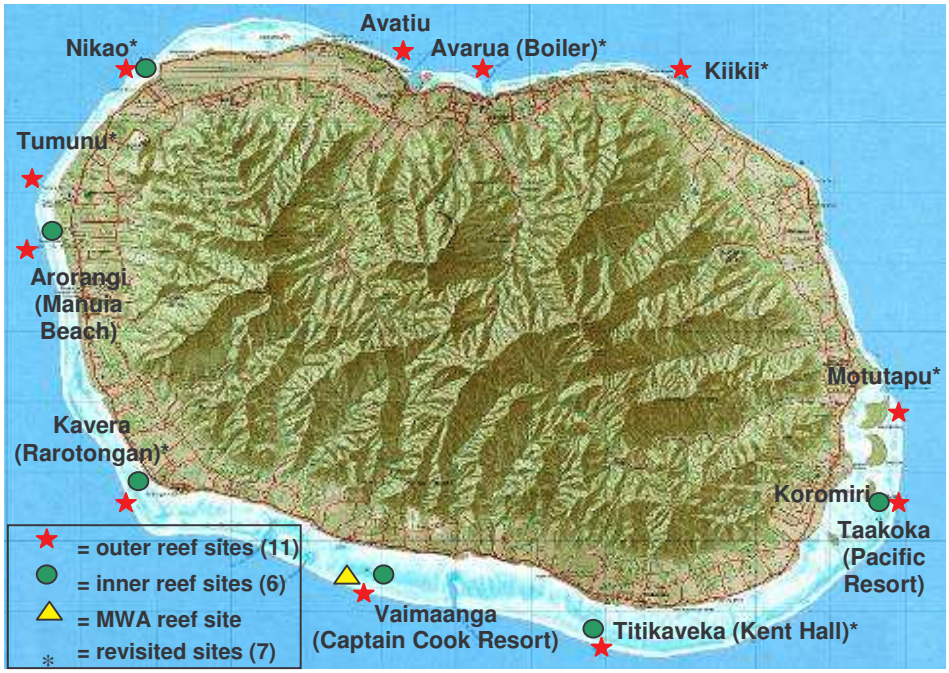

Figure 1. Map of Rarotonga.http://ortho.linz.govt.nz/cook_island/rarotonga_high_res.jpg
* indicates sites revisited from Lyons 2000 and 2003.

Transect deployment (see *Appendix B* for lay of transects)

Fore reef

Four 50-m transects (replicates) were deployed for all sites. Transects were placed following the reef contour at a depth of 10 m parallel to shore and laid consecutively at intervals of 10 m.

Lagoon

Three 50-m transects were deployed at each site. Transects were deployed following the reef contour at depths ranging from 1 to 1.5 m parallel to shore and laid consecutively at intervals of 10 m.

Benthic, macro-invertebrate, and fish surveys

Point Intercept and coral colony size was used to examine benthic communities, and Belt Transect was used for quantifying macro-invertebrates and fishes at all sites. Line Intercept Transect (LIT) was carried out on the seven fore reef sites revisited from the 2000 and 2003 studies for the purposes of comparison (see English *et al.*, 1994 for survey techniques). All species were recorded and identified to the lowest taxonomic level possible (i.e. genus and species) for the purposes of adding to the species inventory for Rarotonga. Species identification was verified using Randall and Myers (1983), Myers (1989 and 1999), Veron (2000), Randall (2005), photographs provided by Dr. Gustav Paulay, and www.fishbase.com.

Survey methods

POINT INTERCEPT (PI) METHOD

A 1-m^2 quadrat frame was tossed every 5 m along a 50-m transect for a total of 10 quadrats. The quadrat is lined with strings equally spaced dividing the quadrat into 25 sections providing 16 points where the strings intercept. Any substratum falling under each intercept was recorded and its percent cover calculated. Substrates included categories of corals, soft corals, algae (i.e. turf, coralline, and macro), and other abiotic substratum (i.e. sand and gravel).

Coral colony size

Coral colony sizes were measured within each 1-m^2 quadrat. At every 20 m interval a 1 x 1 quadrat was tossed haphazardly to analyze coral communities (n = 8). The surface area of a coral within the quadrat was obtained by measuring the maximum length and width (perpendicular to length) along the general contour of each colony. A coral was only included in the quadrat if at least half of the colony falls within the edges of the quadrat frame. Information obtained from this method included percent coverage, population densities, and geometric diameters. For geometric diameter (cm), colonies were grouped into two size classes: Class A (<5) and Class B (≥ 5). Class A colonies were considered new recruits for this survey.

MOVING WINDOW ANALYSIS

Moving Window Analysis is a scaling technique adapted from landscape ecology to reef systems by West and Van Woesik (2001). MWA was utilized to determine over what distance the effects of river discharge influenced reef communities. MWA uses a community dissimilarity measure (Bray-Curtis dissimilarity) between adjacent analysis windows to locate the distance over which benthic community change occurs. The Bray-Curtis distance between two samples *j* and *k* is calculated using Eq. 1:

$$(1)\qquad D_{jk} = \sum_{i=1} \frac{|(Y_{ij} - Y_{ik})|}{(Y_{ij} + Y_{ik})}$$

p represents a coral group (genus or species); Y_{ij} represents the entry in the *i*th group in the *j*th quadrat; and Y_{ik} represents the entry of the *i*th group in the *k*th quadrat. The Bray-Curtis dissimilarity between two quadrats is the absolute summation of the difference between two quadrats along the group axis divided by the summation of all groups within the two quadrats. A high average dissimilarity (AD) measure (100%) indicates two different communities and a low AD measure (0%) indicates two similar communities (Clarke and Warwick, 1994).

BELT TRANSECT

Macro-invertebrates were surveyed using a belt size of 1 m on the fore reef (0.5 m on either side of transect) and 2 m (1 m on each side) within the lagoon. A belt size of 4 m (2 m on each side) was used to survey fish.

DATA ANALYSIS

Microsoft Excel spreadsheet, PivotTable, and PivotChart were used for basic computations. PRIMER and STATISTICA software were used for graphical and comparative analysis (see *Analysis* below for details). Four replicates were used for fore reef analysis and three for the lagoon.

Percent cover calculations

For benthic communities, the total number of points recorded for each category identified using the PI method was divided by 160 (total number of intersects per quadrat x 10 quadrats), and multiplied by 100 (see Eq. 2).

$$(2)\qquad \text{Percent cover} = \frac{\text{Category sum per transect}}{160} \cdot 100\%$$

An average percent cover for each site was calculated from the replicates.

Colony size calculation

The area of each colony was calculated using Eq. 3a, b and c:

(3a) Geometric diameter = $(\text{length} \cdot \text{width})^{1/2}$

(3b) Colony area = $\pi \cdot (\text{Geometric diameter}/2)^2$

(3c) Population density (colonies/ m^2) = n/8.00 m^2

where n is the total number of colonies of any given species and 8.00 m^2 is the total area surveyed by 8 quadrat tosses.

Species diversity (see Clark and Warwick, 1994 for details)

Species diversity for corals and fish was measured using the Shannon – Weiner index (H`), seen in Eq. 4:

$$(4) \qquad H` = - \sum_i p_i (\log p_i)$$

where H` is the index of species diversity, and p_i is the proportion of total count belonging to the *i*th species.

Margalef's species richness (d) is a measure of the number of species present, making some allowance for the number of individuals. Species richness is calculated using Eq. 5 (S= number of species; N = number of individuals):

$$(5) \qquad d = \frac{(S - 1)}{\log (N)}$$

Pielou's evenness (J`) is a measure of equitability or how evenly individuals are distributed among different species. Evenness is calculated using Eq. 6:

$$(6) \qquad J` = \frac{H`}{\log (S)}$$

Average density

Average density for macro-invertebrates and fish were calculated for each site using Eq. 7:

$$(7) \qquad \text{Average density} = \frac{\text{Number of individuals per site / number of replicates}}{\text{Belt area (50 or 100 } m^2 \text{ for inverts and 200 } m^2 \text{ for fish)}}$$

The area (m^2) where one individual of a particular species can be found was also calculated.

Trophic levels

Six categories of fish were implemented based on the diet (trophic level) of each species. These categories are Benthic Invertivores (crustacean-, mollusc-, and urchin-feeders), Carnivores (fish-feeders), Corallivores (coral-feeders), Herbivores (algae-feeders), Omnivores (crustacean- and algae-feeders), and Planktivores (plankton-feeders). To avoid overlapping of some categories, fish placed into their respective category based on their primary food preference. Carnivores were excluded from graphical representation due to their low abundance. For the purposes of this survey, omnivores were used as indicators for impacted reefs.

Total fish abundance

Comparative analysis

Total fish abundance for surgeonfishes, parrotfishes, and butterflyfishes along with selected species of damselfishes (*Chromis vanderbilti, Plectroglyphidodon imparipennis,* and *Stegastes fasciolatus*) were compared to abundance from previous surveys (Miller *et al.*, 1994 and Ponia *et al*., 1999). Raw data from previous surveys were also categorized at the trophic level and their percentages were compared to the present survey. Data from the present survey was corrected to the area (1000 m^2) and compared to the species list used in Ponia *et al*. (1999).

Statistical analysis

Comparative analysis was carried out on benthic and fish communities to determine relationships between sites. A similarity matrix (Bray-Curtis similarity) was constructed using PRIMER for fore reef and lagoon sites from percent cover values for each benthic category and average abundance values within fish trophic levels. Values were square-root transformed (for benthic communities) and log-transformed (for fish) before matrix constructions; matrices were then subjected to CLUSTER analysis and Multi-Dimensional Scaling (MDS). MDS analysis used the following categories for benthic communities based on the area of each species (colonies per 2 m^2): turf algae, macro-algae, coralline algae, soft corals, and hard corals by species. Site spacing on 2D plots indicated how sites differ in relation to each other. Bubbles on MDS plots were graphical representations of respective categories. For comparative analysis on fish trophic levels using MDS analysis from 1994 to 2006, mean abundance values from each year was used.

Based on CLUSTER and MDS analyses, certain sites were selected to examine differences between exposure (windward vs. leeward) and lagoon width (narrow vs. wide). The following were site groupings subjected to further MDS analyses: 1) Avatiu, Avarua, and Kiikii (windward); 2) Kavera, Vaimaanga, and Titikaveka (leeward); 3) Arorangi I & C and Nikao I & C (narrow lagoon); and 4) Kavera I & C, Vaimaanga-C, and Titikaveka-C (wide lagoon).

PRIMER supplemented MWA analysis: Analysis of Similarities (ANOSIM) generated R values that provided a confidence limit on the degree of community similarity: 0 (similar) to 1 (different). Communities are well-separated if the R values are greater than 0.75; communities overlap but are clearly different at R values less than 0.75 but greater than 0.5; communities overlap if R values are greater than 0.25 but less than 0.5; and communities are similar if R values are less than 0.25 (Clarke and Warwick, 1994). Similarity Percentages-Species Contributions (SIMPER) was carried out for zones to see which coral groups contribute to differences between adjacent zones. Mean error plots and Analysis of Variance (ANOVA) tests were generated using STATISTICA.

RESULTS

FORE REEF

BENTHIC COMMUNITIES

Data 2006

A checklist for corals was generated with the average percent cover of benthic communities for fore reef sites (*Appendix C* and *D* and Fig. 2). Algae (mainly turf) dominated all sites with cover ranging from 65 – 99 %. Percent cover of coralline algae was higher on the leeward side of Rarotonga: Titikaveka (30%), Vaimaanga (19%), Kavera (10%), Arorangi (11%), Tumunu (5%), and Nikao (17%). Values were less than 2% on windward exposures (i.e. Avatiu, Avarua, Kiikii, and Motutapu) and 3% at Taakoka. Soft corals were only reported on the leeward exposure: Titikaveka (5%), Vaimaanga (8%), Kavera (2%), Arorangi (6%), and Tumunu (1%). Hard coral cover was highest at Arorangi (6%) followed by Avarua (3%) and Kavera (2%); all other sites had cover less than 2%.

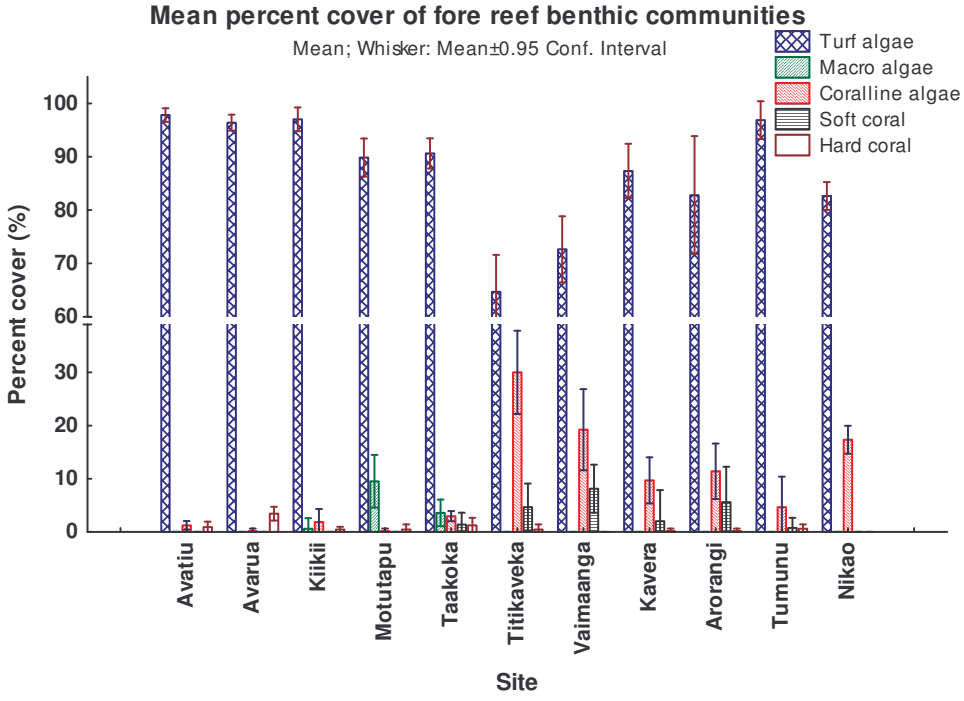

Figure 2. Mean percent cover of fore reef benthic communities by site for 2006.

The PRIMER dendrogram generated for benthic fore reef communities (Fig. 3) identified three major clusters at 80 % similarity (indicated by the red dotted line). The clusters consisted of the following: 1) Taakoka and Motutapu, 2) Kiikii, Avatiu, Tumunu, and Avarua, and 3) Kavera, Arorangi, Nikao, Titikaveka, and Vaimaanga. MDS analysis (Fig. 4) provided a similar outcome. The stress value of 0.03 indicated a high degree of reliability in this result.

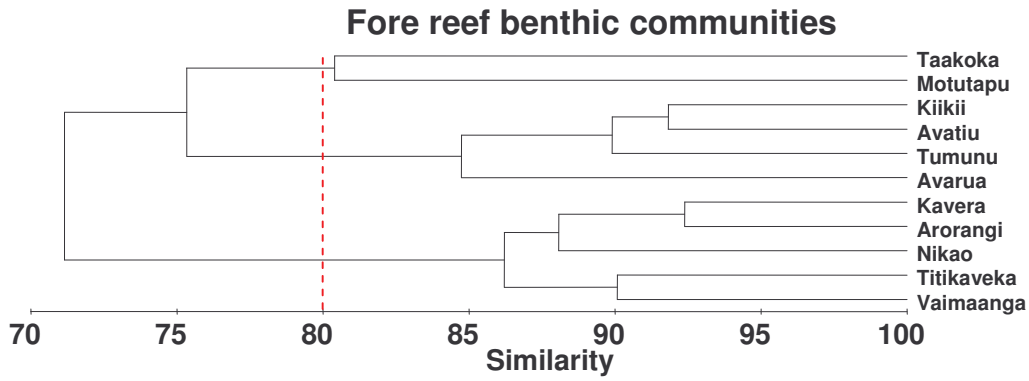

Figure 3. A general cluster analysis dendrogram for fore reef benthic communities by site.

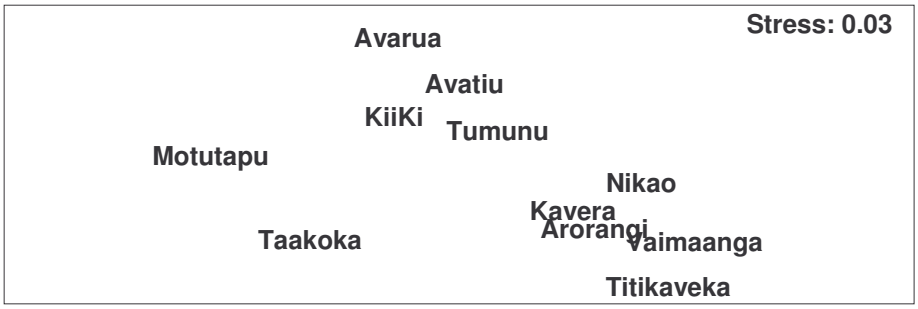

Figure 4. MDS analysis of benthic communities for fore reef sites.

A total of 35 coral species were observed on the fore reef representing 11 families. Coral species diversity and evenness values (Table 1) indicated that Tumunu had the highest diversity (H`), number of species (S), and greatest values of richness (d) and evenness (J`). Avarua had the highest number of individuals (N) recorded. The lowest diversity and richness were reported at Vaimaanga, also where the lowest number of species was recorded. Arorangi had the lowest number of individuals recorded and lowest evenness values.

The average geometric diameter of corals at all fore reef sites (see Table 1 and *Appendix E* for total size abundance) were less than 5 cm, with the greatest value at Avarua (4.94 cm), followed by Avatiu (3.24 cm), and the smallest value at Vaimaanga (1.32 cm). Total abundance of colonies by size class (Fig. 5) indicated that 86% of corals were in Class A (recruitment sizes).

A breakdown of Class A indicated the dominance (81%) of hardy corals (*Acanthastrea, Leptastrea, Leptoria, Montastrea,* and *Porites*). A total of 25 species were recorded in this class. Population density of corals (ind. per m^2; see Table 1) indicated that Avarua had the highest density value (22.38), followed by Kiikii (16.13); the lowest density value was recorded at Vaimaanga (3.63).

Table 1. Biological statistics for all fore reef sites.

Fore reef site	**Coral diversity** (quadrats surveyed; S)	**Coral diversity** (checklist)	**Coral #** (N)	**Coral community diversity** (H')	**Coral community richness** (Margalef's d-statistic)	**Coral community evenness** (J')	**Average geometric diameter** (cm)	**Coral population density** (ind. per m^2)	**Average # of grazing urchins** (# per 50 m^2)	**Fish diversity** (transects surveyed; S)	**Fish diversity** (checklist)	**Fish #** (N)	**Fish community diversity** (H')	**Fish community richness** (Margalef's d-statistic)	**Fish community evenness** (J')
Avatiu	10	23	84	0.7514	2.0312	0.7514	3.24	10.50	3.26	40	54	903	0.8214	5.7305	0.5127
Avarua	15	28	254	0.9358	2.5283	0.7957	4.94	22.38	4.67	46	57	711	1.0536	6.8528	0.6337
Kiikii	15	21	131	0.9482	2.8717	0.8063	2.33	16.13	3.06	51	54	1619	0.9876	6.7663	0.5784
Motutapu	14	22	69	0.8835	3.0703	0.7708	2.33	8.50	3.26	47	55	1664	0.8542	6.2020	0.5109
Taakoka	16	27	81	0.8655	3.4134	0.7188	2.33	10.00	4.55	65	73	2115	0.9737	8.3586	0.5371
Titikaveka	13	19	73	0.7774	2.7969	0.6979	2.10	6.75	5.52	47	49	1549	0.9448	6.2625	0.5650
Vaimaanga	7	13	45	0.5799	1.5762	0.6863	1.32	3.63	1.31	49	64	1312	0.7494	6.6859	0.4434
Kavera	9	22	64	0.7148	1.9236	0.7491	1.43	6.75	1.08	49	47	1508	0.7120	6.5587	0.4213
Arorangi	9	18	38	0.6314	2.1993	0.6617	2.16	4.63	1.65	43	47	717	1.0318	6.3878	0.6317
Tumunu	19	19	124	1.0538	3.7342	0.8241	2.47	15.00	1.17	37	41	1381	0.8615	4.9789	0.5494
Nikao	11	16	57	0.8230	2.4734	0.7903	2.18	7.00	3.48	49	51	2455	0.6663	6.1492	0.3942

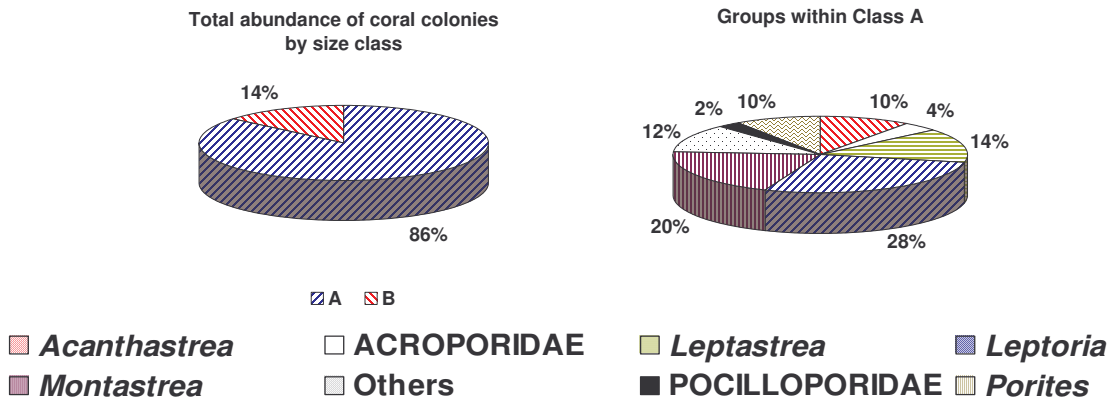

Figure 5. Average percent colony size of corals by class for fore reef sites (lumped) and percent contribution of coral groups within Class A.

Comparative Analysis

Line Intercept Transect and Point Intercept Method

Comparisons of average percent cover of benthic communities using LIT from 2000 and 2003 to 2006 (Fig. 6a and b; 1994 included for Motutapu; see *Appendix F* for raw data) indicated that algae cover (mainly turf) increased at most sites with the exception of Nikao (85 to 73%) and Titikaveka (80 to 47%) where a drop was indicated from 2003. Coralline algae cover decreased from 2003 except for a considerable increase at Nikao (from 10 to 26 %) and Titikaveka (from 7 to 45%) and slightly at Kavera (4 to 10%). Coral cover decreased for most sites except Avarua where a slight increase was noted from 2003 (4 to 10%).

Similar trends observed with comparisons to 1999 using Point Intercept Method (Fig. 7) indicated that turf algae cover increased for all sites. Other algae cover (category not specified in 1999; coralline algae included from the present survey) increased at Nikao (1 to 17%), Arorangi (6 to 11%), and Titikaveka (1 to 30%). There was a decrease in coral cover for all sites, with considerable decreases at Nikao (45 to <1%), Arorangi (31 to <1%), and Titikaveka (22 to <1%). A slight decrease was noted at Avarua (4 to 3%).

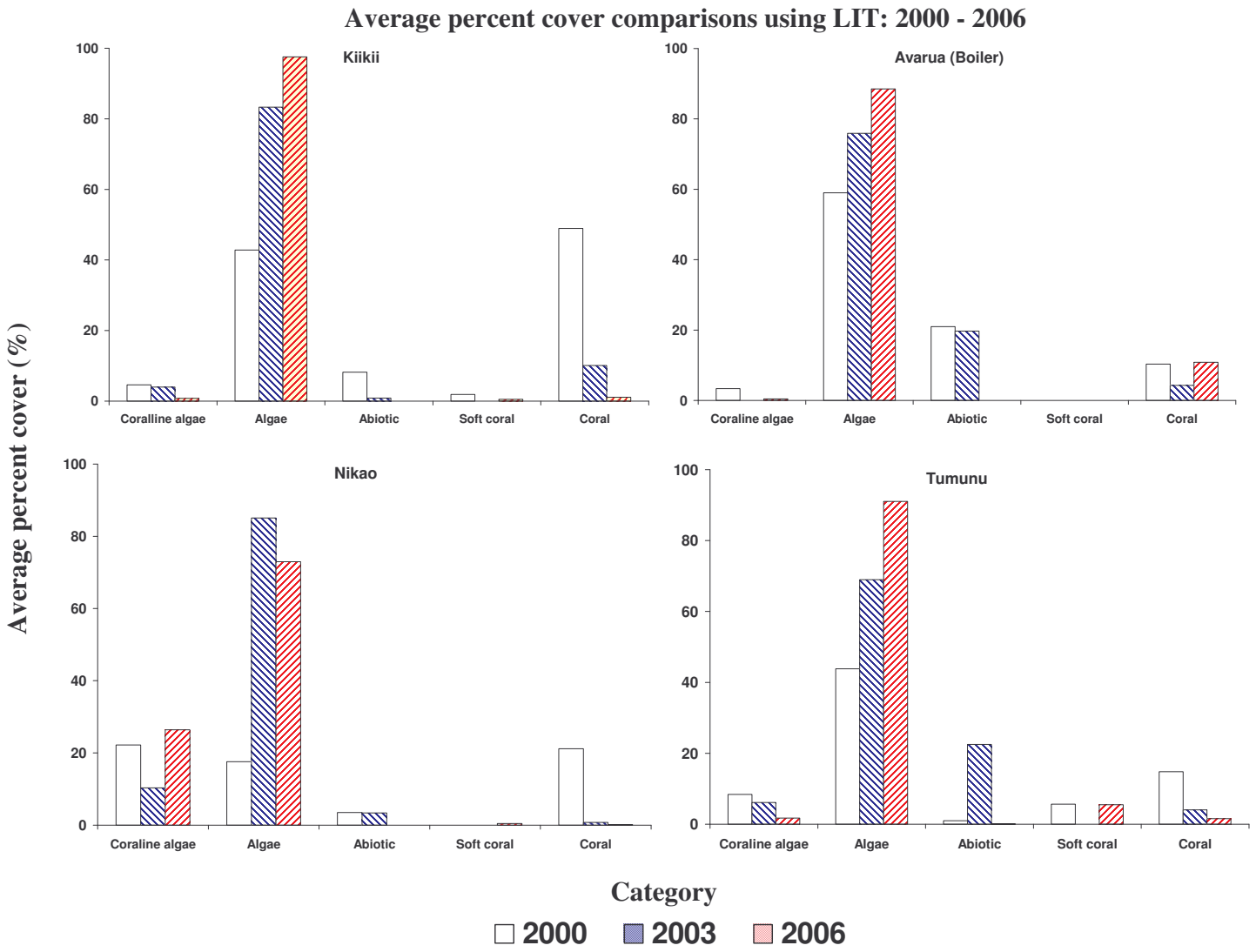

Figure 6a. Comparisons of average percent coral cover using LIT for respective fore reef sites from 2000-2006.

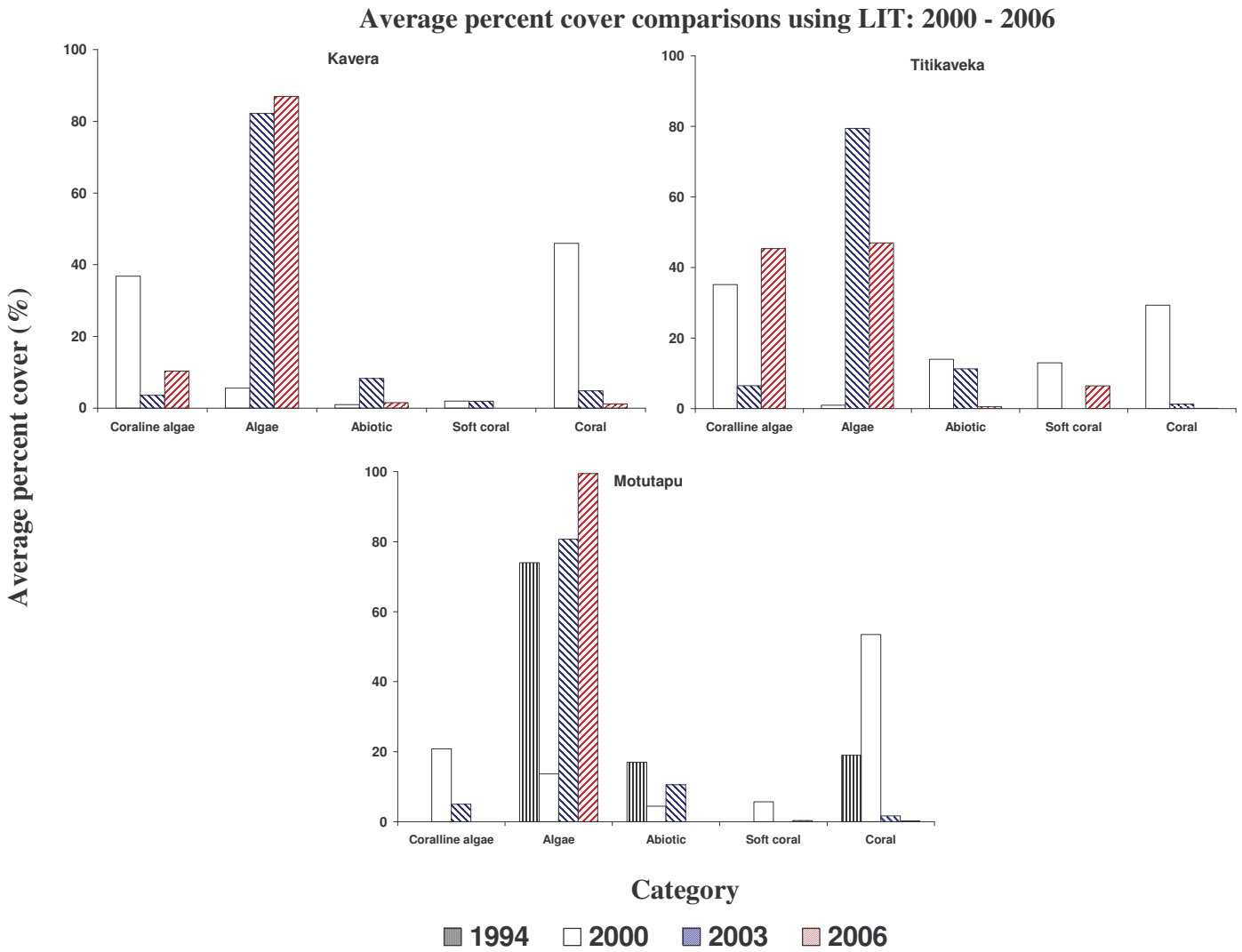

Figure 6b. Comparisons of average percent coral cover using LIT for respective fore reef sites from 2000-2006. Values from the 1994 survey are also included for Motutapu.

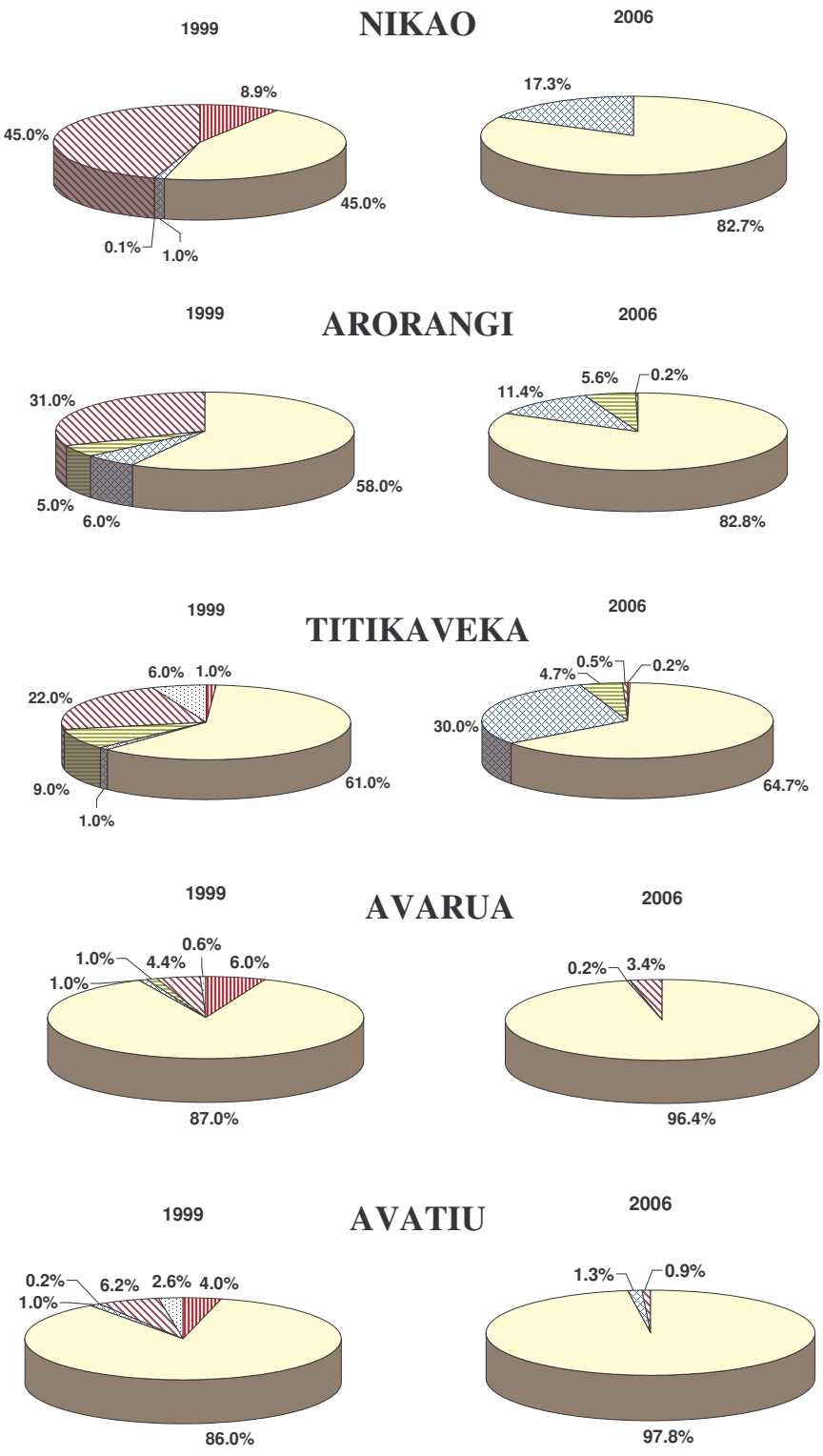

Figure 7. Comparisons of average percent cover of benthic communities on the fore reef between the 1999 survey and the present survey.

MACRO-INVERTEBRATES

A checklist and average density (individuals per m^2) for macro-invertebrates were generated for all fore reef sites (*Appendix G*; see Table 1). Greatest mean densities (ind. per m^2) were attributed to urchins, mainly *Echinometra* spp. (Fig. 8). Mean urchin densities were highest at Titikaveka (5.52), followed by Avarua (4.67) and Taakoka (4.54). Avarua had the highest mean density of mollusks for all sites (1.72), comprised mainly of *Dendropoma* spp.; densities were less than 1 at all other sites. Rori densities were less than 1 at all sites.

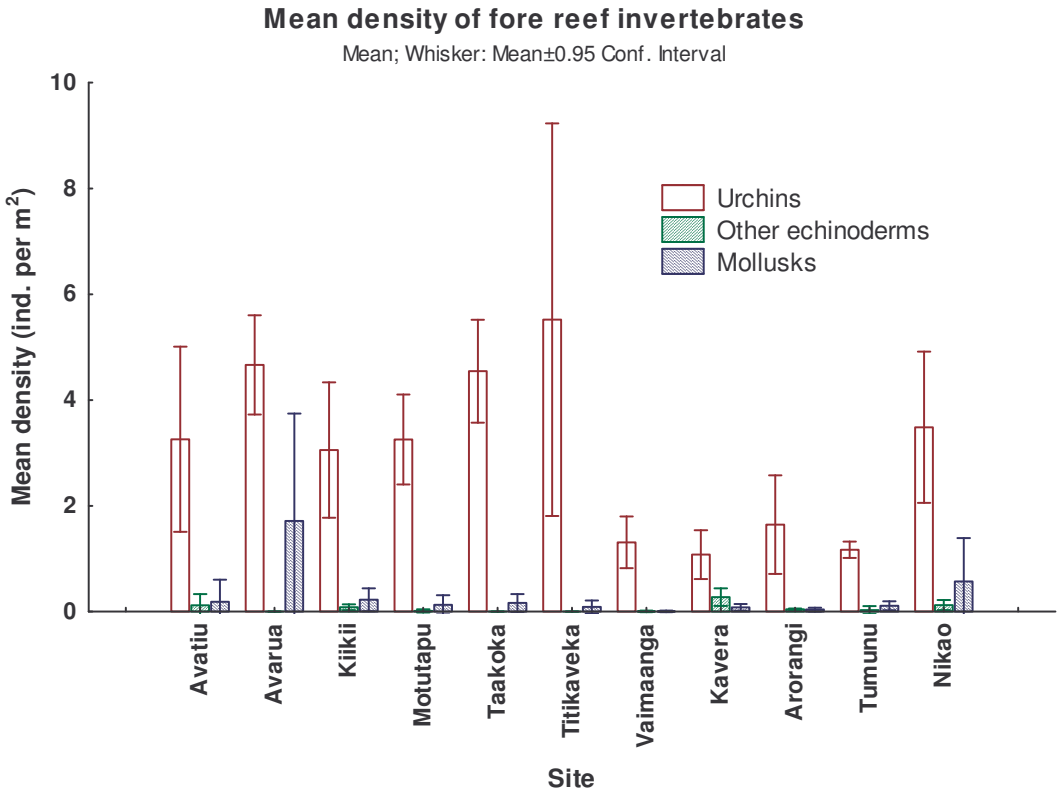

Figure 8. Mean density (ind. per m^2) of fore reef invertebrates for 2006.

FISH

Data 2006

A total of 120 fish species were observed at all sites representing 34 families (see *Appendix H1* and *H2* for average density values). Fish species diversity calculations (see Table 1) for each site indicated that Avarua had the highest diversity (H`) and evenness value (J`), but the lowest number of individuals recorded (N). Kavera had the lowest diversity, and Nikao had the highest number of individuals recorded and the lowest evenness value. Taakoka had the highest number of species (S) recorded and greatest richness value (d), and Tumunu had the least number of species and lowest richness value.

Comparative Analysis

Average density of fish by trophic level was calculated for each site (*Appendix I*). Mean abundance of fish (ind. per 200 m^2) by trophic levels for each site (Fig. 9) indicated that planktivores were most abundant at Taakoka (113) and Titikaveka (97). Benthic invertivore abundance was highest at Taakoka (44) followed by Motutapu (36); corallivores were highest at Titikaveka (7); and omnivores were highest at Kiikii (19). Herbivores were the most abundant group at all sites, with highest abundance recorded at Nikao (577; Fig. 10). Herbivore abundance at other sites was below 400 individuals with the lowest at Avarua (113).

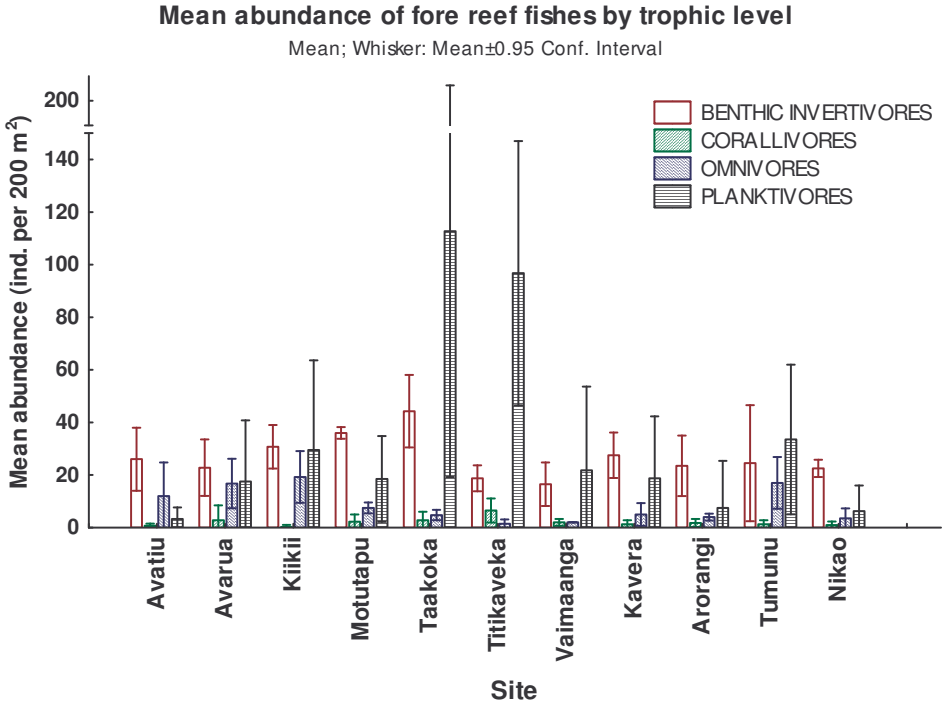

Figure 9. Mean abundance (ind. per 200 m^2) of fore reef fishes by trophic level for 2006.

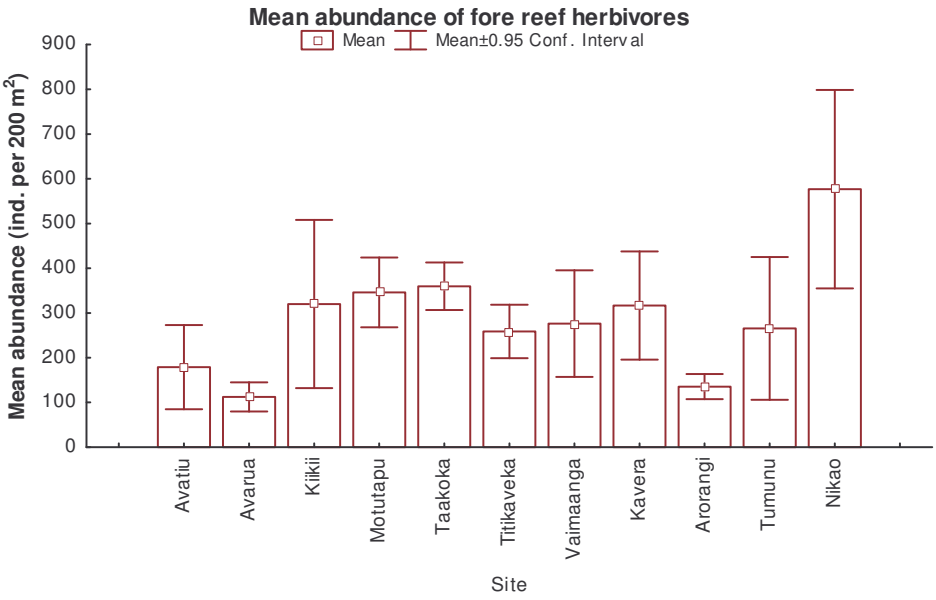

Figure 10. Mean abundance (ind. per 200 m^2) of fore reef herbivores for 2006.

Total abundance of surgeonfish and parrotfish between 1994, 1999, and 2006 (Fig. 11) increased, while butterflyfish abundance decreased with the exception of Tikioki where a slight increase was noted (30 to 33). The abundance of damselfishes *Chromis vanderbilti* and *Stegastes fasciolatus* decreased (Fig. 12) from 1999 while *Plectroglyphidodon imparipennis* abundance increased with the exception of Tikioki.

Comparisons from 1994 to 2006 between sites (Fig. 13a and b; *Appendix J*) indicated a change in fish community composition based on trophic levels. Average percent abundance of planktivores and corallivores decreased while an increase was noted in herbivores at all sites between 1999 and 2006. Planktivore abundance at Ngatangiia and Tikioki increased between 1994 and 1999 and decreased unto 2006. Other groups indicated no conclusive trends over the years.

The butterflyfish *Chaetodon unimaculatus* was a dominant corallivore on leeward exposure sites, notably at Titikaveka, Vaimaanga and Arorangi. *Chaetodon unimaculatus* are corallivores whose diet consists mainly of soft corals, which were fairly common at these sites.

MDS analysis of fish by trophic level (Fig. 14) indicated that changes have occurred over the years with the exception of Tikioki where minimal change was noted between 1994 and 1999. Bubbles indicated that the mean abundance of omnivores decreased from 1994 to 1999 (for Avatiu and Tikioki), and a general increase between 1999 and 2006 (for most sites). A stress value of 0.05 indicated a high degree of reliability in this result.

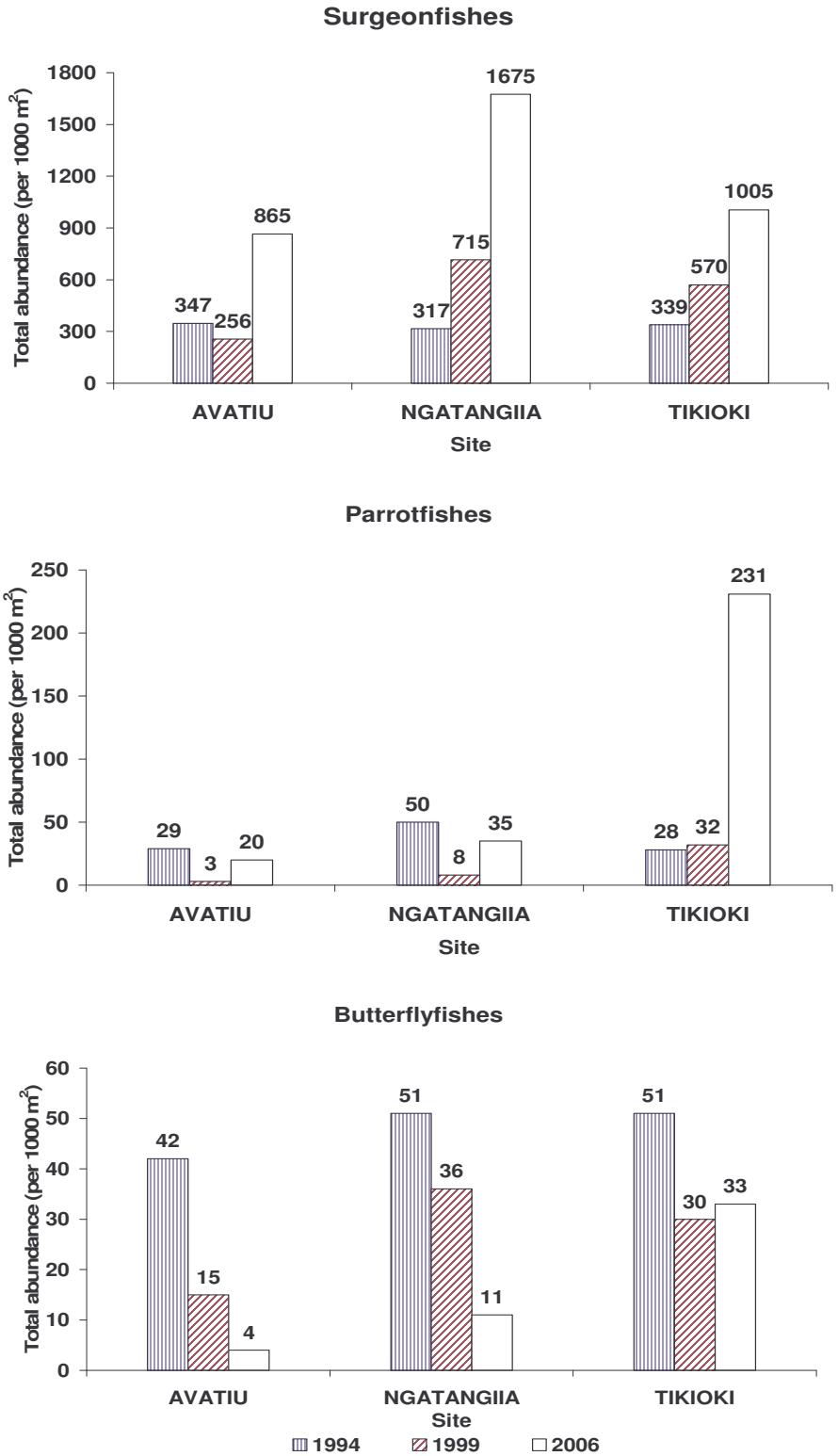

Figure 11. Total abundance (ind. per 1000 m^2) of surgeonfish, parrotfish, and butterflyfish at respective fore reef sites. Comparisons are between the 1994, 1999, and 2006 surveys.

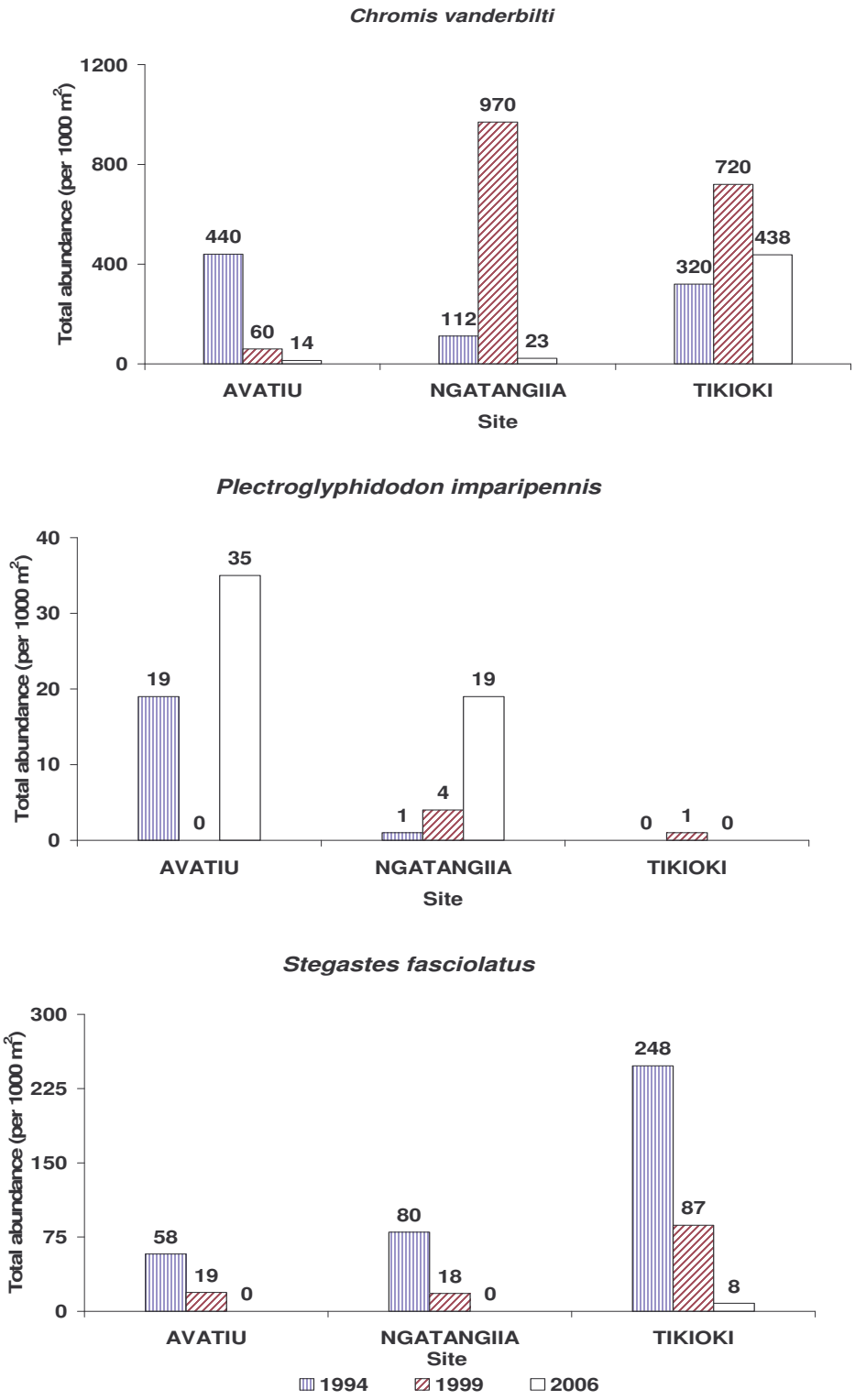

Figure 12. Total damselfish (*Chromis vanderbilti*, *Plectroglyphidodon imparipennis* and *Stegastes fasciolatus*) abundance (per 1000 m^2) at respective fore reef sites. Comparisons are between the 1994, 1999, and 2006 surveys.

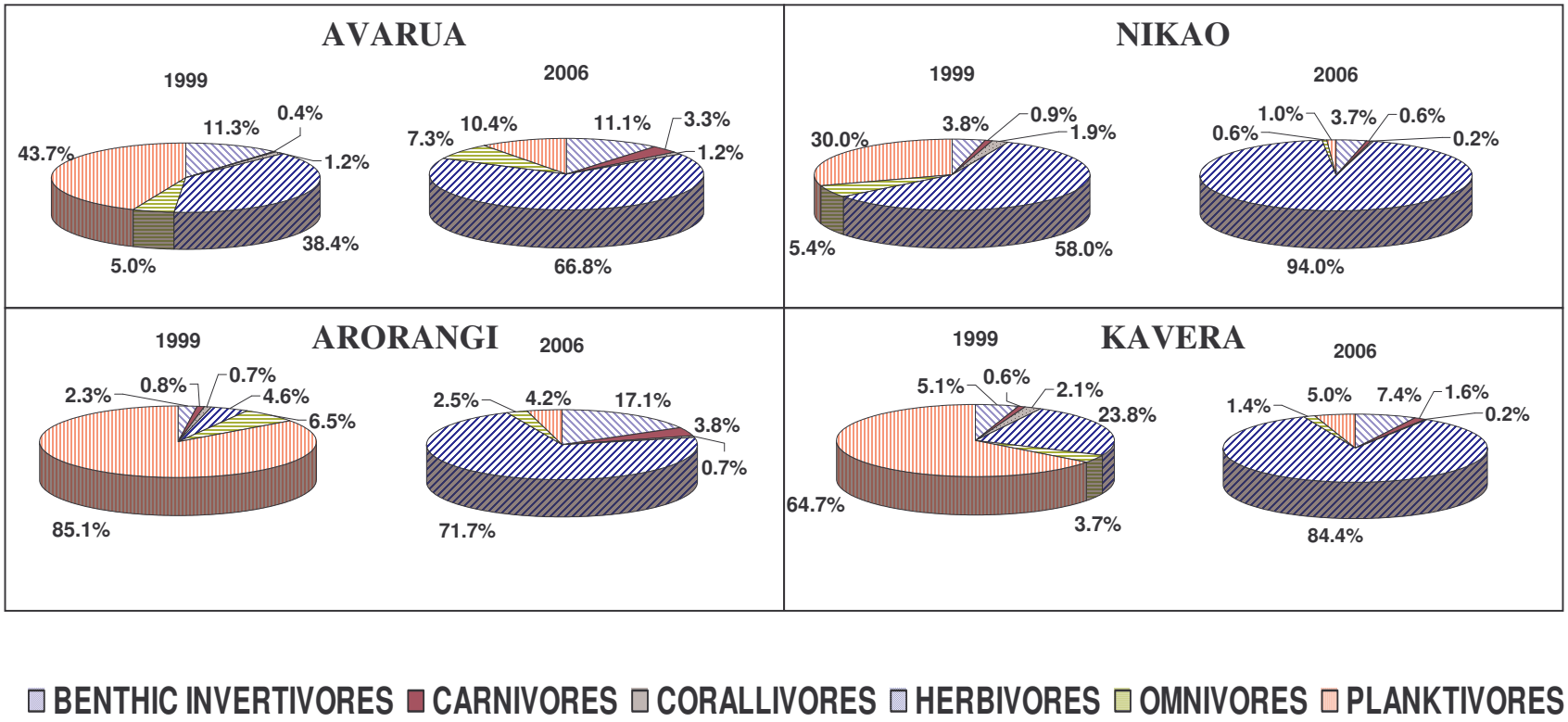

Figure 13a. Comparisons between 1999 and 2006 surveys of average percent fish abundance on fore reef sites based on trophic level.

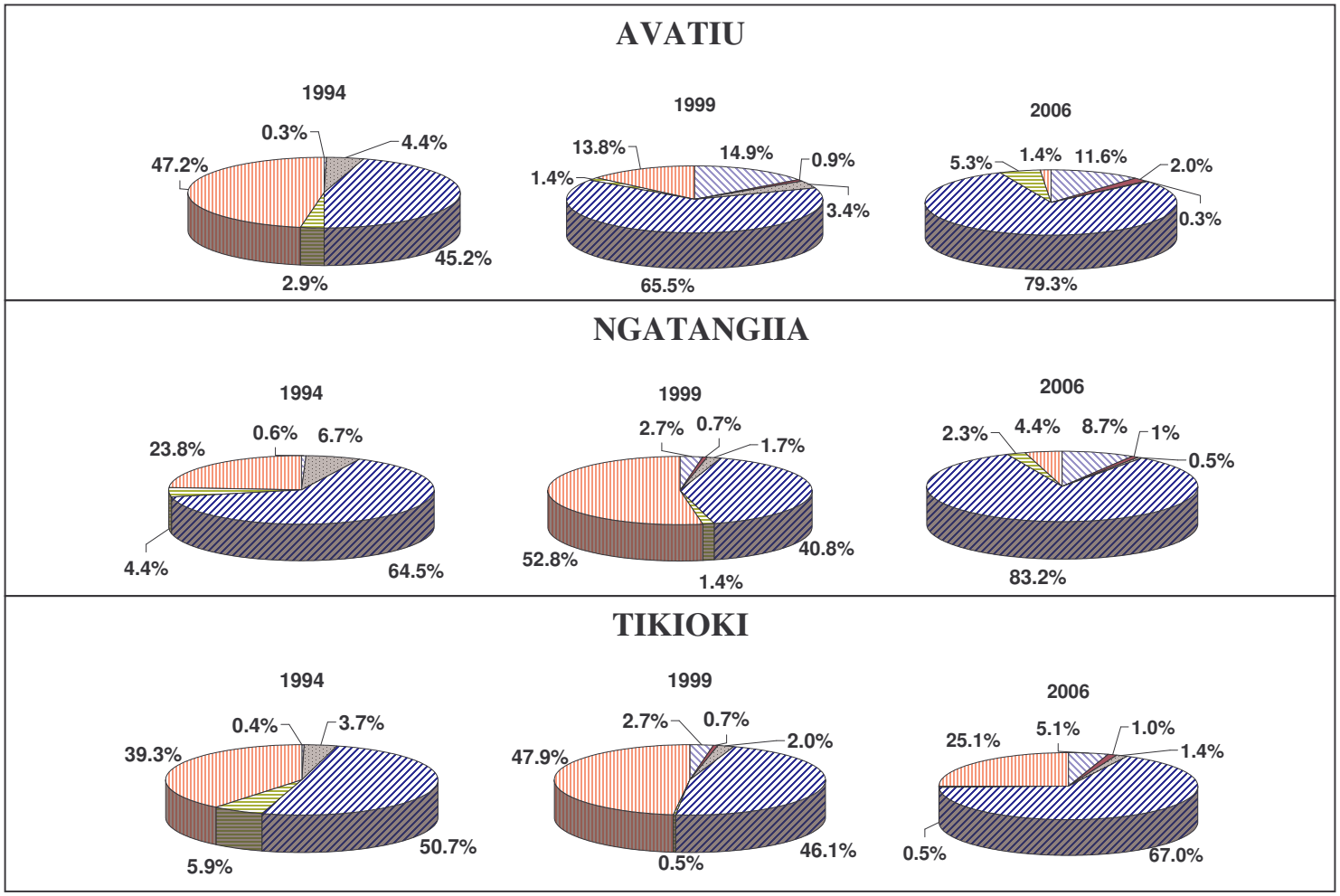

Figure 13b. Comparisons between 1994, 1999, and 2006 surveys of average percent fish abundance on fore reef sites based on trophic level.

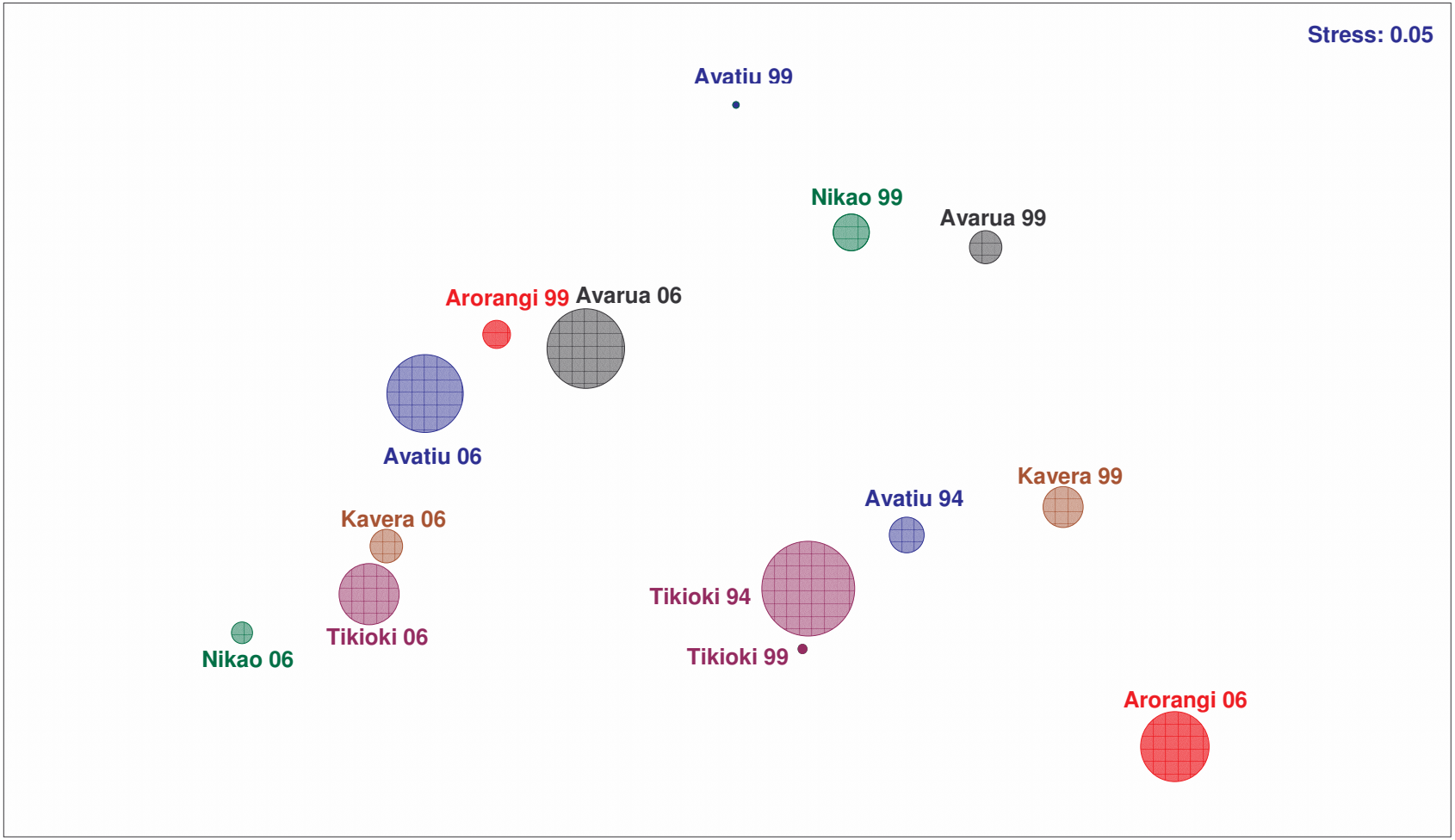

Figure 14. Multi-Dimensional Scaling plot of fish by trophic level for each site between 1994 and 2006. Bubbles (2D): mean abundance of omnivores.

WINDWARD VS. LEEWARD EXPOSURE

Coralline algae cover indicated significant differences between exposures (Fig. 15; $p < 0.01$). ANOSIM and SIMPER were carried out for selected fore reef sites by exposure (*Appendix K*). ANOSIM for coral communities indicated a significant difference between exposures (Global R = 0.497, p = 0.001). SIMPER indicated a dissimilarity value of 85% between exposures with differences explained by: soft corals (29%), *Porites lutea* (15%), *Leptastrea purpurea* (14%), *Montastrea curta* (8%), and *Acanthastrea echinata* (6%). MDS analysis of coral communities (Fig. 16) indicated a similar outcome. The stress value of 0.12 indicated a good degree of reliability in this result. Bubbles (see Fig. 16) indicated that soft corals favored the leeward exposure.

Though mean herbivore abundance was not significantly different (p = 0.0458), the general trend noted a higher abundance on the leeward exposure. Other trophic levels indicated significant differences between exposures; corallivores and planktivores favored the leeward exposure, while omnivores favored the windward. MDS analysis at the trophic level (Fig. 17-20) indicated similar outcomes. The stress value of 0.13 indicated a good degree of reliability in this result. ANOSIM for fish species also indicated a significant difference between exposures (Global R = 0.779, p = 0.001). SIMPER indicated a dissimilarity value of 59% between exposures with differences explained by: *Ctenochaetus striatus* (26%), *Acanthurus nigrofuscus* (25%), *Chromis vanderbilti* (9%), and 12% by *Scarus schlegeli, Stegastes fasciolatus, Chromis xanthura,* and *Pletroglyphidon imparipennis*.

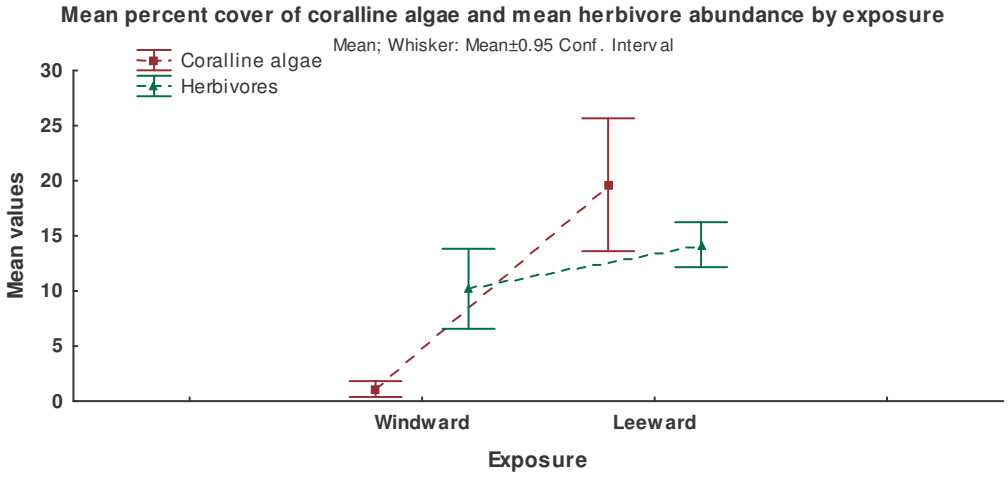

Figure 15. Mean percent cover of coralline algae and mean herbivore abundance (ind. per 20 m^2) by exposure. Sites were lumped as follows: Avatiu, Avarua, and Kiikii (windward); Titikaveka, Vaimaanga, and Kavera (leeward).

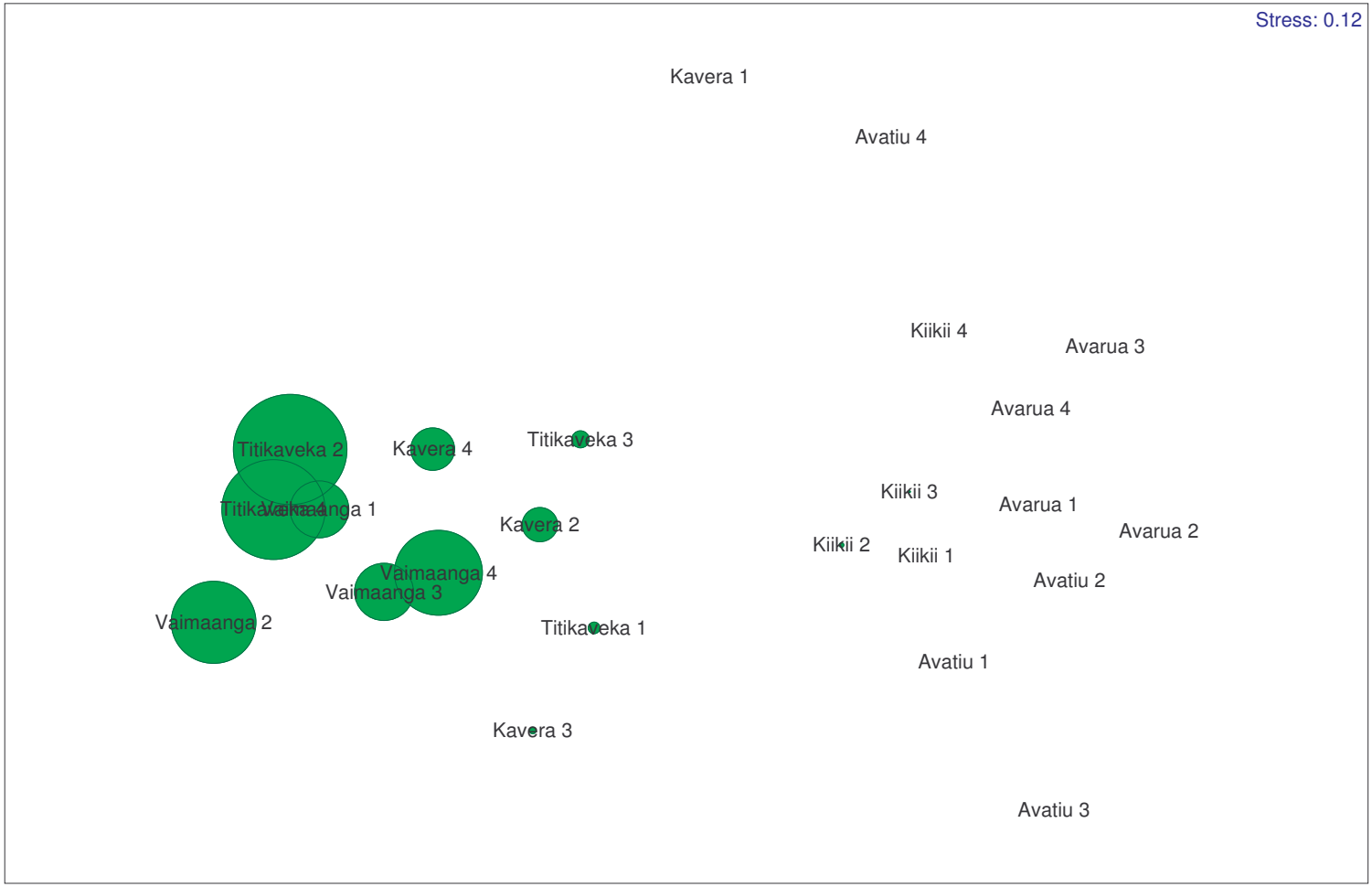

Figure 16. Multi-Dimensional Scaling plot by exposure for fore reef sites. Bubbles (2D): average area cover of soft corals (n = 4).

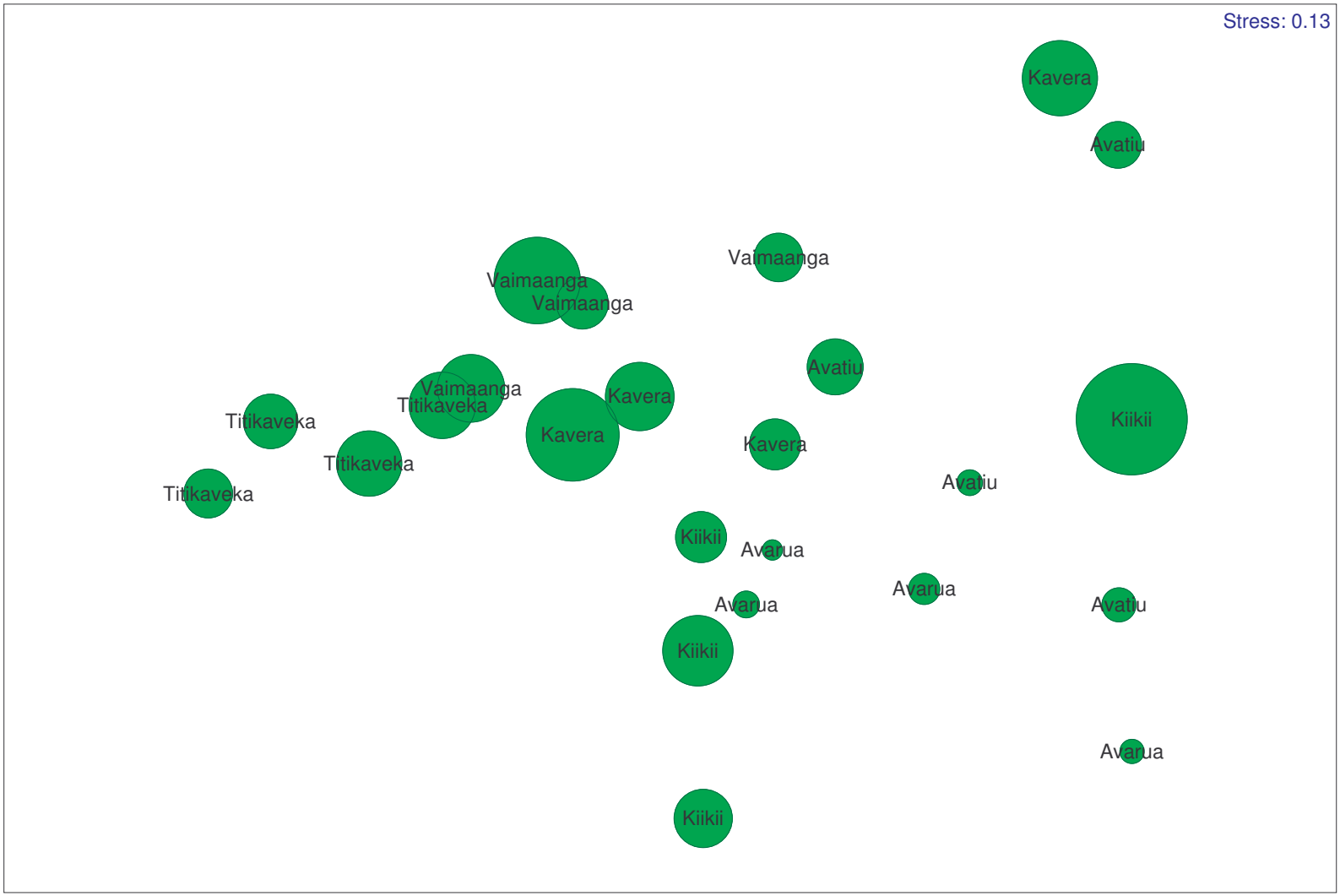

Figure 17. Multi-Dimensional Scaling plot by exposure for fore reef sites. Bubbles (2D): mean abundance of herbivores (n = 4).

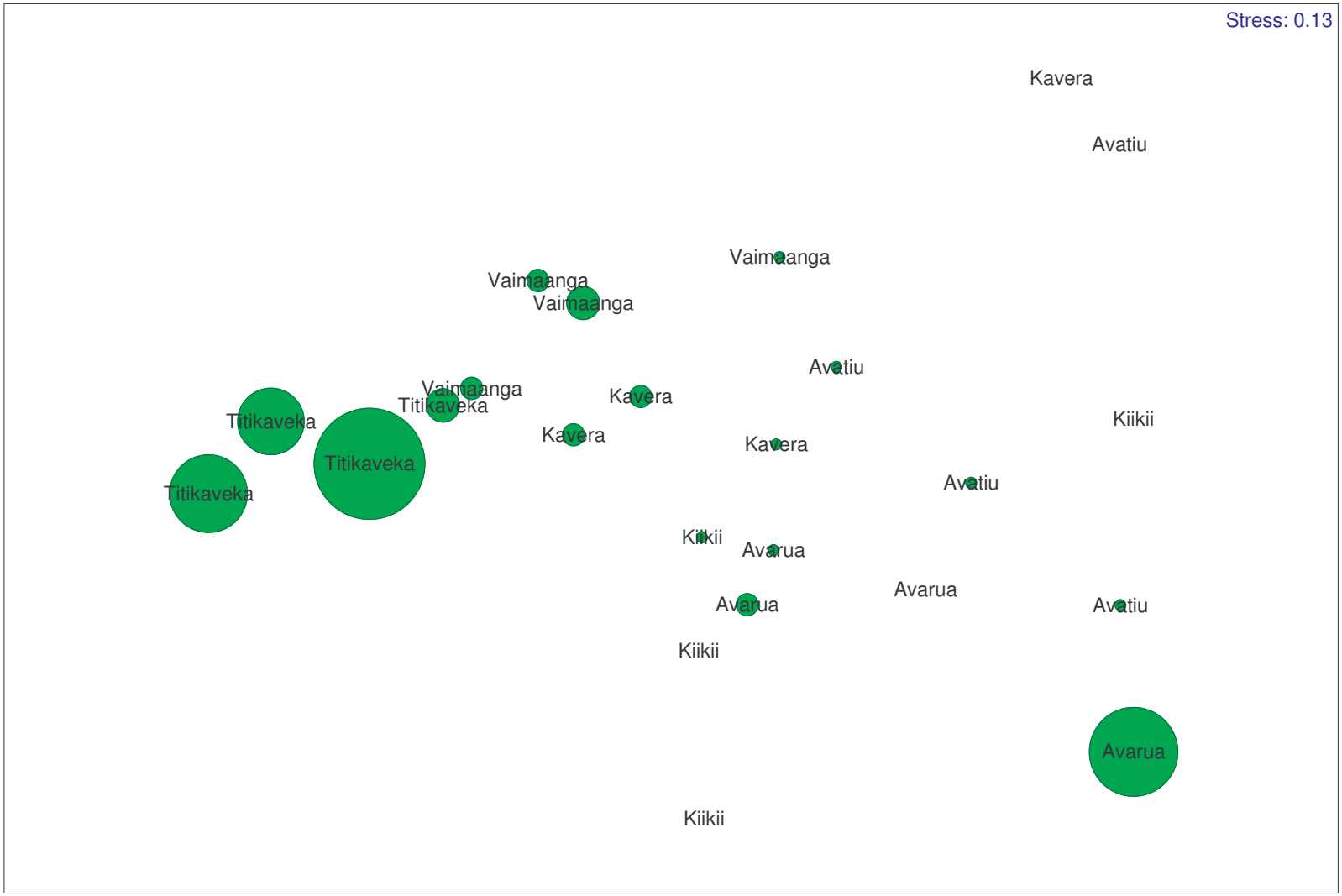

Figure 18. Multi-Dimensional Scaling plot by exposure for fore reef sites. Bubbles (2D): mean abundance of corallivores (n = 4).

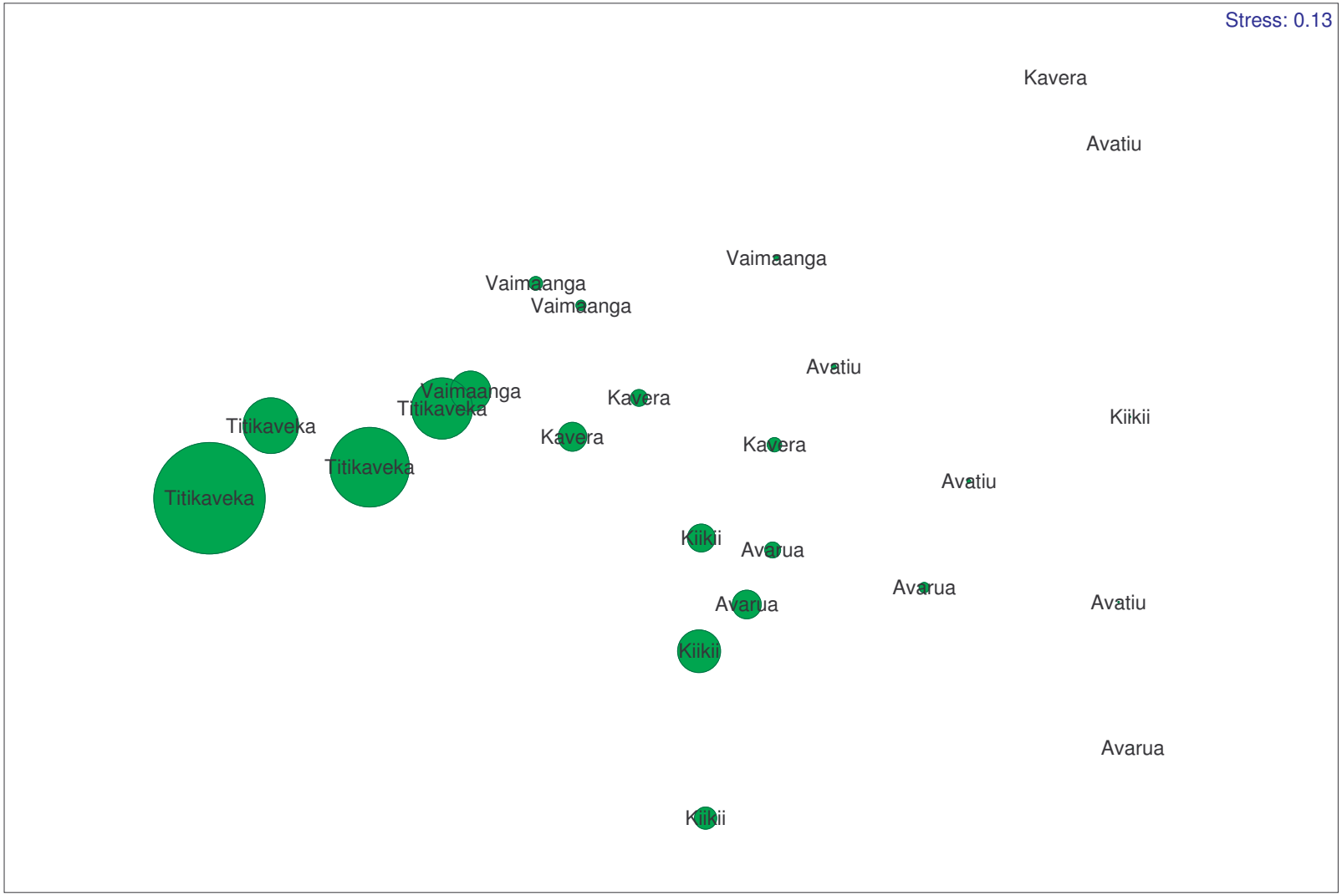

Figure 19. Multi-Dimensional Scaling plot by exposure for fore reef sites. Bubbles (2D): mean abundance of planktivores (n = 4).

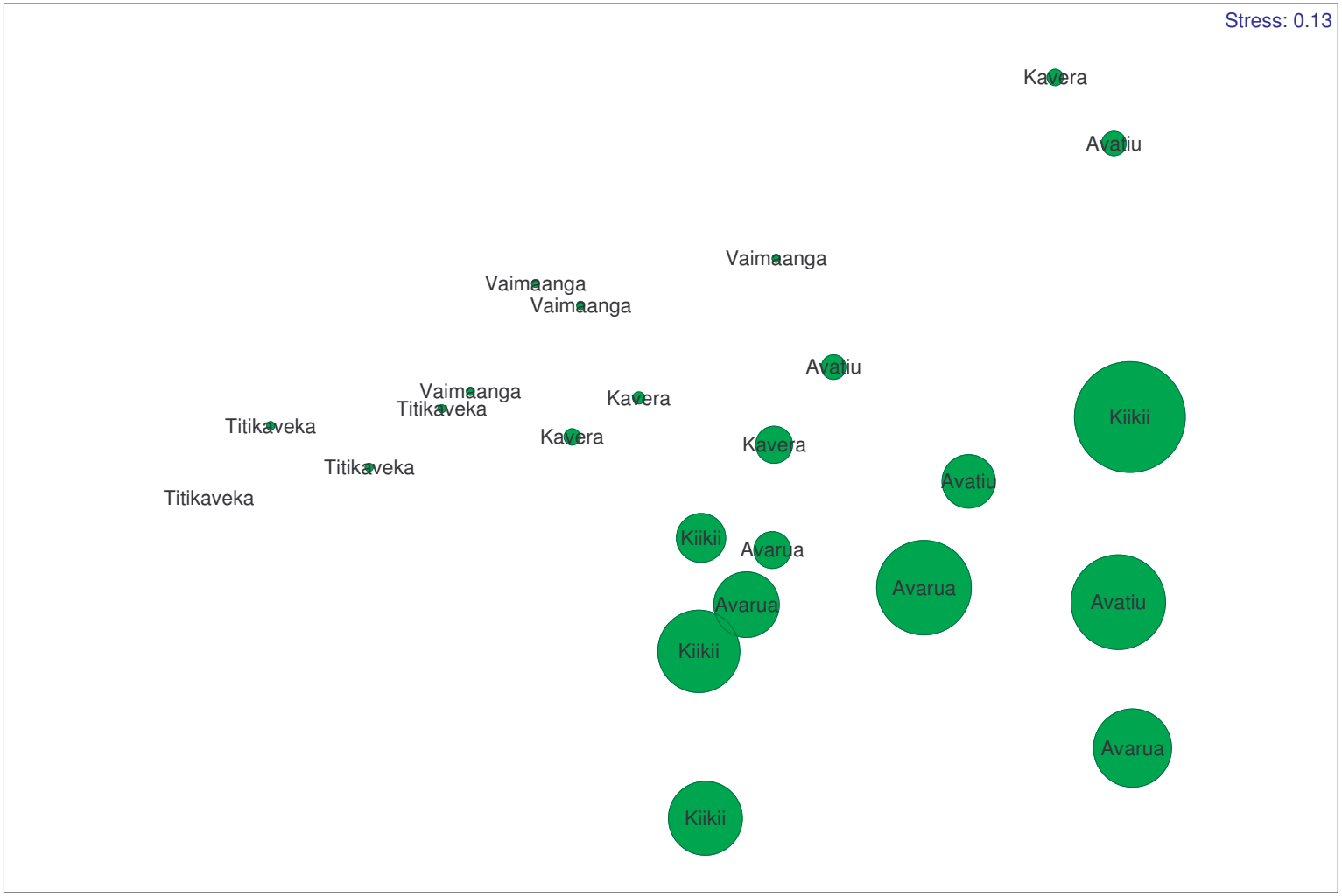

Figure 20. Multi-Dimensional Scaling plot by exposure for fore reef sites. Bubbles (2D): mean abundance of omnivores (n = 4).

LAGOON

BENTHIC COMMUNITIES

Data 2006

A checklist for corals was generated with the average percent cover of benthic communities for lagoon sites (*Appendix L* and *M*). A total of 65 coral species were observed in the lagoon representing 12 families. Algae (mainly turf) dominated all sites (Fig. 21). Cover ranged from 59 – 93 %. Macro-algae cover was high at Vaimaanga (81%), and 5% and under at all other sites. Percent cover of coralline algae was 8% at Titikaveka-C and 6% at Vaimaanga-C, and 2% and under at all other sites. Hard coral cover was highest at the Kavera sites (17% at impact, 13% at control); values ranging from 4 to 9% were reported at all other sites with the exception of Nikao and Arorangi (I and C) where cover was <2%.

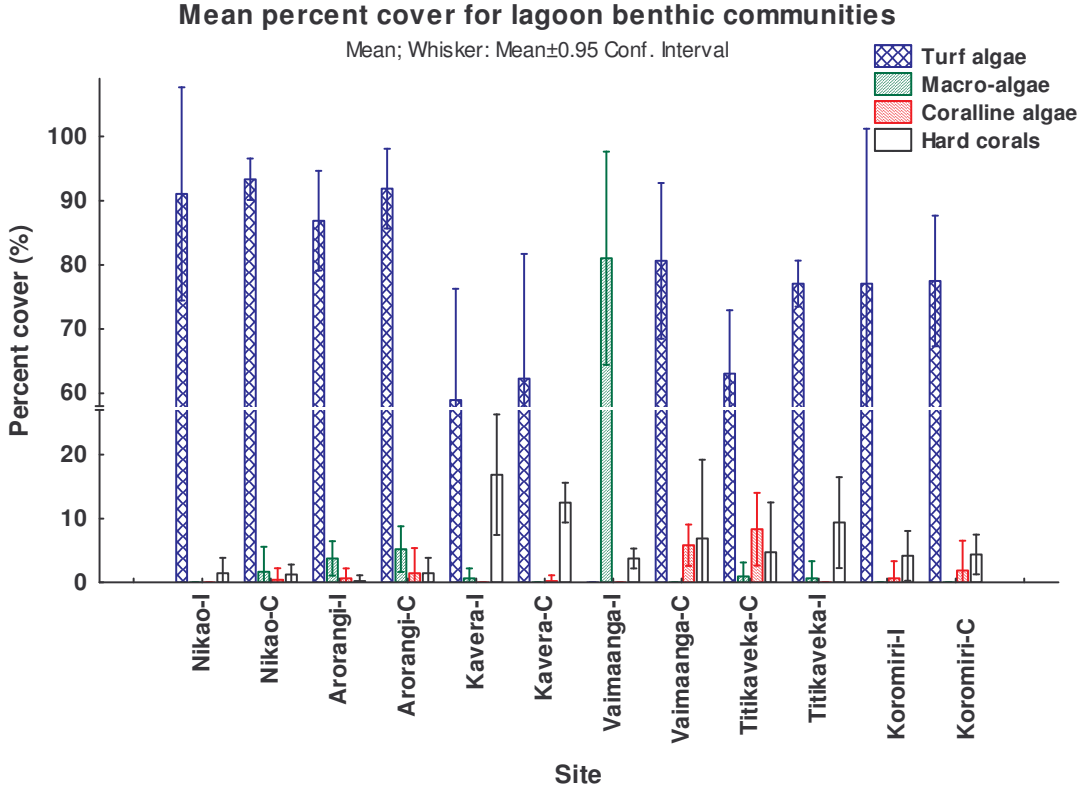

Figure 21. Mean percent cover for lagoon benthic communities by site for 2006.

The PRIMER dendrogram generated for benthic lagoon communities (Fig. 22) identified two major clusters. The first consisted of Vaimaanga-I with a similarity value of ~21 to the rest of the sites. The second consisted of all other inner sites with similarity values greater than 60. Cluster allies were Kavera (I and C), Titikaveka (I and C), Vaimaanga-C, and Koromiri (I and C) who in turn were linked with a cluster consisting of Arorangi (I and C) and Nikao (I and C).

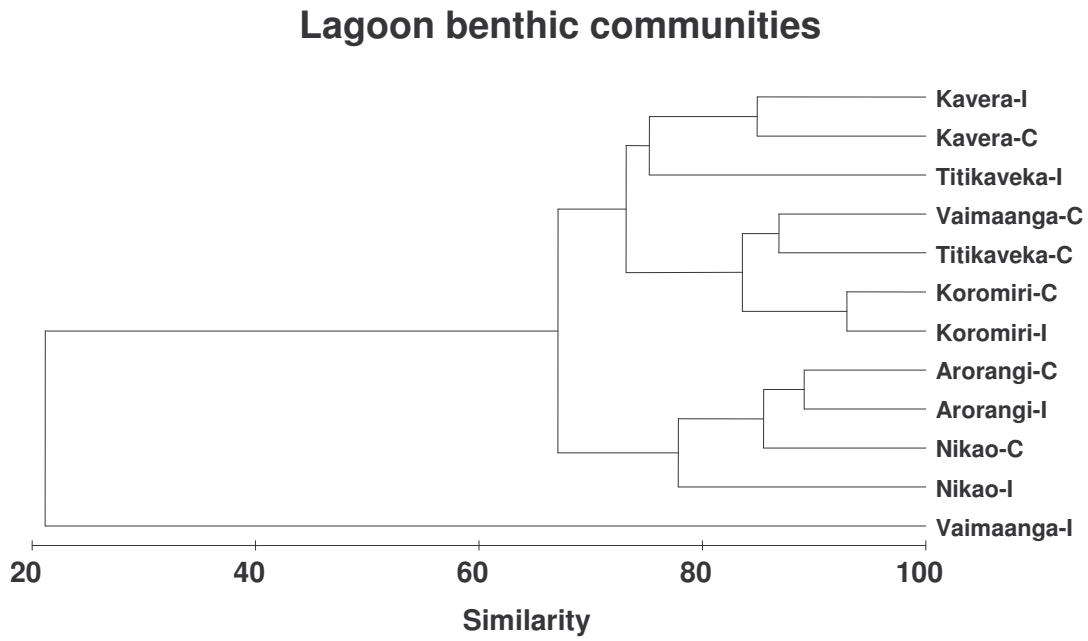

Figure 22. A general cluster analysis dendrogram for lagoon benthic communities by site.

Coral species diversity and evenness values (Table 2) indicated that Vaimaanga-C had the highest diversity (H`) and number of species (S). Kavera (I and C) had high diversity values as well. Vaimaanga-I had the lowest diversity and evenness values (J) however the highest number of individuals (N) reported. Nikao-I had the lowest number of species and individuals reported. Koromiri-I had the highest evenness values.

The average geometric diameter of corals at all lagoon sites (see Table 2 and *Appendix O* for total size abundance) were greater than 5 cm, with the greatest value at Nikao-I (21.83 cm), however species numbers and density recorded were the lowest respectively (S = 7; 0.88). The highest colony density was reported at Vaimaanga-I (12.88) but the lowest geometric diameter (1.32 cm) was also noted here. Total abundance of colonies by size class (Fig. 23) indicated that 39% of corals were in Class A (recruitment sizes). A breakdown of Class A indicated that *Porites*, *Acropora*, and *Leptastrea* were the most common genera.

Table 2. Biological statistics for all lagoon sites.

Lagoon site	**Coral diversity** (quadrats surveyed)	**Coral diversity**(checklist)	**Coral #** (N)	**Coral community diversity** (H')	**Coral community richness** (Margalef's d-statistic)	**Coral community evenness** (J')	**Average geometric diameter** (cm)	**Coral population density** (ind. per m^2)	**Average # of grazing urchins** (# per 50 m^2)	**Fish diversity** (transects surveyed)	**Fish diversity** (checklist)	**Fish #** (N)	**Fish community diversity** (H')	**Fish community richness** (Margalef's d-statistic)	**Fish community evenness** (J')
Nikao-I	4	10	7	0.5546	1.5417	0.9212	21.83	0.88	2.52	30	40	566	1.0393	4.5751	0.7036
Nikao-C	12	13	34	0.9403	3.1194	0.8713	20.24	4.25	5.13	36	53	738	1.1844	5.2999	0.7610
Arorangi-I	5	12	36	0.5425	1.1162	0.7761	9.56	4.50	4.86	43	63	652	1.2589	6.4814	0.7707
Arorangi-C	10	15	55	0.6864	2.2459	0.6864	4.92	6.88	2.22	45	60	1008	0.9837	6.3623	0.5950
Kavera-I	17	44	72	1.0537	3.7412	0.8564	7.71	9.00	0.82	57	78	1051	1.2706	8.0489	0.7236
Kavera-C	16	51	64	0.9974	3.6067	0.8283	15.54	8.00	1.55	63	99	1302	1.3357	8.6451	0.7423
Vaimaanga-I	9	23	103	0.4345	1.7261	0.4554	13.48	12.88	0.34	23	54	540	0.9735	3.4967	0.7149
Vaimaanga-C	20	47	41	1.2102	5.1164	0.9302	6.20	5.13	2.46	42	63	1711	1.1301	5.5072	0.6962
Titikaveka-I	7	15	21	0.7015	1.9708	0.8301	6.75	2.63	0.07	52	65	1153	1.1390	7.2339	0.6638
Titikaveka-C	10	37	44	0.8244	2.3783	0.8244	8.86	5.50	0.71	44	70	1042	1.0686	6.1880	0.6502
Koromiri-I	7	29	43	0.7875	1.5952	0.9319	14.66	5.38	1.89	39	54	805	1.0329	5.6794	0.6492
Koromiri-C	12	37	39	0.9215	3.0025	0.8539	15.13	4.88	2.24	50	74	858	1.1234	7.2543	0.6612

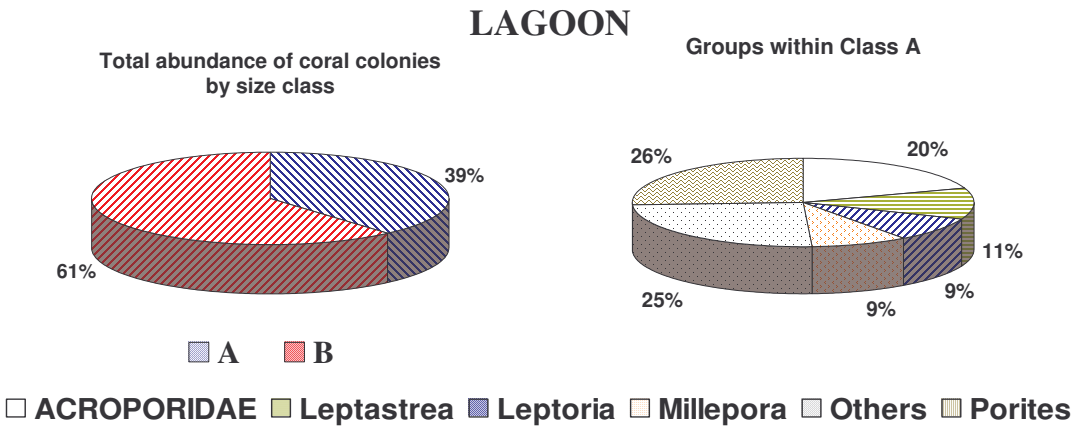

Figure 23. Average percent colony size of corals by class for all lagoon sites (lumped) and percent contribution of coral groups within Class A.

Moving Window Analysis

The MWA for Vaimaanga indicated two major shifts in community: the first at 90 m from shore and the other at 200 m, indicating three different zones (Fig. 24). SIMPER results indicated similarities among quadrats within each zone. The following are percent contributions of each coral to similarities within zones: *Leptastrea* (99%) to Zone 1, *Porites, Leptastrea,* and *Leptoria* (91%) to Zone 2, and *Montipora, Montastrea,* and *Goniastrea* (65%) to Zone 3.

ANOSIM accurately detected a significant change in coral communities between Zone 2 and 3 (R-Statistic = 0.650, p = 0.002). The following corals contributed to 61% of differences between Zones 2 and 3: genus *Porites*, *Montipora, Leptoria, Goniastrea,* and *Cyphastrea* (see *Appendix O* for summary of results). Zone 1 and 2 (R-Statistic = 0.406, p = 0.019) were different with some overlap, and SIMPER suggested that 69% of differences were due to the following corals: genus *Porites*, genus *Leptastrea*, and *Leptoria phrygia*.

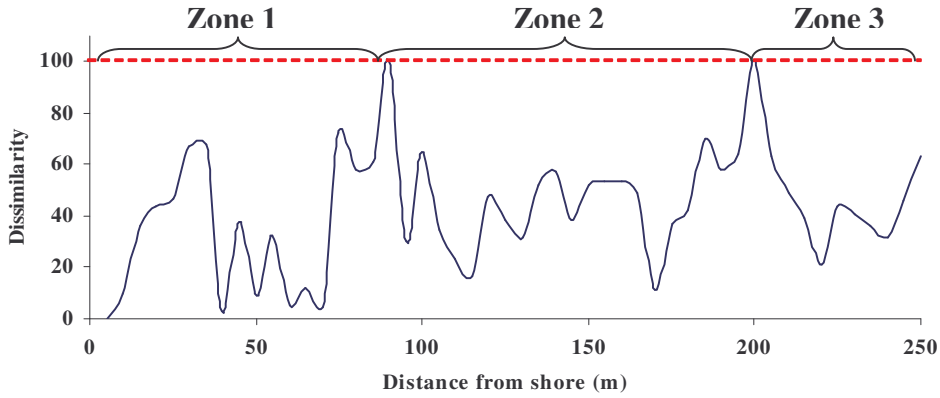

Figure 24. Moving Window Analysis results for Vaimaanga lagoon site.

MACRO-INVERTEBRATES

A checklist and average density (individuals per m^2) for macro-invertebrates were generated for all lagoon sites (*Appendix P*). Greatest densities were attributed to urchins, mainly *Echinometra* spp. (see Table 2 and Fig. 25). Average urchin density calculated were highest at Nikao-C (5.13), followed by Arorangi (4.86). Koromiri-C had the highest density of rori for all sites (1.99), comprised mainly of *Holothuria leucospilata*. Mollusk and starfish densities were less than 1 ind. per m^2 at all sites.

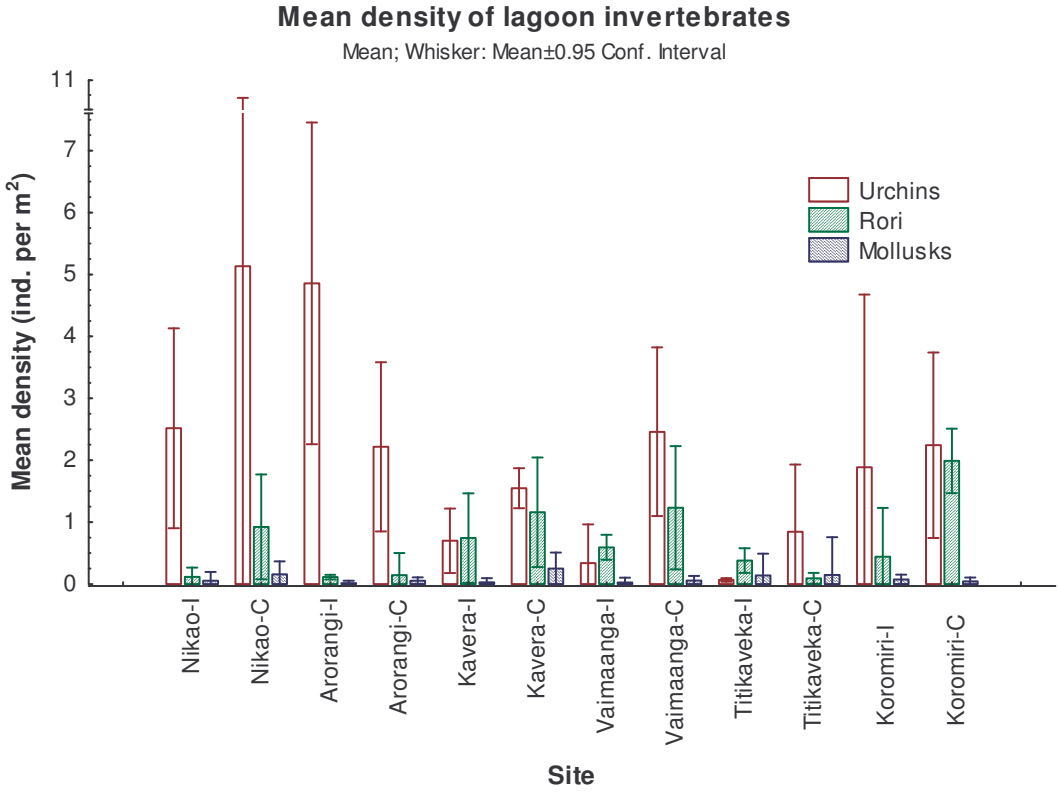

Figure 25. Mean density (ind. per m^2) of lagoon invertebrates for 2006.

FISH

Data 2006

A total of 157 fish species were observed at all sites representing 36 families (see *Appendix Q1* and Q*2* for average density values). Fish species diversity calculations (see Table 2) for each site indicated that Kavera-C had the highest diversity (H`) and greatest number of species (S), followed by Kavera-I. Vaimaanga-I had the lowest diversity, lowest number of species, and lowest number of individuals (N) reported. The most number of individuals for all sites was reported at Vaimaanga-C, and Arorangi-I reported the greatest evenness value while Arorangi-C reported the lowest.

Average density of fish by trophic level was calculated for each site (*Appendix* R). Mean abundance of fish (ind. per 200 m^2) by trophic levels for each site (Fig. 26) indicated that benthic invertivore (mainly wrasses) abundance was highest at Vaimaanga-I (125) followed by Nikao-C (123). Corallivores were highest at Kavera-C (36) followed by Kavera-I (32) where schools of *Chaetodon auriga* were observed at both sites. Omnivore abundance ranged from 60 at Nikao-C (mainly *Chrysiptera glauca*) to 6 at Titikaveka-C. Planktivores were most abundant at Kavera-C (58) followed by Kavera-I and Vaimaanga-C (21 and 20 respectively); abundance at other sites were below 15 individuals per m^2. Herbivores were the most abundant group at all sites, with highest abundance recorded at Vaimaanga-C (407; Fig. 27) of *Acanthurus triostegus* (schooling), *Ctenochaetus striatus*, and *Chlorurus sordidus*. Herbivore abundance at other sites was below 300 individuals. Large variations among certain groups were large due to schooling and patchiness.

Comparisons of percent fish abundance by trophic level between respective impact and control sites (Fig. 28) indicated that herbivores were the dominant trophic level with the exception of Vaimaanga-I, Arorangi-I, and Nikao (I and C) who were dominated by benthic invertivores (70, 41, 40, and 50% respectively).

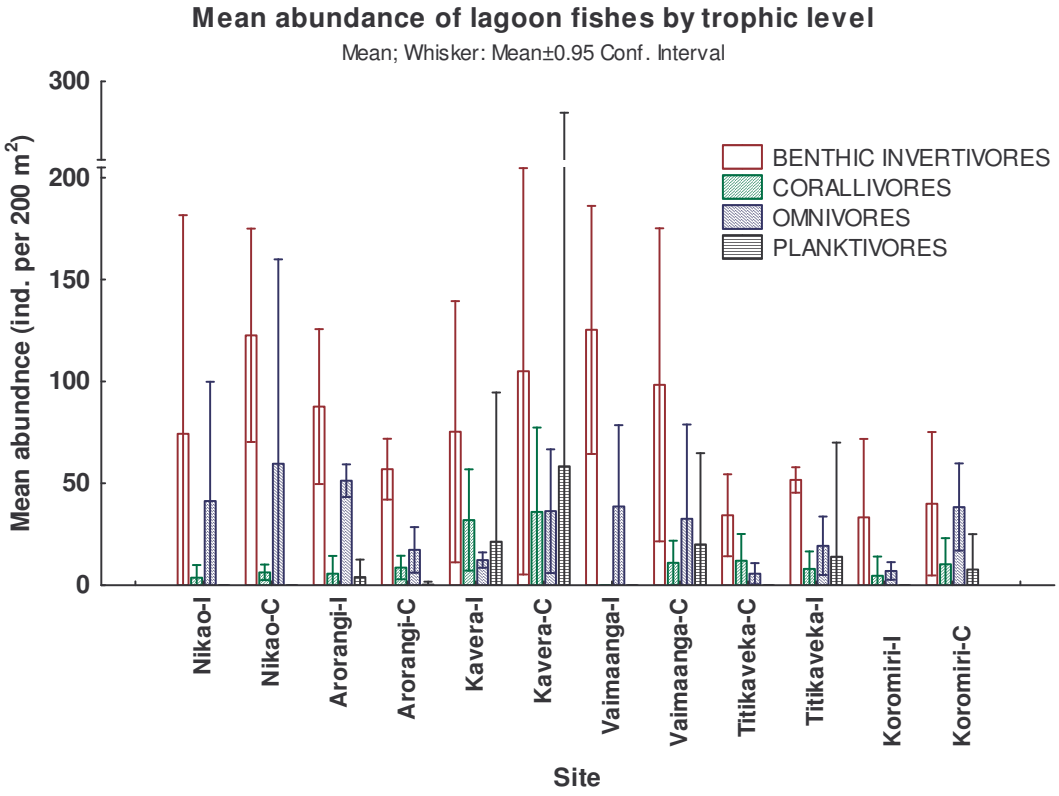

Figure 26. Mean abundance (ind. per 200 m^2) of lagoon fishes by trophic level for 2006.

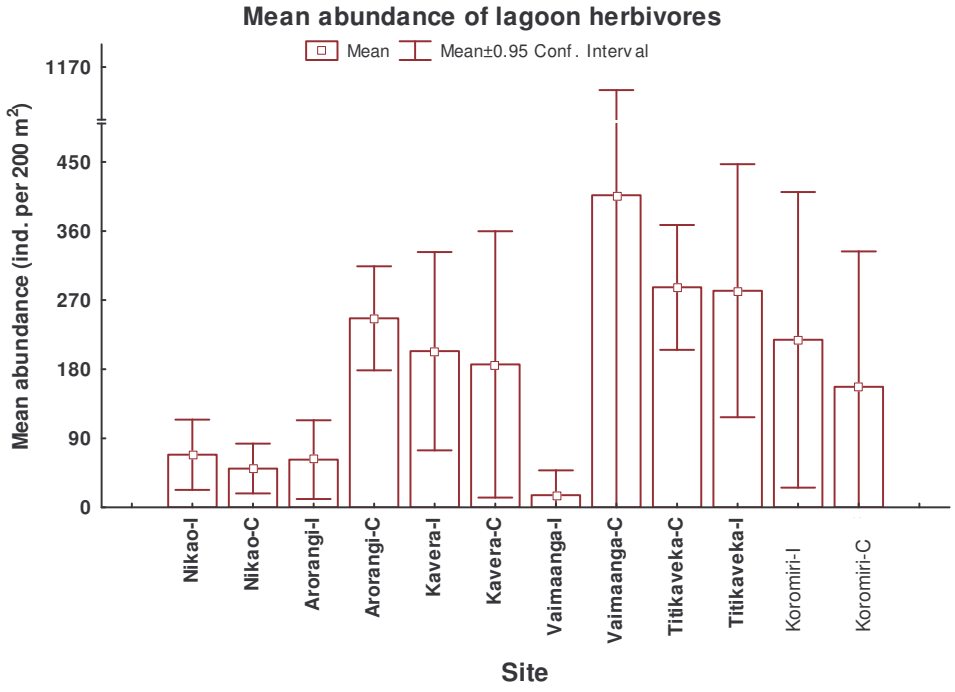

Figure 27. Mean abundance (ind. per 200 m^2) of lagoon herbivores for 2006.

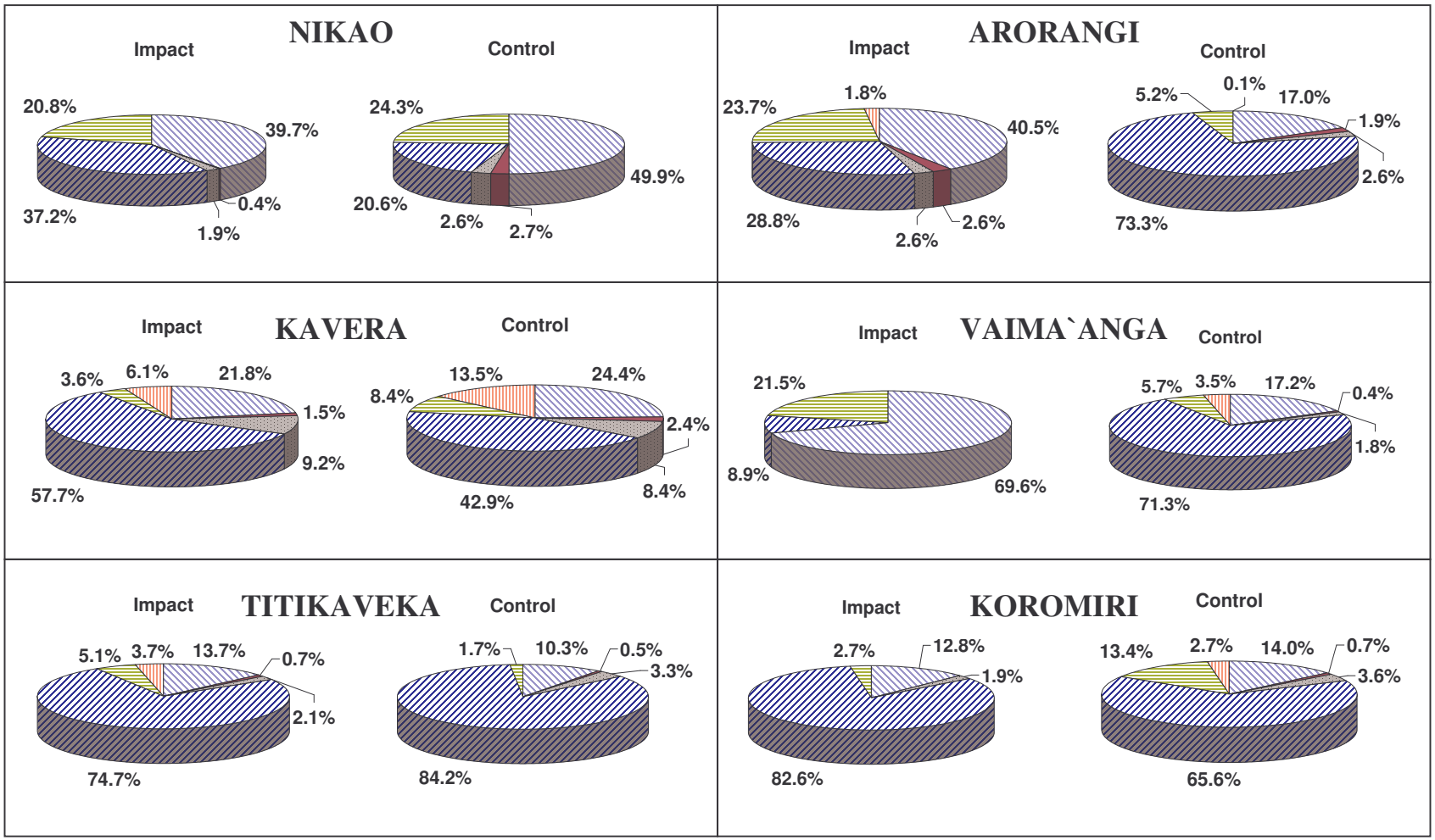

Figure 28. Comparisons of percent fish abundance in the lagoon based on diet between impact sites and their respective control sites.

LAGOON COMPARISONS

Narrow vs. wide

ANOSIM and SIMPER were carried out for selected lagoon sites by lagoon width (*Appendix S*). ANOSIM for fish species also indicated a significant difference between lagoon width (Global R = 0.846, p = 0.001). SIMPER indicated a dissimilarity value of 64% between widths with differences explained by a variety of fish species (refer to *Appendix S*). MDS analysis (*Appendix T*) indicated a similar outcome to ANOSIM. The stress value of 0.13 indicated a good degree of reliability in this result.

F-Statistics were carried out to examine significant differences between treatments of impact and control sites within the lagoon. The following are the results of treatment comparisons at each site:

Impact vs. control site

Nikao

No significant differences were indicated between impact and control.

Arorangi

Significant differences were indicated among fish trophic levels: omnivores ($p < 0.001$) were higher at the impact site, and herbivores ($p < 0.01$) were higher at the control.

Kavera

Urchin abundance was significantly higher at the control ($p < 0.01$).

Vaimaanga

Coralline algae percent cover was significantly higher at the control ($p< 0.01$) as well as turf algae ($p < 0.01$). Urchin abundance was significantly higher at the control ($p < 0.01$). Carnivores were significantly higher at the control ($p < 0.01$). Macro-algae cover was significantly higher at the impact site ($p < 0.01$).

Titikaveka

Coralline algae percent cover was significantly higher at the control ($p < 0.01$) as well as turf algae ($p < 0.01$).

Koromiri

Omnivores were significantly higher at the control ($p < 0.01$) as well as carnivores ($p < 0.01$). No other significant differences were noted between sites.

DISCUSSION AND CONCLUSION

Present data indicated that turf algae cover dominated all fore reef sites. Using LIT data, general comparisons of most fore reef benthic communities between 1994 and 2000 indicated an increase in coral cover and decrease in algae cover. Comparisons between 2000 and 2003 indicated a considerable decrease in coral cover and increase in turf algae cover. Comparisons between 2003 and 2006 suggested that reefs have reached a stable state (i.e. slight decrease in coral cover and slight increase in turf algae cover), which shifted towards an algal-dominated community. A shift was also noted in fish community assemblages with a general decrease in the abundance of planktivores and corallivores, an increase in herbivore abundance (mainly from the families Acanthuridae and Scaridae), and general increase in omnivores between 1999 and 2006.

The phase shift to present conditions was largely due to the recent outbreak of the crown-of-thorns starfish (COTS) that lasted about 10 years, killing most large coral colonies on the fore reef with the exception of a few (i.e. within the surf zone). The impact from the five cyclones that passed through the southern Cooks in 2005 may have been minimal due to the already degraded state of the fore reef. From the 1970's to the mid-90s, Rarotonga's reefs have gone through one major cycle of disturbance (due to the COTS outbreak in the 1970's), and during the recovery period a few disturbances followed (notably the bleaching event in 1992-1993; as indicated in the 1994 survey). In 1994 the hard coral coverage was about 20 % (Motutapu), suggesting that prior disturbances did not completely degrade the fore reefs. Between 1994 and 1999, the increase in planktivore abundance (associated with healthy reefs) and decrease in omnivore abundance noted (at Ngatangiia and Tikioki) as well as an increase in hard coral cover (Motutapu) to about 53 % suggests recovery after bleaching. After 1999, fore reefs saw a decrease in planktivore abundance, increase in omnivore abundance (associated with degraded reefs in this survey), and drastic decrease in hard coral cover to less than 1 % due to the recent COTS outbreak. The impact of the recent COTS outbreak may have set present conditions similar to that of the post-1970's outbreak. The current absence of COTS and the low abundance of fleshy algae on the fore reef suggest that predation by COTS and algal abundance may not be controlling factors to reef recovery.

Although, coral size data indicated that 86% of colonies on the fore reef were new recruits, 82% of these were hardy corals (i.e. *Acanthastrea, Porites, Leptastrea, Montastrea,* and *Leptoria*), suggesting that recovery is still in its early stages and less hardy corals (i.e. Acroporidae family) are slowly colonizing. Though not measured in this survey, high suspended sediment concentrations observed at most fore reef sites (mainly on windward exposures which are also on the most populated and busy side of Rarotonga) may be contributing to hampering the

colonization of less hardy corals. This may be due to the following: 1) the increase of herbivores (known to be the most important sediment producers on reefs; Myers, 1999), 2) the abundance of bioeroders (urchins); and 3) turf algae (known to retain sediment on the reef which resuspend during rough conditions; Purcell, 2000).

Findings have indicated that a combination of high herbivory rates and low nutrient levels favor the colonization of hardy corals and coralline algae (important in providing the framework for coral recruits; Littler *et al.*, 2005). The establishment of soft corals and coralline algae at leeward sites (i.e. clockwise from Titikaveka to Nikao) as well as herbivore abundance and coral recruitment at all sites may be indications that conditions are well set for recovery and recovery has begun. Based on previous observations on reef recovery (i.e. from the 1970's to mid-90s), it may take about 20 years for fore reefs to reach conditions prior to 2000. However, recovery will depend on the frequency of natural disturbances as well as added anthropogenic disturbances.

Though natural events such as elevated temperatures, COTS predation and cyclones have impacted the reefs around Rarotonga, contributions from land may be dependent on factors such as site distance from land (width of lagoon), the size and land-usage and hydrogeology of watersheds, and accessibility for fishing. Differences noted between the exposures are fundamentally the result of differential environmental variables influencing reef development over time (Van Woesik and Done, 1997; Grigg, 1998; and Houk *et al.*, 2005). In turn, the resultant geomorphology may be a primary control of present development, resulting in the noted differences between windward and leeward reefs. Our results suggest that the windward reefs of Rarotonga (i.e. Avarua) are more susceptible to land-based impacts. However, other studies would argue that the benthic community compositions found on the leeward side are more indicative of a continuous fresh water discharge (Houk *et al.*, 2005 and Houk, 2006). One of the goals of our future monitoring efforts will be to elucidate the relative influences of freshwater discharge and associated pollution.

Benthic communities within Rarotonga's lagoon back reefs have a high coverage of turf algae. Coral colonies were larger within the lagoon than on the fore reef, suggesting the impact of COTS may have been less there. Herbivores dominated most lagoon sites with benthic invertebrate predators dominating a few (i.e. Nikao-I and C, Arorangi-I, and Vaimaanga-I). Macro-algae and blue-green algae were observed in all areas of the lagoon, indicating that the lagoon may be experiencing elevated nutrient levels overall as a result of terrestrial runoff. Though data indicated no correlation between benthic invertebrate predators and macro-algae

cover (known to host invertebrates), this trophic group may be an indicator for the presence of macro-algae. Future time series data may enable the testing of this hypothesis.

With the dominance of herbivores, it is expected that macro-algae cover would be low (top-down control). However, elevated nutrient levels may be the controlling factor (bottom-up control) regardless of high herbivory within the lagoon. Factors on Rarotonga affecting top-down control are minimal (i.e. reduced fishing pressure due to ciguatera scare) therefore bottom-up controls (i.e. land-based nutrient inputs) are the foremost concern.

Some treatments (i.e. coralline and turf algae, urchins, and fish trophic levels) between impact and control sites indicated significant differences, however long-term monitoring of these sites is needed to explain these differences. In the present survey, Vaimaanga (I and C) were the only sites which clearly indicated differences due to impacts from terrestrial runoff. In terms of benthic communities, Vaimaanga-I (dominated by macro-algae) was significantly different from Vaimaanga-C as well as all other lagoon sites (dominated by turf algae). This may be due to its close proximity to freshwater outlets as well as natural seepages along this coastline. Furthermore, reef communities at this site may be vulnerable to land-based activities. Therefore, both fish and benthic community data obtained from this survey, including community shifts identified by MWA, will be useful for monitoring the impacts from the establishment of the Captain Cook Resort.

Data presented in this survey provides a snap-shot of present conditions around Rarotonga, however time series data obtained from continuous monitoring of all fore reef and lagoon sites may enable us to identify changes at the community level that may be related to land-based activities. Multi-Dimensional Scaling analyses of fore reef corals and fish (by trophic level) between windward and leeward exposures indicated differences between groups (i.e. soft corals were significantly higher on leeward exposures as were corallivores and planktivores; omnivores were significantly higher on windward exposures). It will be of value to monitor changes within these groups over time, as they may indicate direct or indirect impacts from land-based activities.

RECOMMENDATIONS

The present survey provides additional data to supplement that of previous surveys carried out for Rarotonga as well as baseline data for newly established fore reef and lagoon sites. The objective of this survey is to examine changes over time, and the emphasis should be placed upon changes at the community level rather than simple analyses comparing abundance, density or percent cover. This is because the potential or actual impact would likely be acting at the community level over time. Subsequent monitoring should utilize multivariate analyses (i.e. MDS analysis of benthic communities) comparing to data available in this survey to examine changes over time. For example, differences in treatment positions in MDS analysis may indicate changes at sites. Additional monitoring should include the deployment of conductivity meters at the sites to evaluate which side is influenced by fresh water pollutants. While changes may not be directly caused by land-based activities, a long-term monitoring program will provide a historical pattern reflecting these changes which may enable us to pinpoint the cause.

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GLOSSARY

AIMS: Australian Institute of Marine Science.

ANOSIM: Analysis of Similarities. Analysis generated by PRIMER which examines the "analysis of similarities" hypothesis for differences between groups of community samples (defined a priori), using permutation/randomization methods on similarity matrix.

ANOVA: Analysis of Variance. Analysis generated by PRIMER which tests for differences between groups of (multivariate) samples from different times, locations, experimental treatments, etc.

Benthic Invertivores: fish that primarily feed on crustaceans, molluscs, and urchins.

Carnivores: fish that primarily feed on other fish.

CINES: Cook Islands National Environment Service.

CLUSTER: hierarchical clustering into sample (or species) groups. Analysis generated by PRIMER.

Corallivores: fish that primarily feed on coral polyps.

COTS: crown-of-thorns starfish.

Herbivores: fish that primarily feed on algae.

LIT: Line Intercept Transect. A method used to quantify benthic communities (i.e. corals and algae).

MDS: Multi-Dimensional Scaling. Analysis generated by PRIMER. 2D and 3D results are produced together with a scatter plot. The scatter plot will display 2D or 3D results. Plots can be rotated and flipped.

MMR: Ministry of Marine Resources.

MWA: Moving Window Analysis. A method (adapted from landscape ecology) used to determine over what distance the effects of river discharge influence reef communities.

Omnivores: fish that primarily feed on crustaceans and algae.

PI: Point Intercept. A method used to quantify benthic communities (i.e. corals, algae, sponges, etc.).

Planktivores: fish that primarily feed on plankton.

PRIMER: statistical analysis program which covers a wide range of univariate, graphical and multivariate routines for analyzing the species/sample abundance (or biomass) matrices that arise in biological monitoring of environmental impact and more fundamental studies in community ecology.

SIMPER: Similarity Percentages-Species Contribution. Analysis generated by PRIMER which examines the contribution of each species to the average Bray-Curtis dissimilarity and also similarity between groups of samples

STATISTICA: statistical analysis program.

APPENDICES

Appendix A. Terms of Reference for the present survey.

The Rarotonga Coral Monitoring Programme is one of the National Environment Service's outputs for the 2005-2006 financial year. This programme aims to assess the status and health of corals around the island of Rarotonga. This monitoring programme will involve:

- The collection of raw data form selected points around Rarotonga (the selected points for the survey should be similar to that for previous surveys carried out in 2000 and 2003. Survey points should be identified by GPS and sub-surface markers).
- Analyzing data with comparison to previous surveys undertaken on Rarotonga.
- Compilation, documentation and analysis of all data into a bounded report.
- Provide the National Environment Service three (3) bound hard copies of the final report and one (1) copy of the full document on CD ROM or DVD ROM.
- The final report should be submitted on or before the 1st of May 2006.
- The final report should include assessments on the density and distribution of coral and marine species and communities. Please also include the methods [e.g. Line Intercept Transect (LIT)] and results used for all assessments.

Appendix B. GPS readings for survey sites. * indicates sites previously established (Lyons 2000 and 2003).

OUTER SITES	Lay of transect	GPS	Date surveyed
Avatiu (Harbor Western Basin Extension)	West to East	21º 12.027' S 159º 47.157' W	28/03/2006
Avarua (Boiler)*	West to East	21º 12.161' S 159º 46.563' W	27/03/2006
Kiikii* (*confirmation needed for GPS)*	North to South	21º 12.180' S 159º 44.800' W	30/03/2006
Motutapu*	North to South	21º 14.944' S 159º 43.244' W	29/03/2006
Ta'akoka (Pacific Resort)	North to South	21º 16.061' S 159º 43.614' W	5/04/2006
Titikaveka (Kent Hall)*	East to West	21º 16.699' S 159º 45.645' W	3/04/2006
		LIT: 21º 16.502' S 159º 45.982' W	
Vaimaanga (Captain Cook Resort Hotel)	East to West	21º16.059' S 159º 48.024' W	4/04/2006
Kavera (Rarotongan Beach Resort)*	South to North	21º 15.389' S 159º 49.442' W	22/03/2006
Arorangi (Manuia Beach Hotel)	North to South	21º 13.457' S 159º 50.029' W	21/03/2006
Tumunu*	South to North	21º 13.086' S 159º 50.053' W	23/03/2006
Nikao (Runway)*	North to South	21º 12.013' S 159º 49.124' W	24/03/2006
		LIT: 21º 12.633' S 159º 49.318' W	
INNER SITES	**Lay of transect**	**GPS**	**Date surveyed**
Ta'akoka	North to South	21º 16.047' S 159º 43.906' W	12/04/2006
Ta'akoka (control)	North to South	21º 15.677' S 159º 43.520' W	10/01/2006
Vaimaanga (Captain Cook Resort Hotel)	East to West	21º 15.844' S 159º 47.883' W	4/01/2006
Vaima'anga (control)	West to East	21º 15.926' S 159º 47.639' W	24/01/2006
Vaimaanga (Moving Window Analysis)		21º 15.768' S 159º 47.889' W	3-4/01/2006
Titikaveka (Kent Hall)	East to West	21º 16.418' S 159º 45.668' W	20/01/2006
Titikaveka (Tikioki Rau'i site)	East to West	St: 21º 16.553' S 159º 44.897' W	6-9/01/2006
		End: 21º 16.561' S 159º 44.026' W	
Kavera (Rarotongan Beach Resort)	South to North	21º 15.575' S 159º 48.705' W	13,19/1/2006
Kavera (control)	South to North	21º 15.522' S 159º 49.037' W	18-19/01/2006
Arorangi (Manuia Beach Hotel)	North to South	21º 13.375' S 159º 49.905' W	17/01/2006
Arorangi (control)	South to North	21º 13.271' S 159º 49.943' W	13/04/2006
Nikao (Runway)	West to East	21º 12.215' S 159º 49.238' W	25/01/2006
Nikao (control)	West to East	21º 12.376' S 159º 49.441' W	26-27/01/2006

Appendix C. Checklist of coral species for fore reef sites.

FORE REEF SPECIES	Kavera	Arorangi	Tumunu	Nikao	Avarua	Avatiu	Motutapu	Kikii	Titikaveka	Vaimaanga	Taakoka
ACROPORIDAE											
Acropora humilis	x	x	x		x	x	x	x	x	x	x
Acropora hyacinthus	x	x	x		x	x					
Acropora palmerae							x				
Acropora digitifera (?)											x
Acropora lutkeni				x		x					x
Astreopora randalli					x						
Montipora brown	x	x	x	x	x	x	x	x			x
Montipora purple											x
AGARICIIDAE											
Pavona minuta				x	x						
DENDROPHYLLIIDAE											
Turbinaria reniformis		x	x				x				x
FAVIIDAE											
Cyphastrea chalcidicum	x	x	x	x	x	x	x	x	x	x	x
Favia rotumana				x	x	x	x	x	x		
Favia matthaii									x		
Favia favus	x			x	x	x	x	x	x		x
Favites flexuosa					x	x		x		x	x
Leptastrea purpurea	x	x	x	x	x	x	x	x	x	x	x
Leptastrea transversa	x	x		x	x						x
Leptoria phrygia	x	x	x	x	x	x	x	x	x	x	x
Montastrea curta	x	x	x	x	x	x	x	x	x	x	x
Goniastrea edwardsi	x			x	x	x	x		x		
Goniastrea pectinata	x				x	x	x	x	x		x
MERULINIDAE											
Hydnophora microconos	x	x	x	x	x	x	x	x	x		x
MILLEPORIDAE											
Millepora platyphyla	x	x	x	x	x	x	x	x	x	x	x
MUSSIDAE											
Acanthastrea echinata	x	x	x		x	x	x	x			x
Lobophylia hemprichii			x		x	x					
OCCULINIDAE											
Galaxea fascicularis					x						
POCILLOPORIDAE											
Pocillopora verrucosa	x	x	x	x	x	x	x	x	x	x	x
Pocillopora meandrina	x										
Pocillopora eydouxi			x		x				x	x	x
Pocillopora woodjonesi	x										
PORITIDAE											
Porites lutea	x	x		x	x	x	x	x	x	x	x
Porites lobata											x
SIDERASTREIDAE											
Coscinaraea columna	x	x	x	x	x	x	x	x			x
Psammocora obstusangula							x	x	x		x
Psammocora profundacella			x		x		x	x			x
Other Cnidarians											
Discosoma spp.(anemone)											
ALCYONIDS (soft corals)											
Sarcophyton spp.	x	x	x		x	x		x	x	x	x
Sinularia spp	x	x	x		x	x	x	x	x	x	x
Cladiella spp	x	x	x		x	x	x	x	x	x	x
TOTAL SPECIES	**22**	**18**	**19**	**16**	**28**	**23**	**22**	**21**	**19**	**13**	**27**
TOTAL FAMILIES	**9**	**9**	**9**	**7**	**12**	**9**	**10**	**9**	**8**	**5**	**10**

Appendix D. Average percent coral cover (%) and standard deviation (SD) for fore reef sites.

	Arorangi		Kavera		Tumunu		Nikao		Avarua		Taakoka	
Category	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD
Abiotic	0.00	0.00	0.78	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.31
Turf algae	82.81	6.95	87.34	3.20	96.88	2.22	82.66	1.64	96.41	0.94	90.63	1.77
Macro-algae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.59	1.56
Coralline algae	11.41	3.28	9.69	2.72	4.69	3.59	17.34	1.64	0.16	0.31	2.97	0.60
Soft corals	5.63	4.18	2.03	3.66	0.78	1.18	0.00	0.00	0.00	0.00	1.41	1.39
Hard corals	5.78	4.31	2.19	3.55	1.41	1.18	0.00	0.00	3.44	0.81	1.25	0.88
	Avatiu		**Motutapu**		**Kiikii**		**Vaimaanga**		**Titikaveka**			
Abiotic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.31		
Turf algae	97.81	0.81	89.84	2.25	97.03	1.39	72.66	3.90	64.69	4.35		
Macro-algae	0.00	0.00	9.53	3.12	0.63	1.25	0.00	0.00	0.00	0.00		
Coralline algae	1.25	0.51	0.16	0.31	1.88	1.53	19.22	4.80	30.00	4.92		
Soft corals	0.00	0.00	0.00	0.00	0.00	0.00	8.13	2.84	4.69	2.77		
Hard corals	0.94	0.63	0.47	0.60	0.47	0.31	0.00	0.00	0.47	0.60		

Appendix E. Total coral colony size abundance for fore reef sites. Class based on geometric diameter (cm): A = < 5 and B = ≥ 5.

FORE REEF GENUS	Avatiu		Avarua		KiiKii		Motutapu		Taakoka		Titikaveka		Vaimaanga		Kavera		Arorangi		Tumunu		Nikao	
	SIZE CLASS																					
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Acanthastrea	13		25	8	20		3				1						1		9		5	
Acropora			1		3		1		1	2	2				1				1		2	
Coscinarea					1	1	2	1	1								2				3	
Cyphastrea	1	1	4	5	3		8	4		1							1		5		1	1
Echinopora												1										1
Favia			6	1	5						2		1						2	1		
Favites									1													
Goniastrea	1		2	1							1								6			
Hydnophora	1		5	6	2		5		3						2				4			
Leptastrea	28	8	14	15	15	1	4		1				1	1	4		17	2	15	2	12	
Leptoria	12		19	1	21	1	24		21		28		20		26		5		18	1	17	
Lobophylia			2																			
Montastrea	5	1	24	7	30		10	1	16		5		1		15		4		30	1	12	
Montipora	3	1	4	7	2		1		2							1			4	2	1	
Pavona											1								1			
Pocillopora			3	2	4		1		4	1	1		1		1				3			
Porites	7	2	5	30	14	5	1	1	19	4	8	3	4		4			1	10	2	1	
Psammocora						1	1		3			1										
Turbinaria																			2			
Grand Total	**71**	**13**	**114**	**83**	**120**	**9**	**61**	**7**	**72**	**8**	**49**	**5**	**28**	**1**	**53**	**1**	**30**	**3**	**110**	**9**	**54**	**2**

Appendix F. Line Intercept Transect data for respective fore reef sites.

Site	Benthos	Mean percentage cover	St. dev.
Titikaveka (seawall)	CA	73.717	15.895
Titikaveka (seawall)	TA	15.417	3.170
Titikaveka (seawall)	SC	7.467	6.972
Titikaveka (seawall)	Non-Acroporid	0.067	0.115
Titikaveka (Kent)	CA	45.350	7.961
Titikaveka (Kent)	TA	46.950	8.793
Titikaveka (Kent)	SC	6.450	8.627
Titikaveka (Kent)	Non-Acroporid	0.083	0.144
Kavera	CA	10.333	3.862
Kavera	TA	86.933	4.616
Kavera	Acroporid	0.083	0.144
Kavera	Non-Acroporid	1.317	1.061
Kavera	Abiotic	1.550	1.285
Kiikii	CA	0.783	1.188
Kiikii	TA	97.533	1.583
Kiikii	Acroporid	0.217	0.202
Kiikii	Non-Acroporid	0.933	0.503
Kiikii	Abiotic	0.533	0.924
Motutapu	TA	81.683	13.205
Motutapu	MA	17.750	13.833
Motutapu	Non-Acroporid	0.233	0.225
Motutapu	SC	0.333	0.577
Boiler	CA	0.433	0.448
Boiler	TA	88.533	8.031
Boiler	Non-Acroporid	10.583	8.411
Boiler	Acroporid	0.367	0.247
Boiler	Abiotic	0.167	0.289
Runway	CA	26.400	4.025
Runway	TA	72.967	3.624
Runway	Non-Acroporid	0.167	0.289
Runway	SC	0.467	0.808
Tumunu	CA	1.767	1.533
Tumunu	TA	91.050	9.758
Tumunu	Non-Acroporid	1.583	1.882
Tumunu	SC	5.517	9.555

Appendix G. Checklist and average invertebrate species density (individuals/m^2) for fore reef sites.

FORE REEF SPECIES	Arorangi	Avarua	Avatiu	Kavera	Kiikii	Motutapu	Nikao	Taakoka	Titikaveka	Tumunu	Vaimaanga
Tridacna maxima		0.0100			0.0050	0.0050	0.0050			0.0050	
Dendropoma maxima	0.0100	1.7550	0.1600		0.1600	0.0900	0.5650	0.1100	0.0350	0.0650	
Conus spp.			0.0250		0.0650	0.0400	0.0050	0.0350	0.0150	0.0400	0.0050
Trochus niloticus	0.0300			0.0800				0.0200	0.0400		
Echinometra mathaei	0.7450	3.3600	1.9100	0.1300	2.1150	2.4950	2.3550	3.3100	3.0850	0.6150	0.6700
Echinometra (black/white-tip)		0.0100		0.0150	0.0100		0.0100	0.0100	0.0150		0.0200
Echinometra oblongata	0.0350	0.3650	0.6500	0.0200	0.1600	0.2000	0.1500	0.3500	0.9050	0.0400	0.1050
Echinostrephus aciculatis					0.2050	0.0450		0.0700	0.0150		0.0400
Echinothrix diadema	0.8650	0.8350	0.7000	0.9150	0.5650	0.5150	0.9600	0.8050	1.5000	0.5150	0.4750
Holothuria atra	0.0050		0.0500	0.0200	0.0300		0.0200			0.0050	
Holothuria leucospilata											
Stichopus chloronotus	0.0400		0.0700	0.2550	0.0550	0.0150	0.1050			0.0250	0.0050
Hetaractis crispa							0.0100				

Appendix H1. Checklist of fish species present at respective fore reef sites. Average density (ind. per m^2) and area (m^2) where the average number of a particular species can be found are also included. Trophic level: B = Benthic Invertivores, C = Carnivores, Co = Corallivores, H = Herbivores, O = Omnivores, and P = Planktivores.

FORE REEF SPECIES	Trophic	Avatiu		Avarua		Ki'iki'i		Motutapu		Ta'akoka		Titikaveka	
		Av D	m2/ fish	Av. D	m2/ fish	Av. D	m2/ fish	Av. D	m2/ fish	Av. D	m2/ fish	Av. D	m2/ fish
ACANTHURIDAE		**0.8650**	**1**	**0.5225**	**2**	**1.4163**	**1**	**1.6750**	**1**	**1.7113**	**1**	**1.0050**	**1**
Acanthurus achilles	H											0.0463	22
Acanthurus blochii	H			x		0.0088	114	x					
Acanthurus leucopareius	H	x		x		0.0038	267	0.0038	267	0.0025	400	x	
Acanthurus nigricans	H					0.0025	400					0.0063	160
Acanthurus nigrofuscus	H	0.4438	2	0.3750	3	0.6125	2	0.8500	1	0.6875	1	0.1750	6
Acanthurus olivaceus	H	x		0.0050	200	0.0050	200	0.0050	200	0.0075	133		
Acanthurus strigosus	H									0.0013	800		
Acanthurus triostegus	H	0.0025	400	0.0075	133	0.0988	10						
Ctenochaetus striatus	H	0.3900	3	0.0775	13	0.6150	2	0.6088	2	0.8075	1	0.7513	1
Naso lituratus	H	0.0250	40	0.0525	19	0.0638	16	0.1200	8	0.1763	6	0.0225	44
Naso unicornis	H			0.0050	200	0.0063	160	0.0063	160				
Naso brevirostris	H	0.0038	267					0.0813	12	0.0263	38	x	
Zebrasoma scopus	H									0.0025	400	0.0038	267
Zebrasoma veliferum	H	x						x					
APOGONIDAE				**0.0013**	**800**								
Apogon spp.	P			0.0013	800								
BALISTIDAE		**0.0338**	**30**	**0.0500**	**20**	**0.0488**	**21**	**0.0313**	**32**	**0.0175**	**57**	**0.0038**	**267**
Balistoides viridescens	O									x			
Melichthys niger	H									0.0013	800	0.0013	800
Melichthys vidua	O					0.0025	400	0.0025	400	0.0025	400	0.0013	800
Rhinecanthus rectangulus	C	0.0113	89	0.0175	57	0.0063	160	0.0038	267	0.0013	800		
Sufflamen bursa	O	0.0225	44	0.0100	100	0.0400	25	0.0250	40	0.0125	80	0.0013	800
BLENNIIDAE		**0.0013**	**800**	**0.0063**	**160**					**0.0013**	**800**		
Plagiotremus tapienosoma	C	0.0013	800	0.0063	160	x		x		0.0013	800		
BOTHIDAE													
Bothus mancus	C							x					
CARANGIDAE													
Carangoides orthogrammus	B			x									
Caranx melampygus	C	x		x									
CHAETODONTIDAE		**0.0038**	**267**	**0.0138**	**73**	**0.0013**	**800**	**0.0113**	**89**	**0.0138**	**73**	**0.0325**	**31**
Chaetodon auriga	Co	x		0.0013	800					0.0013	800	0.0013	800
Chaetodon citrinellus	Co	0.0013	800					0.0013	800				
Chaetodon ornatissimus	Co			0.0013	800								
Chaetodon pelewensis	Co									0.0025	400		
Chaetodon quadrimaculatus	Co			0.0063	160			0.0075	133	0.0013	800		
Chaetodon reticulatus	Co	0.0013	800							0.0025	400		
Chaetodon ulietensis	Co											0.0013	800
Chaetodon unimaculatus	Co	0.0013	800					0.0025	400	0.0038	267	0.0263	38

Chaetodon vagabundus	Co			0.0013	800	x		x					
Forcipiger flavissimus	Co			0.0050	200					0.0025	400	0.0038	267
Heniochus monoceros	Co	x				0.0013	800						
CIRRHITIDAE						**0.0013**	**800**			**0.0025**	**400**	**0.0063**	**160**
Paracirrhitus arcatus	C	x								0.0013	800	0.0050	200
Cirrhitops hubbardi? (red body w/ yellow tail)				x		0.0013	800			0.0013	800	0.0013	800
FISTULARIIDAE				**0.0013**	**800**	**0.0025**	**400**	**0.0025**	**400**	**0.0013**	**800**		
Fistularia commersonii	C			0.0013	800	0.0025	400	0.0025	400	0.0013	800		
GOBIIDAE		**0.0013**	**800**										
Valenciennea strigata	B	0.0013	800	x									
HEMIRHAMPHIDAE													
Hemiramphus spp.	O			x		x							
LABRIDAE		**0.1125**	**9**	**0.0850**	**12**	**0.1213**	**8**	**0.1625**	**6**	**0.1838**	**5**	**0.0775**	**13**
Anampses caeruleopunctatus	B							0.0025	400	0.0050	200		
Cheilinus chlorourus	B	0.0013	800	0.0025	400			0.0013	800				
Cheilinus trilobatus	B									0.0013	800		
Cheilio inermis	B	0.0038	267			0.0013	800			0.0013	800		
Coris aygula	B	0.0025	400	0.0013	800	0.0075	133	0.0025	400	0.0038	267		
Coris dorsomaculata	B							0.0013	800	0.0125	80		
Coris gaimard	B			0.0013	800	0.0013	800	0.0013	800	0.0063	160		
Gomphosus varius	B	0.0013	800			0.0025	400	0.0025	400	0.0013	800	0.0088	114
Halichoeres biocellatus?	B					0.0050	200	0.0250	40	0.0500	20	0.0075	133
Halichoeres hortulanus	B	0.0275	36	0.0100	100	0.0213	47	0.0138	73	0.0013	800	0.0025	400
Halichoeres trimaculatus	B			0.0038	267								
Hemigymnus fasciatus	B									0.0013	800	0.0075	133
Hologymnosus annulatus	C	0.0088	114	0.0025	400			0.0013	800				
Labroides dimidiatus		0.0013	800	0.0013	800	0.0050	200	0.0063	160	x		0.0025	400
Labroides pectoralis										x		0.0025	400
Macropharngodon meleagris	B	0.0025	400	0.0013	800	0.0050	200	0.0100	100	0.0163	62		
Macropharngodon negrosensis	B					0.0063	160	x		0.0175	57	0.0025	400
Oxycheilinus unifasciatus	C									0.0013	800		
Pseudocheilinus tetrataenia	B									0.0013	800		
Stethojulis bandanensis	B	0.0275	36	0.0200	50	0.0088	114	0.0200	50	0.0125	80	0.0038	267
Thalassoma lutescens	B	0.0138	73	0.0013	800	0.0200	50	0.0475	21	0.0463	22	0.0375	27
Thalassoma purpureum	B	0.0225	44	0.0150	67	0.0375	27	0.0275	36	0.0050	200	0.0025	400
LETHRINIDAE													
Lethrinus xanthochilus	B									x			
Monotaxis grandoculus	B			x									
LUTJANIDAE								**0.0038**	**267**	**0.0013**	**800**	**0.0013**	**800**
Aphareus furca	C	x						0.0038	267	0.0013	800	0.0013	800
Lutjanus bohar	C												
MICRODESMIDAE		**0.0100**	**100**	**0.0150**	**67**	**0.0200**	**50**	**0.0025**	**400**	**0.0250**	**40**	**0.0038**	**267**
Nemateleotris magnifica	B	0.0100	100	0.0150	67	0.0175	57	0.0025	400	0.0250	40	0.0038	267
Ptereleotris evides	B	x				0.0025	400						
MONACANTHIDAE				**0.0025**	**400**			**0.0013**	**800**	**0.0013**	**800**	**0.0013**	**800**
Cantherhines pardalis	H			0.0025	400			0.0013	800	0.0013	800	0.0013	800

MULLIDAE		**0.0100**	**100**	**0.0150**	**67**	**0.0200**	**50**	**0.0188**	**53**	**0.0138**	**73**	**0.0125**	**80**
Parupeneus bifasciatus	B	0.0038	267	0.0025	400	0.0050	200	0.0038	267	0.0013	800	0.0075	133
Parupeneus cyclostomus	C	0.0025	400	0.0025	400	0.0038	267	0.0038	267	0.0013	800		
Parupeneus multifasciatus	B	0.0038	267	0.0100	100	0.0113	89	0.0113	89	0.0113	89	0.0050	200
MURAENIDAE													
Gymnothorax meleagris	C			x				x					
PINGUIPEDIDAE		**0.0075**	**133**			**0.0025**	**400**	**0.0013**	**800**	**0.0025**	**400**		
Parapercis millipunctuata	C	0.0075	133			0.0025	400	0.0013		0.0025	400		
POMACANTHIDAE				**0.0063**	**160**	**0.0025**	**400**	**0.0188**	**53**	**0.0338**	**30**	**0.0325**	**31**
Centropyge flavissima	H	x		0.0038	267	0.0013	800	0.0188	53	0.0325	31	0.0325	31
Centropyge loricula	H			0.0013	800					0.0013	800		
Pomacanthus imperator	B			0.0013	800	0.0013	800			x			
POMACENTRIDAE		**0.0588**	**17**	**0.1350**	**7**	**0.2013**	**5**	**0.1113**	**9**	**0.5725**	**2**	**0.4963**	**2**
Chromis vanderbilti	P	0.0138	73	0.0638	16	0.0850	12	0.0225	44	0.0700	14	0.4375	2
Pomachromis fuscidorsalis	P	0.0025	400	0.0225	44	0.0625	16	0.0700	14	0.2738	4		
Chromis xanthura	P									0.2200	5	0.0463	22
Chrysiptera brownriggii	O	0.0013	800										
Dascyllus trimaculatus	P					0.0013	800			x			
Plectroglyphidodon imparipennis	O	0.0350	29	0.0488	21	0.0500	20	0.0188	53	0.0050	200		
Stegastes fasciolatus	H									x		0.0075	133
Stegastes yellow tail (unID)	H	0.0063	160	x		0.0025	400			0.0038	267	0.0050	200
SCARIDAE		**0.0200**	**50**	**0.0300**	**33**	**0.1788**	**6**	**0.0350**	**29**	**0.0425**	**24**	**0.2313**	**4**
Chlorurus sordidus	H	0.0013	800	0.0013	800	0.0438	23	0.0050	200	0.0125	80	0.0375	27
Chlorurus frontalis	H											0.0850	12
Scarus altipinnis	H	0.0063	160	0.0025	400	0.0025	400	0.0038	267			0.0113	89
Scarus forsteni	H	x		0.0175	57	0.0138	73	0.0200	50	0.0113	89	0.0138	73
Scarus frenatus	H	0.0013	800	0.0025	400	0.0038	267	0.0013	800	0.0013	800	x	
Scarus globiceps	H	x		0.0025	400	0.0013	800						
Scarus psittacus	H	0.0025	400			0.0050	200	x		0.0075	133	0.0025	400
Scarus schlegeli	H	0.0088	114	0.0038	267	0.1088	9	0.0050	200	0.0100	100	0.0813	12
SERRANIDAE						**0.0013**	**800**	**0.0038**	**267**	**0.0075**	**133**	**0.0113**	**89**
Cephalopholis argus	C	x		x		x		0.0025	400	0.0025	400	0.0100	100
Cephalopholis urodeta	C							0.0013	800	0.0038	267		
Epinephelus fasciatus	C									x			
Epinephelus hexagonatus	C											0.0013	800
Grammistes sexlineatus	C					0.0013	800			0.0013	800		
Variola louti	C									x			
SIGANIDAE						**0.0013**	**800**			**0.0025**	**400**	**0.0050**	**200**
Siganus argenteus	H					0.0013	800			0.0025	400	0.0050	200
TETRADONTIDAE		**0.0038**	**267**	**0.0025**	**400**					**0.0038**	**267**	**0.0050**	**200**
Canthigaster solandri	H	0.0038	267	0.0025	400					0.0038	267	0.0050	200
OSTRACIIDAE													
Ostracion meleagris	O	x											
ZANCLIDAE		**0.0013**	**800**	**0.0025**	**400**	**0.0038**	**267**	**0.0013**	**800**	**0.0038**	**267**	**0.0050**	**200**
Zanclus cornutus	O	0.0013	800	0.0025	400	0.0038	267	0.0013	800	0.0038	267	0.0050	200
TOTAL # OF FAMILIES OBSERVED:		**19**		**22**		**17**		**18**		**20**		**15**	
TOTAL # OF SPECIES OBSERVED:		**54**		**57**		**54**		**55**		**73**		**49**	

Appendix H2. Checklist of fish species present at respective fore reef sites. Average density (ind. per m^2) and area (m^2) where the average number of a particular species can be found are also included. Trophic level: B = Benthic Invertivores, C = Carnivores, Co = Corallivores, H = Herbivores, O = Omnivores, and P = Planktivores.

FORE REEF SPECIES	Trophic	Vaima'anga		Kavera		Arorangi		Tumunu		Nikao	
		Av. D	m2/ fish	Av. D	m2/ fish	Av. D	m2/ fish	Av. D	m2/ fish	Av. D	m2/ fish
ACANTHURIDAE		**1.1713**	**1**	**1.4688**	**1**	**0.6050**	**2**	**1.2338**	**1**	**2.5725**	**0.4**
Acanthurus achilles	H									0.0013	800
Acanthurus blochii	H	0.0025	400			0.0013	800			0.0025	400
Acanthurus leucopareius	H	x								0.0025	400
Acanthurus nigricans	H	0.0013	800								
Acanthurus nigrofuscus	H	0.1000	10	1.1750	1	0.3500	3	0.8875	1	1.1000	1
Acanthurus olivaceus	H							0.0050	200		
Acanthurus pyroferos	H			0.0050	200						
Ctenochaetus flavicauda	H	0.0013	800								
Acanthurus triostegus	H	0.0225	44			0.0075	133	0.1013	10		
Ctenochaetus striatus	H	1.0188	1	0.2663	4	0.1575	6	0.1500	7	1.4250	1
Naso lituratus	H	0.0213	47	0.0200	50	0.0200	50	0.0263	38	0.0325	31
Naso unicornis	H							0.0013	800		
Naso brevirostris	H					0.0688	15	0.0625	16	0.0088	114
Zebrasoma scopus	H	0.0013	800	0.0025	400						
Zebrasoma veliferum	H	0.0025	400								
AULOSTOMIDAE											
Aulostomus chinensis	C	x									
BALISTIDAE		**0.0100**	**100**	**0.0163**	**62**	**0.0138**	**73**	**0.0438**	**23**	**0.0138**	**73**
Melichthys vidua	O	0.0063	160	0.0038	267	0.0038	267	0.0050	200		
Rhinecanthus rectangulus	C	0.0038	267					0.0038	267	0.0013	800
Sufflamen bursa	O			0.0125	80	0.0100	100	0.0350	29	0.0125	80
BELONIDAE											
Tylosurus crocodilus crocodilus	C	x									
BLENNIIDAE		**0.0013**	**800**	**0.0038**	**267**	**0.0025**	**400**	**0.0088**	**114**		
Plagiotremus tapienosoma	C	0.0013	800	0.0038	267	0.0025	400	0.0088	114		
CHAETODONTIDAE		**0.0100**	**100**	**0.0063**	**160**	**0.0088**	**114**	**0.0063**	**160**	**0.0050**	**200**
Chaetodon auriga	Co									0.0025	400
Chaetodon ephippium	Co	x									
Chaetodon quadrimaculatus	Co			0.0013	800			0.0025	400	0.0013	800
Chaetodon reticulatus	Co			0.0013	800						
Chaetodon ulietensis	O			0.0013	800	0.0013	800				
Chaetodon unimaculatus	Co	0.0075	133	0.0013	800	0.0063	160	0.0038	267	0.0013	800
Forcipiger flavissimus	B	0.0013	800	0.0013	800						
Hemitaurichthys polylepis	P	x									
Heniochus monoceros	O	0.0013	800			0.0013	800				
CIRRHITIDAE		**0.0013**	**800**	**0.0088**	**114**	**0.0025**	**400**				
Cirrhitus pinnulatus	B					0.0013	800				

Paracirrhitus arcatus	C			0.0088	114	0.0013	800				
Cirrhitops hubbardi? (red body yllw tail)		0.0013	800								
DIODONTIDAE				**0.0025**	**400**						
Diodon hystrix	B			0.0025	400						
HEMIRHAMPHIDAE											
Hemiramphus spp.	O									x	
HOLOCENTRIDAE		**0.0050**	**200**			**0.0013**	**800**				
Myripristis murdjan	P	0.0050	200								
Sargocentron spiniferum	B					0.0013	800				
KYPHOSIDAE											
Kyphosus bigibbus	H	x									
LABRIDAE		**0.0738**	**14**	**0.1000**	**10**	**0.0775**	**13**	**0.1113**	**9**	**0.0938**	**11**
Anampses caeruleopunctatus	B	0.0013	800	0.0013	800	0.0013	800			0.0025	400
Cheilinus chlorourus	B									0.0013	800
Cheilinus trilobatus	B	0.0025	400								
Cheilio inermis	B	0.0013	800							0.0013	800
Coris aygula	B	x		0.0025	400	0.0025	400	0.0013	800	0.0063	160
Gomphosus varius	B	0.0063	160			0.0025	400			0.0050	200
Halichoeres biocellatus?	B	0.0038	267							0.0050	200
Halichoeres hortulanus	B	0.0025	400	0.0338	30	x		0.0138	73	0.0050	200
Halichoeres trimaculatus	B			0.0013	800						
Hemigymnus fasciatus	B	0.0013	800			0.0013	800			0.0013	800
Labroides bicolor		0.0025	400			0.0025	400				
Labroides dimidiatus		0.0038	267	0.0013	800	0.0075	133	0.0063	160	0.0050	200
Labroides pectoralis		0.0013	800	0.0013	800						
Macropharngodon meleagris	B							0.0013	800	0.0013	800
Macropharngodon negrosensis	B	0.0025	400								
Novaculichthys taeniourus	B			x							
Oxycheilinus unifasciatus	C	x									
Stethojulis bandanensis	B	0.0063	160	0.0100	100	0.0038	267	0.0063	160	0.0038	267
Thalassoma lutescens	B	0.0388	26	0.0488	21	0.0425	24	0.0025	400	0.0513	20
Thalassoma purpureum	B					0.0138	73	0.0800	13	0.0050	200
LETHRINIDAE		**0.0013**	**800**								
Gnathodentex aurolineatus	B	0.0013	800								
Lethrinus xanthochilus	B	x									
Monotaxis grandoculus	B	x									
LUTJANIDAE		**0.0063**	**160**	**0.0038**	**267**					**0.0013**	**800**
Aphareus furca	C	0.0063	160	0.0038	267					0.0013	800
Lutjanus bohar	C	x									
MICRODESMIDAE		**0.0025**	**400**	**0.0100**	**100**	**0.0275**	**36**	**0.0050**	**200**	**0.0025**	**400**
Nemateleotris magnifica	B	0.0025	400	0.0075	133	0.0188	53	0.0050	200	0.0025	400
Ptereleotris evides	B			0.0025	400	0.0088	114				
MONACANTHIDAE				**0.0013**	**800**			**0.0025**	**400**		
Cantherhines pardalis	H			0.0013	800			0.0025	400		
MULLIDAE		**0.0063**	**160**	**0.0225**	**44**	**0.0125**	**80**	**0.0063**	**160**	**0.0188**	**53**
Parupeneus bifasciatus	B	0.0063	160	0.0125	80	0.0038	267	0.0038	267	0.0088	114
Parupeneus cyclostomus	C					0.0025	400	x		0.0025	400

Parupeneus multifasciatus	B			0.0100	100	0.0063	160	0.0025	400	0.0075	133
MURAENIDAE								**0.0013**	**800**		
Gymnothorax meleagris	C							0.0013	800		
PINGUIPEDIDAE				**0.0050**	**200**			**0.0025**	**400**	**0.0013**	**800**
Parapercis millipunctuata	C			0.0050	200			0.0025	400	0.0013	
POMACANTHIDAE		**0.0250**	**40**	**0.0275**	**36**	**0.0100**	**100**	**0.0063**	**160**	**0.0075**	**133**
Centropyge flavissima	H	0.0238	42	0.0250	40	0.0100	100	0.0063	160	0.0075	133
Pomacanthus imperator	B	0.0013	800	0.0025	400					x	
POMACENTRIDAE		**0.2313**	**4**	**0.1075**	**9**	**0.0500**	**20**	**0.2138**	**5**	**0.0450**	**22**
Chromis vanderbilti	P	0.0088	114	0.0038	267	0.0213	47	0.0650	15	0.0150	67
Chromis xanthura	P	0.0950	11								
Chromis yellowtail (unID)	P							0.0025	400		
Chrysiptera brownriggii	O							0.0013	800		
Dascyllus trimaculatus	P									0.0138	73
Plectroglyphidodon imparipennis	O					0.0025	400	0.0425	24	0.0025	400
Pomachromis fuscidorsalis	P			0.0900	11	0.0163	62	0.1000	10	0.0025	400
Pomacentrus vaiuli	O	0.0038	267	0.0050	200	0.0013	800				
Stegastes fasciolatus	H	0.1238	8	0.0075	133	0.0088	114			0.0113	89
Stegastes yellow tail (unID)	H			0.0013	800			0.0025	400		
SCARIDAE		**0.0825**	**12**	**0.0650**	**15**	**0.0538**	**19**	**0.0825**	**12**	**0.2900**	**3**
Chlorurus sordidus	H	0.0413	24	0.0363	28	0.0363	28	x		0.1250	8
Chlorurus frontalis	H	x		0.0075	133	0.0013	800				
Scarus altipinnis	H					0.0088	114			0.0038	267
Scarus forsteni	H	0.0063	160			x				0.0050	200
Scarus frenatus	H	0.0138	73	0.0075	133	0.0075	133	0.0063	160	0.0100	100
Scarus globiceps	H	x		0.0025	400	x		x		0.0250	40
Scarus psittacus	H	0.0025	400			x				0.1075	9
Scarus schlegeli	H	0.0188	53	0.0113	89	x		0.0763	13	0.0138	73
SERRANIDAE		**0.0125**	**80**	**0.0088**	**114**	**0.0300**	**33**			**0.0125**	**80**
Cephalopholis argus	C	0.0063	160	0.0025	400	0.0138	73	x		0.0063	160
Cephalopholis urodeta	C	0.0038	267	0.0038	267	0.0125	80			0.0050	200
Epinephelus fasciatus	C									0.0013	800
Epinephelus hexagonatus	C	0.0025	400	0.0013	800						
Variola louti	C			0.0013	800						
SIGANIDAE											
Siganus argenteus	H	x									
SPHYRAENIDAE											
Sphyraena barracuda	C	x									
SYNANCEIIDAE								**0.0013**	**800**		
Synanceia verrucosa	C							0.0013	800		
TETRADONTIDAE				**0.0150**	**67**					**0.0025**	**400**
Canthigaster solandri	H	x		0.0150	67					0.0025	400
ZANCLIDAE				**0.0038**	**267**	**0.0025**	**400**	**0.0013**	**800**	**0.0025**	**400**
Zanclus cornutus	O	x		0.0038	267	0.0025	400	0.0013	800	0.0025	400
TOTAL # OF FAMILIES OBSERVED:		**21**		**18**		**14**		**16**		**15**	
TOTAL # OF SPECIES OBSERVED:		**64**		**47**		**47**		**41**		**51**	

Appendix I. Average density of fish (average individual per m^2) for fore reef sites based on trophic levels for the present survey. Percent contribution of trophic level at each site are also included.

AVERAGE DENSITY	AVARUA 06	AVATIU 06	NIKAO 06	TUMUNU 06	ARORANGI 06	KAVERA 06	VAIMA`ANGA 06	TITIKAVEKA 06	TA`AKOKA 06	MOTUTAPU 06	KI`IKI`I 06
BENTHIC INVERTIVORES	0.0938	0.1313	0.2388	0.1225	0.1525	0.1388	0.0863	0.0975	0.2238	0.1800	0.1588
CARNIVORES	0.0275	0.0225	0.0175	0.0175	0.0338	0.0300	0.0250	0.0188	0.0188	0.0188	0.0175
CORALLIVORES	0.0100	0.0038	0.0050	0.0063	0.0063	0.0038	0.0075	0.0275	0.0113	0.0113	0.0000
HERBIVORES	0.5625	0.8950	2.7588	1.3275	0.6413	1.5838	1.4013	1.2938	1.8000	1.7300	1.6000
OMNIVORES	0.0613	0.0600	0.0175	0.0850	0.0225	0.0263	0.0113	0.0088	0.0238	0.0475	0.0975
PLANKTIVORES	0.0875	0.0163	0.0313	0.1675	0.0375	0.0938	0.1088	0.4838	0.5638	0.0925	0.1488
SUM	0.8425	1.1288	3.0688	1.7263	0.8938	1.8763	1.6400	1.9300	2.6413	2.0800	2.0225
PERCENTAGE	%	%	%	%	%	%	%	%	%	%	%
BENTHIC INVERTIVORES	11.1	11.6	7.8	7.1	17.1	7.4	5.3	5.1	8.5	8.7	7.8
CARNIVORES	3.3	2.0	0.6	1.0	3.8	1.6	1.5	1.0	0.7	0.9	0.9
CORALLIVORES	1.2	0.3	0.2	0.4	0.7	0.2	0.5	1.4	0.4	0.5	0.0
HERBIVORES	66.8	79.3	89.9	76.9	71.7	84.4	85.4	67.0	68.1	83.2	79.1
OMNIVORES	7.3	5.3	0.6	4.9	2.5	1.4	0.7	0.5	0.9	2.3	4.8
PLANKTIVORES	10.4	1.4	1.0	9.7	4.2	5.0	6.6	25.1	21.3	4.4	7.4

Appendix J. Average density of fish (average individuals per m^2) for fore reef sites compared based on trophic levels. Percent contribution of trophic level at each site are also included.

AVERAGE DENSITY	AVARUA		NIKAO		ARORANGI		KAVERA		TIKIOKI			NGATANGIIA			AVATIU		
	1999	2006	1999	2006	1999	2006	1999	2006	1994	1999	2006	1994	1999	2006	1994	1999	2006
BENTHIC INVERTIVORES	0.0580	0.0938	0.0200	0.1138	0.0190	0.1525	0.0440	0.1388	0.0090	0.0400	0.0975	0.0010	0.0490	0.1800	0.0030	0.0650	0.1313
CARNIVORES	0.0020	0.0275	0.0050	0.0175	0.0070	0.0338	0.0050	0.0300	0.0000	0.0110	0.0188	0.0000	0.0130	0.0188	0.0000	0.0040	0.0225
CORALLIVORES	0.0060	0.0100	0.0100	0.0050	0.0060	0.0063	0.0180	0.0038	0.0510	0.0300	0.0275	0.0510	0.0310	0.0113	0.0420	0.0150	0.0038
HERBIVORES	0.1980	0.5625	0.3090	2.8838	0.0380	0.6413	0.2040	1.5838	0.6220	0.6930	1.2938	0.4500	0.7490	1.7300	0.4340	0.2850	0.8950
OMNIVORES	0.0260	0.0613	0.0290	0.0175	0.0540	0.0225	0.0320	0.0263	0.0720	0.0080	0.0088	0.0310	0.0250	0.0475	0.0280	0.0060	0.0600
PLANKTIVORES	0.2250	0.0875	0.1600	0.0313	0.7100	0.0375	0.5550	0.0938	0.4820	0.7200	0.4838	0.1660	0.9700	0.0925	0.4530	0.0600	0.0163
SUM	0.5150	0.8425	0.5330	3.0689	0.8340	0.8938	0.8580	1.8763	1.2360	1.5020	1.9300	0.6990	1.8370	2.0800	0.9600	0.4350	1.1288

PERCENTAGES	AVARUA		NIKAO		ARORANGI		KAVERA		TIKIOKI			NGATANGIIA			AVATIU		
	1999	2006	1999	2006	1999	2006	1999	2006	1994	1999	2006	1994	1999	2006	1994	1999	2006
BENTHIC INVERTIVORES	11.3	11.1	3.8	3.7	2.3	17.1	5.1	7.4	0.7	2.7	5.1	0.1	2.7	8.7	0.3	14.9	11.6
CARNIVORES	0.4	3.3	0.9	0.6	0.8	3.8	0.6	1.6	0.0	0.7	1.0	0.0	0.7	0.9	0.0	0.9	2.0
CORALLIVORES	1.2	1.2	1.9	0.2	0.7	0.7	2.1	0.2	4.1	2.0	1.4	7.3	1.7	0.5	4.4	3.4	0.3
HERBIVORES	38.4	66.8	58.0	94.0	4.6	71.7	23.8	84.4	50.3	46.1	67.0	64.4	40.8	83.2	45.2	65.5	79.3
OMNIVORES	5.0	7.3	5.4	0.6	6.5	2.5	3.7	1.4	5.8	0.5	0.5	4.4	1.4	2.3	2.9	1.4	5.3
PLANKTIVORES	43.7	10.4	30.0	1.0	85.1	4.2	64.7	5.0	39.0	47.9	25.1	23.7	52.8	4.4	47.2	13.8	1.4

Appendix K. ANOSIM and SIMPER results for fore reef corals and fish by trophic level.

SIMILARITY MATRIX

Parameters
Analyse between: Samples
Similarity measure: Bray Curtis
Standardise: No
Transform: Log(X+1)
Factor: Exposure (Windward and Leeward)

ANOSIM for Corals

Global Test
Sample statistic (Global R): 0.497
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

SIMPER for Corals

Parameters
Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Exposure (Windward and Leeward)

Group Windward
Average similarity: 36.20

Species	*Av.Abund*	*Av.Sim*	*Sim/SD*	*Contrib%*	*Cum.%*
Leptastrea purpurea	64.17	11.51	1.04	31.80	31.80
Porites lutea	152.79	7.95	0.77	21.96	53.76
Montastrea curta	23.89	5.76	0.86	15.91	69.68
Leptoria phrygia	10.44	4.68	1.12	12.93	82.61
Acanthastrea echinata	23.99	3.88	0.90	10.73	93.33

Group Leeward
Average similarity: 28.56

Species	*Av.Abund*	*Av.Sim*	*Sim/SD*	*Contrib%*	*Cum.%*
Soft coral	639.64	16.93	0.67	59.27	59.27
Leptoria phrygia	7.85	7.32	0.78	25.63	84.91
Porites lutea	14.17	2.06	0.29	7.23	92.13

Groups Windward & Leeward
Average dissimilarity = 84.45

Species	*Group W Av.Abund*	*Group L Av.Abund*	*Av.Diss*	*Diss/SD*	*Contrib%*	*Cum.%*
Soft coral	0.95	639.64	24.28	0.98	28.75	28.75
Porites lutea	152.79	14.17	13.01	1.10	15.41	44.16
Leptastrea purpurea	64.17	1.47	11.77	1.03	13.94	58.10
Montastrea curta	23.89	2.98	6.40	1.26	7.58	65.68
Acanthastrea echinata	23.99	0.03	5.35	1.12	6.34	72.02
Leptoria phrygia	10.44	7.85	4.23	1.15	5.01	77.03
Montipora purple	10.01	0.00	2.92	0.41	3.45	80.48
Cyphastrea serailia	13.25	0.00	2.81	0.48	3.33	83.81
Hydnophora microcornis	10.64	0.20	2.09	0.51	2.47	86.28
Pocillopora verrucosa	4.71	0.46	1.85	0.59	2.19	88.48
Montipora brown	7.17	1.15	1.84	0.40	2.17	90.65

ANOSIM for fish

Global Test

Sample statistic (Global R): 0.779
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 1352078)
Number of permuted statistics greater than or equal to Global R: 0

SIMPER

Parameters

Standardise data: No
Transform: None
Cut off for low contributions: 90.00%
Factor name: Exposure (Windward and Leeward)

Group Windward
Average similarity: 59.99

Species	*Av.Abund*	*Av.Sim*	*Sim/SD*	*Contrib%*	*Cum.%*
Acanthurus nigrofuscus	95.42	29.82	4.07	49.70	49.70
Ctenochaetus striatus	72.17	13.51	1.40	22.52	72.22
Plectroglyphidodon imparipennis	8.92	2.60	1.97	4.34	76.56
Naso lituratus	9.42	2.54	1.38	4.23	80.79
Chromis vanderbilti	10.83	1.89	0.78	3.15	83.93
Sufflamen bursa	6.33	1.82	1.86	3.03	86.96
Halichoeres hortulanus	3.92	0.99	1.48	1.64	88.60
Thalassoma lutescens	4.00	0.94	1.42	1.57	90.17

Group Leeward
Average similarity: 47.84

Species	*Av.Abund*	*Av.Sim*	*Sim/SD*	*Contrib%*	*Cum.%*
Ctenochaetus striatus	135.75	25.29	1.64	52.87	52.87
Acanthurus nigrofuscus	96.67	10.48	0.76	21.92	74.79
Thalassoma lutescens	8.33	1.90	2.60	3.96	78.75
Chromis vanderbilti	30.00	1.79	0.35	3.75	82.50
Chlorurus sordidus	7.67	1.34	1.67	2.81	85.31
Centropyge flavissimus	5.42	1.09	2.43	2.27	87.58
Naso lituratus	4.25	0.92	2.22	1.93	89.51
Stegastes fasciolatus	9.25	0.81	0.41	1.69	91.20

Groups Windward & Leeward
Average dissimilarity = 58.69

Species	*Group W Av.Abund*	*Group L Av.Abund*	*Av.Diss*	*Diss/SD*	*Contrib%*	Cum.%
Ctenochaetus striatus	72.17	135.75	15.19	1.30	25.87	25.87
Acanthurus nigrofuscus	95.42	96.67	14.66	1.69	24.97	50.85
Chromis vanderbilti	10.83	30.00	5.16	0.86	8.79	59.64
Scarus schlegeli	8.08	7.42	1.63	0.79	2.78	62.42
Stegastes fasciolatus	0.00	9.25	1.60	0.74	2.73	65.15
Chromis xanthura	0.00	9.42	1.51	0.71	2.57	67.72
Plectroglyphidodon imparipennis	8.92	0.00	1.45	2.12	2.48	70.20
Pomachromis fuscidorsalis	5.83	6.00	1.39	0.89	2.37	72.57
Chlorurus sordidus	3.08	7.67	1.18	1.29	2.00	74.57
Acanthurus triostegus	7.25	1.50	1.06	0.66	1.81	76.38
Naso lituratus	9.42	4.25	1.02	1.49	1.73	78.11
Scarus frontalis	0.00	6.17	0.96	0.37	1.63	79.74
Sufflamen bursa	6.33	0.92	0.88	1.91	1.49	81.24
Thalassoma lutescens	4.00	8.33	0.86	1.52	1.46	82.69
Centropyge flavissimus	0.33	5.42	0.81	2.08	1.38	84.08
Thalassoma purpureum	5.00	0.17	0.76	1.26	1.30	85.38
Halichoeres hortulanus	3.92	2.58	0.58	1.46	0.98	86.36
Stethojulis bandanensis	3.75	1.33	0.52	0.84	0.89	87.25
Acanthurus achilles	0.00	3.08	0.48	0.56	0.82	88.07
Scarus forsteni	2.08	1.33	0.42	0.73	0.72	88.79
Nemateleotris magnifica	2.83	0.92	0.39	1.38	0.66	89.45
Chaetodon unimaculatus	0.08	2.33	0.37	0.90	0.62	90.07

Appendix L. Checklist of coral species for lagoon sites.

LAGOON SPECIES	Nikao	Nikao (C)	Arorangi	Arorangi (C)	Kavera	Kavera (C)	Vaimaanga	Vaimaanga (C)	Titikaveka (Kent)	Titikaveka (Ra`ui)	Koromiri	Koromiri (C)
ACROPORIDAE												
Acropora humilis	x	x	x	x	x	x	x	x	x	x	x	x
Acropora hyacinthus		x			x	x	x	x		x		
Acropora cf. lutkeni					x	x	x	x				
Acropora robusta					x	x		x				
Acropora surculosa					x	x		x				
Acropora vaughani						x	x			x	x	
Acropora austere					x	x		x		x		
Acropora verweyi					x	x		x				x
Acropora aculeus					x	x		x			x	x
Acropora studeri						x				x		
Acropora digitifera/nasuta (?)					x	x	x			x		
Acropora tenuis						x						
Astreapora listeri									x			
Astreopora myriophthalma				x	x	x		x		x		
Montipora cf hoffmeisteri												x
Montipora cf. planiuscula					x	x				x		
Montipora caliculata	x	x	x	x	x	x		x		x	x	x
Montipora sp. 2 (Veron)						x		x				
Montipora foveolata					x	x		x				x
Montipora lobulata						x					x	
Montipora hispida					x	x		x				
AGARICIIDAE												
Pavona minuta					x	x		x		x	x	x
Pavona maldivensis					x							
Pavona varians					x	x		x				
DENDROPHYLLIIDAE												
Turbinaria reniformis	x	x			x	x		x		x	x	x
FAVIIDAE												
Cyphastrea chalcidicum		x		x	x	x	x	x	x			x
Cyphastrea (NEW SPECIES)								x		x	x	x
Echinopora lamellosa					x	x		x		x		x
Favia pallida					x	x						
Favia mathaii				x	x	x	x	x	x			x
Favia stelligera				x	x	x		x		x	x	x
Favia favus											x	
Favia cf. danae								x				
Favites flexuosa			x	x	x	x	x		x	x	x	x
Favites rotundata								x			x	x
Leptastrea purpurea	x	x	x	x	x	x	x	x	x	x	x	x
Leptastrea transversa					x	x	x	x		x	x	x
Leptastrea agazzi											x	x
Leptoria phrygia	x	x	x	x	x	x	x	x	x	x	x	x
Montastrea curta	x	x	x	x	x	x	x	x	x	x	x	x
Platygyra pini						x	x	x		x	x	x
Goniastrea edwardsi					x	x		x			x	x
Goniastrea pectinata					x	x		x		x	x	x
MERULINIDAE												
Hydnophora exesa					x	x	x	x		x	x	x
Hydnophora microconos	x	x	x	x	x	x	x	x	x	x	x	x
MILLEPORIDAE												
Millepora platyphyla		x		x	x	x	x	x		x		x
Millepora dichotoma									x	x	x	x
MUSSIDAE												
Acanthastrea echinata			x	x	x	x	x	x	x	x	x	x
Acanthastrea hillae							x	x				
Lobophylia hemprichii						x		x		x	x	x
Lobophylia costata					x							

OCCULINIDAE												
Galaxea fascicularis					x	x		x		x		x
POCILLOPORIDAE												
Pocillopora damicornis					x	x		x		x	x	x
Pocillopora verrucosa	x	x	x		x	x	x	x	x	x		x
Pocillopora danae						x		x		x		
Pocillopora eydouxi					x	x						
PORITIDAE												
Porites murrayensis					x	x						
Porites lutea	x	x	x	x	x	x	x	x	x	x	x	x
Porites lobata						x	x	x		x		x
SIDERASTREIDAE												
Coscinaraea columna								x	x	x		
Psammocora contigua								x				x
Psammocora obstusangula	x	x	x	x	x	x	x	x	x	x	x	x
Psammocora stellata					x	x	x	x				
Psammocora profundacella								x				
FUNGIIDAE												
Fungia repanda											x	x
ALCYONIDS (soft corals)												
Sarcophyton spp										x		
Sinularia spp						x				x		
Cladiella spp			x		x							
TOTAL SPECIES	**10**	**13**	**12**	**15**	**44**	**51**	**23**	**47**	**15**	**37**	**29**	**37**
TOTAL FAMILIES	**7**	**7**	**7**	**7**	**11**	**11**	**8**	**11**	**6**	**11**	**11**	**11**

Appendix M. Average percent coral cover (%) and standard deviation (SD) for lagoon sites.

	Koromiri-C		Koromiri		Vaimaanga-C		Vaimaanga-I		Titikaveka		Titikaveka-C	
Category	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV
Turf algae	77.50	4.10	77.08	9.71	78.28	6.15	48.13	4.10	77.08	1.44	63.07	3.98
Macro-algae							37.92	1.91	0.63	1.08	0.95	0.87
Coralline algae	1.88	1.88	0.63	1.08	4.69	2.53					8.33	2.30
Soft coral									0.21	0.36		
Hard corals	4.38	1.25	4.17	1.57	6.56	4.10	4.38	1.88	9.38	2.86	4.36	2.00
	Kavera-C		Kavera-I		Arorangi-I		Arorangi-C		Nikao-I		Nikao-C	
Turf algae	62.29	7.81	58.96	6.97	86.88	3.13	91.88	2.50	90.31	5.65	92.81	1.49
Macro-algae			0.63	0.63	3.75	1.08	5.21	1.44			1.25	1.53
Coralline algae	0.21	0.36			0.63	0.63	1.46	1.57			0.63	0.72
Abiotic									8.59	5.34	4.06	2.53
Hard corals	12.50	1.25	16.46	3.08	0.42	0.36	1.46	0.95	1.09	1.07	1.25	0.51

Appendix N. Total coral colony size abundance for lagoon sites. Class based on geometric diameter (cm): A = < 5 and B = ≥ 5.

LAGOON GENUS	Nikao		Nikao-C		Arorangi		Arorangi-C		Kavera		Kavera-C		Vaimaanga		Vaimaanga-C		Titikaveka		Titikaveka-C		Koromiri		Koromiri-C	
	SIZE CLASS																							
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Acanthastrea													2											
Acropora			1				1		5		4		1		8								12	
Astreopora							5								1	4								
Cyphastrea		1		2				1		1														1
Echinopora										1														
Favia									4	2					2	1								1
Favites									6				1		2		1							
Galaxea											1													
Goniastrea									2						4									
Hydnophora			1				1		1		2				2				2					
Leptastrea		3		8		19	13	6		1		7	6	4	1	1		1			6			5
Leptoria		1		7		9	6	15		10		2	3		2		2		5		3	2		7
Millepora				3													6	1	10	4	5			
Montastrea			1		2		4			2	1			1	1	4			2				1	
Montipora				1		2				3		4				2	6	1		4	2	11		1
Pavona																				2				
Platigyra																2								
Pocillopora				2		4		1		1		11												
Porites	1	1		5				1	9	12	3	16	45	32		3		3		11		4	2	4
Psammocora				3			1			11	8	5		8		1				3	2	8	1	4
Turbinaria										1										1				
Grand Total	**1**	**6**	**3**	**31**	**2**	**34**	**31**	**24**	**27**	**45**	**19**	**45**	**58**	**45**	**23**	**18**	**15**	**6**	**19**	**25**	**18**	**25**	**16**	**23**

Appendix O. SIMPER results of corals for Vaimaanga-I MWA.

Parameters
Standardise data: No
Data: Square-root transformed
Cut off for low contributions: 90.00%
Factor groups: Zone 1, Zone 2, Zone 3

Zone 1
Average similarity: 46.76

Species	*Av.Abund*	*Av.Sim*	*Sim/SD*	*Contrib%*	*Cum.%*
Leptastrea Genus	95.91	46.46	1.53	99.36	99.36

Zone 2
Average similarity: 30.10

Species	*Av.Abund*	*Av.Sim*	*Sim/SD*	*Contrib%*	*Cum.%*
Porites genus	579.84	16.68	0.78	55.43	55.43
Leptastrea Genus	92.14	8.47	0.87	28.16	83.59
Leptoria phrygia Total	117.06	2.41	0.50	8.01	91.60

Zone 3
Average similarity: 29.61

Species	*Av.Abund*	*Av.Sim*	*Sim/SD*	*Contrib%*	*Cum.%*
Montipora genus	128.96	9.44	1.13	31.89	31.89
Montastrea curta	68.96	5.26	0.91	17.76	49.64
Goniastrea pectinata	159.91	3.76	0.50	12.70	62.35
Leptoria phrygia Total	170.82	2.81	0.51	9.48	71.83
Porites genus	353.35	2.57	0.31	8.70	80.52
Cyphastrea chalcidicum	159.99	1.66	0.26	5.59	86.12
Favia genus	137.29	1.30	0.33	4.40	90.52

Zones 1 & 2
Average dissimilarity = 79.94

Species	*Zone 1 Av.Abund*	*Zone 2 Av.Abund*	*Av.Diss*	*Diss/SD*	*Contrib%*	*Cum.%*
Porites genus	3.05	579.84	30.52	1.18	38.18	38.18
Leptastrea Genus	95.91	92.14	15.36	1.11	19.22	57.40
Leptoria phrygia Total	3.32	117.06	9.00	0.52	11.26	68.66
Montastrea curta	0.00	25.17	6.14	0.65	7.68	76.34
Acanthastrea echinata	7.85	25.85	3.92	0.37	4.90	81.24
Acropora Genus Total	0.00	21.71	3.09	0.36	3.86	85.10
Echinopora lamelosa	0.00	69.19	2.66	0.22	3.32	88.43
Montipora genus	0.00	49.16	2.55	0.31	3.19	91.61

Zones 2 & 3
Average dissimilarity = 80.07

Species	*Group 2 Av.Abund*	*Group 3 Av.Abund*	*Av.Diss*	*Diss/SD*	*Contrib%*	*Cum.%*
Porites genus	579.84	353.35	16.70	1.16	20.86	20.86
Montipora genus	49.16	128.96	9.89	1.42	12.35	33.21
Leptoria phrygia Total	117.06	170.82	8.18	0.84	10.22	43.43
Goniastrea pectinata	0.00	159.91	7.37	0.87	9.20	52.63
Cyphastrea chalcidicum	7.46	159.99	6.63	0.66	8.28	60.90
Leptastrea Genus	92.14	12.80	5.82	1.07	7.27	68.18
Montastrea curta	25.17	68.96	5.71	1.29	7.13	75.30
Favia genus	14.46	137.29	5.02	0.69	6.26	81.57
Acropora Genus Total	21.71	78.85	4.55	0.55	5.69	87.26
Acanthastrea echinata	25.85	47.99	4.37	0.58	5.46	92.72

Appendix P. Checklist and average invertebrate species density (individuals/m^2) for lagoon sites.

LAGOON SPECIES	Nikao	Nikao-C	Arorangi	Arorangi-C	Kavera	Kavera-C	Vaimaanga	Vaimaanga-C	Titikaveka	Titikaveka-C	Koromiri	Koromiri-C
Tridacna maxima	0.0067	0.0067	0.0067	0.0233	0.0200	0.0100	0.0167	0.0500	0.0033		0.0533	0.0267
Dendropoma maxima	0.0367	0.1200		0.0100	0.0067	0.2400	0.0100	0.0067	0.1300	0.1433	0.0200	0.0167
Conus spp.	0.0033	0.0167	0.0033	0.0167	0.0033				0.0067	0.0033		
Trochus niloticus	0.0067	0.0133	0.0067	0.0033								
Echinometra mathaei	2.2233	4.4267	4.2633	1.9500	0.3833	0.7167	0.3100	1.8233	0.0233	0.4633	1.3500	1.3267
Echinometra (black/white-tip)	0.0567	0.1267	0.0200	0.0300	0.2167	0.3133	0.0300	0.5233	0.0367	0.2267	0.4133	0.3467
Echinometra oblonga	0.1600	0.4767	0.4467	0.1467	0.0933	0.0533		0.1033		0.1233	0.0633	0.0400
Echinothrix diadema	0.0567	0.0867	0.1267	0.0900	0.0067	0.2933			0.0033	0.0300	0.0167	0.3600
Tripneustes gratilla	0.0167	0.0167				0.1733		0.0100	0.0033	0.0033	0.0433	0.1700
Heterocentrotus spp.	0.0033											
Holothuria hilla								0.0433				
Holothuria atra	0.0733	0.1400	0.0267	0.0633	0.3800	0.4800	0.0600	0.7333	0.1900	0.0200	0.1233	0.4667
Holothuria leucospilata	0.0167	0.0833	0.0100	0.0667	0.1733	0.5533	0.4567	0.1533	0.1167	0.0167	0.3167	1.4800
Stichopus chloronotus	0.0233	0.6667	0.0700		0.1900	0.1267	0.0767	0.3033	0.0733	0.0567	0.0033	0.0433
Actinopyga mauritiana	0.0033	0.0333	0.0067	0.0133								
Holothuria cinerascens				0.0767								
Linckia spp.		0.0067	0.0133	0.0133	0.0133	0.0033	0.0400	0.0067	0.0167	0.0600	0.0233	0.0133
Acanthaster planci				0.0033		0.0033						
Hetaractis crispa		0.0033	0.0067									

Appendix Q1. Checklist of fish species present at respective lagoon sites. Average density (ind. per m^2) and area (m^2) where the average number of a particular species can be found are also included. Trophic level: B = Benthic Invertivores, C = Carnivores, Co = Corallivores, H = Herbivores, O = Omnivores, and P = Planktivores.

LAGOON SPECIES	Trophic	Ta'akoka		Ta'akoka (C)		Titikaveka (Kent)		Titikaveka (Ra'ui)		Vaima'anga		Vaima'anga (C)	
		Av D	m2/ fish	Av D	m2/ fish	Av D	m2/ fish	Av D	m2/ fish	Av D	m2/ fish	Av D	m2/ fish
ACANTHURIDAE		**0.8200**	**1**	**0.1083**	**9**	**0.3117**	**3**	**0.5783**	**2**	**0.0617**	**16**	**1.4067**	**1**
Acanthurus blochii	H							x					
Acanthurus leucopareius	H											x	
Acanthurus nigrofuscus	H	0.0817	12	0.0017	600	0.0117	86	0.0017	600	0.0100	100	0.1500	7
Acanthurus olivaceus	H			x									
Acanthurus thompsoni	P							x		x			
Acanthurus triostegus	H	0.4567	2	0.0233	43	0.1117	9	0.1133	9	0.0400	25	0.8350	1
Ctenochaetus striatus	H	0.2450	4	0.0350	29	0.1467	7	0.4017	2	0.0117	86	0.3800	3
Naso lituratus	H	0.0150	67	0.0217	46	0.0200	50	0.0367	27	x		0.0267	38
Naso unicornis	H	x		0.0217	46			x		x		x	
Naso vlamingi	H									x			
Zebrasoma scopus	H	0.0050	200	0.0050	200	0.0217	46	0.0250	40			0.0150	67
Zebrasoma veliferum	H	x											
AULOSTOMIDAE													
Aulostomus chinensis	C									x		x	
BALISTIDAE		**0.0200**	**50**	**0.0017**	**600**	**0.0117**	**86**	**0.0017**	**600**	**0.0233**	**43**	**0.0150**	**67**
Balistapus undulatus	B					x							
Balistoides viridescens	O			0.0017	600								
Rhinecanthus aculeatus	B	0.0200	50	x		0.0117	86	0.0017	600	0.0233	43	0.0150	67
Sufflamen bursa	O			x									
BLENNIIDAE				**0.0033**	**300**	**0.0067**	**150**					**0.0033**	**300**
Aspidontus taeniatus	C												
Blue blenny (unidentified)				0.0033	300	0.0017	600					0.0017	600
Exalias brevis	Co			x									
Plagiotremus tapienosoma	C	x				0.0050	200			x		0.0017	600
BOTHIDAE													
Bothus mancus	C									x			
CARANGIDAE				**0.0017**	**600**			**0.0033**	**300**				
Carangoides orthogrammus	B							x					
Caranx melampygus	C			0.0017	600	x		0.0033	300	x			
CARCHARHINIDAE													
Carcharinus melanopterus	C									x			
CHAETODONTIDAE		**0.0267**	**38**	**0.0517**	**19**	**0.0417**	**24**	**0.0600**	**17**			**0.0567**	**18**
Chaetodon auriga	Co	0.0083	120	0.0233	43	0.0233	43	0.0300	33	x		0.0133	75
Chaetodon bennetti	Co									x			
Chaetodon citrinellus	Co	0.0017	600	0.0183	55	0.0050	200	0.0167	60	x		0.0250	40
Chaetodon ephippium	Co	0.0033	300	0.0017	600	0.0050	200	0.0067	150			x	
Chaetodon lunula	Co			0.0017	600	0.0017	600	0.0033	300				

Chaetodon ornatissimus	Co	0.0100	100	0.0033	300	0.0033	300	x					
Chaetodon pelewensis	Co			0.0017	600			x				0.0067	150
Chaetodon quadrimaculatus	Co	x						x					
Chaetodon reticulatus	Co	x				0.0017	600	0.0033	300			x	
Chaetodon trifasciatus	Co					x							
Chaetodon unimaculatus	Co	x		0.0017	600			x				0.0067	150
Chaetodon vagabundus	Co			x				x				x	
Forcipiger flavissimus	B	0.0033	300			0.0017	600	x				0.0050	200
Heniochus chrysostomus	Co					x		x					
Heniochus monoceros	O	x											
DIODONTIDAE						**0.0017**	**600**	**0.0017**	**600**	**0.0067**	**150**	**0.0083**	**120**
Diodon hystrix	B	x		x		0.0017	600	0.0017	600	0.0067	150	0.0083	120
FISTULARIIDAE													
Fistularia commersonii	C			x									
GOBIIDAE				**0.0083**	**120**	**0.0017**	**600**						
White goby (unidentified)	B			0.0050	200	0.0017	600					x	
Valenciennea strigata	B			0.0033	300					x		x	
HEMIRHAMPHIDAE													
Hemiramphus spp.	O	x		x				x					
HOLOCENTRIDAE		**0.0033**	**300**	**0.0150**	**67**								
Myripristis murdjan	P	x		0.0033	300								
Neoniphon opercularis	B			0.0033	300								
Sargocentron microstoma	B	0.0033	300	0.0067	150								
Sargocentron spiniferum	B			0.0017	600	x		x					
KYPHOSIDAE								**0.0050**	**200**				
Kyphosus bigibbus	H							0.0050	200				
LABRIDAE		**0.0900**	**11**	**0.1567**	**6**	**0.2050**	**5**	**0.1367**	**7**	**0.5600**	**2**	**0.4117**	**2**
Anampses caerulopunctatus	B					0.0017	600						
Cheilio inermis	B											0.0017	600
Cheilinus chlorourus	B			0.0217	46	0.0067	150	0.0167	60			0.0167	60
Cheilinus trilobatus	B	0.0100	100										
Coris aygula	B	0.0017	600	x		0.0083	120	0.0050	200	0.0017	600	0.0067	150
Coris gaimard	B					0.0017	600						
Coris variegata	B									0.2750	4	x	
Epibulus insidiator	B							x					
Gomphosus varius	B	0.0017	600	0.0100	100	0.0117	86	0.0100	100			0.0200	50
Halichoeres hortulanus	B			0.0017	600	x				0.0017	600		
Halichoeres trimaculatus	B	0.0117	86	0.0900	11	0.0400	25	0.0050	200	0.0483	21	0.0683	15
Hemigymnus fasciatus	B					0.0017	600						
Labroides bicolor						0.0017	600	x				0.0017	600
Labroides dimidiatus		0.0033	300	0.0033	300	0.0100	100	0.0067	150	0.0067	150	0.0100	100
Pseudocheilinus octotaenia	B											0.0050	200
Stethojulis bandanensis	B	0.0167	60	0.0117	86	0.0267	38	0.0133	75	0.1433	7	0.0450	22
Stethojulis strigiventor	B			0.0017	600	x		0.0100	100	0.0383	26		
Thalassoma hardwickii	B			x		0.0117	86	0.0017	600	x		0.0017	600
Thalassoma lutescens	B	0.0433	23	0.0150	67	0.0833	12	0.0683	15	0.0083	120	0.2350	4
Thalassoma purpureum	B					x						x	

Thalassoma trilobatum	B	0.0017	600										
Thalassoma quinquevittatum	B	x		0.0017	600					0.0367	27		
LETHRINIDAE		**0.0050**	**200**					**0.0033**	**300**			**0.0067**	**150**
Monotaxis grandoculus	B	0.0050	200	x		x		0.0033	300			0.0067	150
LUTJANIDAE													
Lutjanus fulvus	B							x					
Lutjanus kasmira	B											x	
MONACANTHIDAE													
Cantherhines dumerilii	Co			x									
MUGILIDAE								**0.0083**	**120**				
Crenimugil crenilabis	H			x				0.0083	120	x			
MULLIDAE		**0.0433**	**23**	**0.0233**	**43**	**0.0383**	**26**	**0.0300**	**33**	**0.0367**	**27**	**0.0517**	**19**
Mulloides flavolineatus	B	0.0350	29	x						x			
Mulloides vanicolensis	B					x						x	
Parupeneus barberinus	B			x		x							
Parupeneus bifasciatus	B	0.0050	200	0.0133	75	0.0067	150	0.0217	46	0.0100	100	x	
Parupeneus cyclostomus	C	0.0017	600	0.0033	300	0.0033	300	0.0033	300			0.0067	150
Parupeneus multifasciatus	B	0.0017	600	0.0067	150	0.0283	35	0.0033	300	0.0267	38	0.0133	75
Parupeneus pleurostigma	B			x		x		0.0017	600			0.0317	32
MURAENIDAE													
Echidna nebulosa	B			x								x	
Gymnothorax meleagris	C									x			
MYLIOBATIDAE													
Aetobatis narinari										x			
OPHICHTHIDAE													
Myrichthys magnificus				x						x			
PINGUIPEDIDAE													
Parapercis millipunctata	C	x		x		x				x			
POMACANTHIDAE		**0.0050**	**200**	**0.0033**	**300**	**0.0117**	**86**	**0.0100**	**100**			**0.0217**	**46**
Centropyge flavissima	H	0.0050	200	0.0033	300	0.0100	100	0.0100	100	x		0.0217	
Pomacanthus imperator	B					0.0017	600						
POMACENTRIDAE		**0.2233**	**4**	**0.3483**	**3**	**0.1550**	**6**	**0.0183**	**55**	**0.1900**	**5**	**0.3283**	**3**
Abudefduf sordidus	O	0.0033	300			0.0033	300	x					
Chromis viridis	P	x		x		x						x	
Chrysiptera biocellata	O			0.0783	13			x		0.0100		0.1000	10
Chrysiptera blue stripe (unidentified)	O			0.0033	300			0.0017	600				
Chrysiptera brownriggii	O											x	
Chrysiptera glauca	O	0.0017	600	0.0750	13	0.0200	50			0.1700	6	0.0217	46
Chrysiptera unimaculata	O											x	
Dascyllus aruanus	P	x		0.0333	30	0.0700	14	x				0.1000	10
Plectroglyphidodon imparipennis	O					0.0017	600						
Plectroglyphidodon johnstonianus	O									0.0017	600		
Pomacentrus pavo	O							x					
Pomacentrus vaiuli	O	0.0200	50	0.0317	32	0.0500	20	0.0167	60	0.0083	120	0.0417	24
Stegastes albifasciatus	H	0.1100	9	0.0183	55	0.0050	200					0.0033	300
Stegastes lividus	H	0.0883	11	0.1083	9	0.0050	200	x				0.0617	16

SCARIDAE		**0.0300**	**33**	**0.7000**	**1**	**1.0367**	**1**	**0.7967**	**1**	**0.0133**	**75**	**0.5267**	**2**
Chlorurus frontalis	H	0.0250	40	0.0017	600	0.1067	9	0.1317	8	x		0.1133	9
Chlorurus sordidus	H	0.0017	600	0.4033	2	0.6150	2	0.4950	2	0.0133	75	0.2550	4
Scarus altipinnis	H	x		0.0017	600	0.0067	150	0.0100	100	x		0.0033	300
Scarus frenatus	H			x		0.0050	200	0.0017	600				
Scarus ghobban	H									x			
Scarus globiceps	H									x			
Scarus psittacus	H	0.0033	300	0.2933	3	0.3033	3	0.1250	8	x		0.1550	6
Scarus schlegeli	H	x				x		0.0333	30				
SCORPAENIDAE													
Synanceia verrucosa	C									x			
SERRANIDAE				**0.0017**	**600**	**0.0033**	**300**	**0.0017**	**600**			**0.0017**	**600**
Cephalopholis argus	C			0.0017	600	x		0.0017	600	x			
Epinephelus hexagonatus	C											0.0017	
Epinephelus macrospilos	C			x		0.0033	300	x		x			
Epinephelus merra	C					x		x					
Grammistes sexlineatus	C							x				x	
SIGANIDAE		**0.0233**	**43**			**0.0317**	**32**	**0.0350**	**29**				
Siganus argenteus	H	0.0233	43					0.0350	29				
Siganus spinus	H					0.0317	32					x	
SYNGNATHIDAE				**0.0017**	**600**								
Corythoichthys spp.	P			0.0017	600								
TETRADONTIDAE		**0.0150**	**67**			**0.0117**	**86**			**0.0050**	**200**	**0.0133**	**75**
Arothron hispidus	B			x				x					
Arothron nigropunctatus	Co			x				x					
Canthigaster amboinensis	H											x	
Canthigaster solandri	H	0.0150		x		0.0117	86	x		0.0050	200	0.0133	75
OSTRACIIDAE		**0.0033**	**300**	**0.0033**	**300**	**0.0017**	**600**	**0.0033**	**300**				
Ostracion cubicus	B	0.0033	300	0.0033	300			0.0017	600	x		x	
Ostracion meleagris	O					0.0017	600	0.0017	600				
ZANCLIDAE		**0.0100**	**100**	**0.0017**	**600**	**0.0200**	**50**	**0.0083**	**120**	**0.0033**	**300**		
Zanclus cornutus	O	0.0100	100	0.0017	600	0.0200	50	0.0083	120	0.0033	300		
TOTAL # OF SPECIES OBSERVED:		**54**		**74**		**65**		**70**		**54**		**63**	
TOTAL # OF FAMILIES OBSERVED:		**18**		**26**		**19**		**21**		**25**		**19**	

Appendix Q2. Checklist of fish species present at respective lagoon sites. Average density (ind. per m^2) and area (m^2) where the average number of a particular species can be found are also included. Trophic level: B = Benthic Invertivores, C = Carnivores, Co = Corallivores, H = Herbivores, O = Omnivores, and P = Planktivores.

LAGOON SPECIES	Trophic	Kavera		Kavera (C)		Arorangi		Arorangi (C)		Nikao		Nikao (C)	
		Av D	m2/ fish	Av D	m2/ fish	Av D	m2/ fish	Av D	m2/ fish	Av D	m2/ fish	Av D	m2/ fish
ACANTHURIDAE		**0.4033**	**2**	**0.5883**	**2**	**0.2917**	**3**	**1.1533**	**1**	**0.2983**	**3**	**0.2033**	**5**
Acanthurus achilles	H							0.0017	600				
Acanthurus leucopareius	H					x				0.0033	300		
Acanthurus nigricans	H			x									
Acanthurus nigrofuscus	H	0.0017	600	0.0083	120	0.0617	16	0.6667	2	0.0417	24	0.0250	40
Acanthurus pyroferus	H							x					
Acanthurus thompsoni	P					0.0150	67						
Acanthurus triostegus	H	0.0250	40	0.3633	3	0.1783	6	0.0200	50	0.2400	4	0.1200	8
Ctenochaetus striatus	H	0.3417	3	0.1700	6	0.0117	86	0.4167	2	x		0.0333	30
Naso lituratus	H	0.0067	150	0.0417	24	0.0200	50	0.0467	21	0.0133	75	0.0250	40
Naso unicornis	H	0.0017	600	0.0033	300	0.0033	300	0.0017	600	x		x	
Naso vlamingi	H	0.0033	300										
Zebrasoma scopus	H	0.0233	43	0.0017	600	0.0017	600	x					
AULOSTOMIDAE				**0.0017**	**600**								
Aulostomus chinensis	C			0.0017									
BALISTIDAE		**0.0133**	**75**	**0.0517**	**19**	**0.0100**	**100**	**0.0300**	**33**	**0.0017**	**600**	**0.0017**	**600**
Rhinecanthus aculeatus	B	0.0133	75	0.0517	19	0.0033	300	0.0200	50	0.0017	600	0.0017	600
Rhinecanthus rectangulus	C			x		0.0067	150	0.0100	100				
BELONIDAE												**0.0250**	**40**
Platybelone argalus platyura	C			x						x		0.0250	40
BLENNIIDAE		**0.0033**	**300**	**0.0150**	**67**	**0.0050**	**200**						
Aspidontus taeniatus?	C			0.0017									
Blue blenny (unidentified)		0.0033	300										
Plagiotremus tapienosoma	C	x		0.0133	75	0.0050	200						
BOTHIDAE				**0.0017**	**600**								
Bothus mancus	C			0.0017	600								
CARANGIDAE				**0.0017**	**600**								
Caranx lugubris	C	x											
Caranx melampygus	C	x		0.0017	600			x		x			
CHAETODONTIDAE		**0.1583**	**6**	**0.1817**	**6**	**0.0283**	**35**	**0.0450**	**22**	**0.0183**	**55**	**0.0317**	**32**
Chaetodon auriga	Co	0.0767	13	0.1150	9	0.0133	75	0.0050	200	0.0100	100	0.0133	75
Chaetodon bennetti	Co												
Chaetodon citrinellus	Co	0.0150	67	0.0200	50	0.0150	67	0.0350	29	0.0083	120	0.0150	67
Chaetodon ephippium	Co	0.0183	55	x									
Chaetodon flavirostris	Co			x									
Chaetodon lunula	Co	0.0117	86	0.0217	46	x		x					
Chaetodon ornatissimus	Co	x						x					
Chaetodon pelewensis	Co			0.0017	600								

Chaetodon quadrimaculatus	Co			0.0017	600	x		0.0033	300			0.0033	300
Chaetodon spp. (like *C. auriga*-darker)	Co			x									
Chaetodon reticulatus	Co			x									
Chaetodon trifasciatus	Co	0.0100	100	0.0017	600								
Chaetodon ulietensis	Co	0.0033	300										
Chaetodon unimaculatus	Co	0.0033	300	0.0117	86								
Chaetodon vagabundus	Co	0.0150	67	0.0050	200								
Forcipiger flavissimus	Co			0.0017	600			0.0017	600				
Heniochus chrysostomus	Co	0.0050	200	0.0017	600								
Heniochus monoceros	Co					x		x				x	
CIRRHITIDAE				**0.0050**	**200**	**0.0017**	**600**						
Paracirrhitus arcatus	C			0.0050	200								
Paracirrhitus forsteri	C			x		0.0017	600						
DIODONTIDAE		**0.0017**	**600**	**0.0033**	**300**			**0.0017**	**600**			**0.0050**	**200**
Diodon hystrix	B	0.0017	600	0.0033	300	x		0.0017	600	x		0.0050	200
FISTULARIIDAE								**0.0150**	**67**				
Fistularia commersonii	C			x		x		0.0150	67	x		x	
GOBIIDAE		**0.0017**	**600**			**0.0083**	**120**						
White goby (unidentified)	B	0.0017	600	x									
Valenciennea strigata	B			x		0.0083	120	x					
HEMIRHAMPHIDAE								**0.0067**	**150**				
Hemiramphus spp.	O			x				0.0067	150				
HOLOCENTRIDAE		**0.0067**	**150**	**0.0033**	**300**								
Myripristis murdjan	P			x				x				x	
Neoniphon opercularis	B	0.0017	600										
Sargocentron microstoma	B	0.0050	200	0.0033	300							x	
KYPHOSIDAE		**0.0033**	**300**										
Kyphosus bigibbus	H	0.0033											
LABRIDAE		**0.2633**	**4**	**0.3333**	**3**	**0.3967**	**3**	**0.2167**	**5**	**0.3500**	**3**	**0.5883**	**2**
Anampses caerulopunctatus	B	x		x		x							
Cheilio inermis	B	x		x									
Cheilinus chlorourus	B	0.0150	67	0.0233	43	0.0033	300	0.0017	600	0.0067	150	0.0017	600
Cheilinus trilobatus	B	x		x		x							
Coris aygula	B	0.0017	600	0.0067	150	0.0117	86	0.0200	50	0.0083	120	0.0083	120
Coris gaimard	B			0.0050	200							x	
Coris variegata	B					x		0.0417	24	0.0950	11	0.2333	4
Cymolutes praetextatus	B			x									
Gomphosus varius	B	0.0100	100	0.0200	50	x		0.0033	300	0.0050	200	0.0217	46
Halichoeres hortulanus	B			x		0.1367	7					0.0017	600
Halichoeres trimaculatus	B	0.0417	24	0.0300	33	0.0950	11	0.0317	32	0.0617	16	0.0150	67
Hemigymnus fasciatus	B					0.0033	300						
Labroides bicolor				x									
Labroides dimidiatus		0.0017	600	0.0200	50	0.0133	75	0.0050	200	0.0017	600	0.0083	120
Macropharyngodon meleagris	B					x							
Novaculichthys taeniourus	B	x		x									
Pseudocheilinus octotaenia	B			0.0100	100								
Stethojulis bandanensis	B	0.0017	600	0.0217	46	x		0.0400	25	0.0383	26	0.1200	8

Stethojulis strigiventor	B	0.0017	600	x		0.0483	21						
Thalassoma hardwickii	B	0.0083	120	0.0017	600	x		0.0033	300	x		0.0067	150
Thalassoma lutescens	B	0.1800	6	0.1867	5	0.0717	14	0.0333	30	0.1317	8	0.1483	7
Thalassoma purpureum	B			0.0083	120	x		0.0233	43	0.0033	300	0.0233	43
Thalassoma trilobatum	B	0.0017	600			0.0100	100						
Thalassoma quinquevittatum	B					0.0033	300	0.0133	75			x	
LETHRINIDAE		**0.0550**	**18**	**0.0750**	**13**			**0.0067**	**150**				
Gnathodentex aurolineatus	B	0.0533	19	0.0750	13			0.0017	600				
Lethrinus xanthochilus	B			x									
Monotaxis grandoculus	B	0.0017	600	x				0.0050	200				
LUTJANIDAE													
Lutjanus kasmira	B			x									
MONACANTHIDAE								**0.0017**	**600**			**0.0017**	**600**
Amanses scopus						x							
Cantherhines dumerilii	Co			x									
Cantherhines pardalis	H	x		x				0.0017	600			0.0017	600
MUGILIDAE													
Crenimugil crenilabis	H												
MULLIDAE		**0.0450**	**22**	**0.0700**	**14**	**0.0283**	**35**	**0.0383**	**26**	**0.0217**	**46**	**0.0183**	**55**
Mulloides flavolineatus	B			x				0.0033	300				
Mulloides vanicolensis	B			x									
Parupeneus barberinus	B	x		x									
Parupeneus bifasciatus	B	0.0067	150	0.0433	23	0.0267	38	0.0283	35	0.0117	86	0.0117	86
Parupeneus ciliatus	B			0.0017	600								
Parupeneus cyclostomus	C	0.0083	120	0.0133	75								
Parupeneus multifasciatus	B	0.0200	50	0.0100	100	0.0017	600	0.0067	150	0.0100	100	0.0067	150
Parupeneus pleurostigma	B	0.0100	100	0.0017	600					x			
MURAENIDAE													
Echidna nebulosa	B					x							
Gymnothorax meleagris	C			x				x					
PINGUIPEDIDAE		**0.0017**	**600**			**0.0133**	**75**	**0.0067**	**150**	**0.0017**	**600**	**0.0050**	**200**
Parapercis millipunctata	C	0.0017	600			0.0133	75	0.0067	150	0.0017	600	0.0050	200
POMACANTHIDAE		**0.0150**	**67**	**0.0100**	**100**	**0.0017**	**600**	**0.0250**	**40**	**0.0050**	**200**	**0.0033**	**300**
Centropyge flavissima	H	0.0150	67	0.0100	100	0.0017	600	0.0250	40	0.0050	200	0.0033	300
Centropyge loricula	H	x											
Pomacanthus imperator	B	x		x				x				x	
POMACENTRIDAE		**0.4600**	**2**	**0.5283**	**2**	**0.2717**	**4**	**0.1050**	**10**	**0.2233**	**4**	**0.3283**	**3**
Abudefduf sordidus?	O			x		0.0033	300	0.0083	120	0.0033	300	x	
Abudefduf septemfasciatus	O			0.0150	67								
Abudefduf sexfasciatus	O			0.0050	200								
Chromis viridis	P	x											
Chrysiptera biocellata	O			0.0017	600	0.0183	55			x		0.0117	86
Chrysiptera blk/wht (unidentified)	O							0.0150	67				
Chrysiptera blue stripe (unidentified)	O	0.0017	600	x									
Chrysiptera brownriggii	O					0.0617	16					0.0017	600
Chrysiptera glauca	O	x		0.0217	46	0.1333	8	0.0033	300	0.1783	6	0.1700	6
Chrysiptera c.f. *leucopoma?*	O	x				x							

Chrysiptera unimaculata?	O					0.0400	25	0.0267	38	0.0067	150	0.0717	14
Dascyllus aruanus	P	0.1067	9	0.2917	3								
Dascyllus trimaculatus	P			x		0.0150	67						
Plectroglyphidodon imparipennis	O					x		0.0217	46	0.0083	120	0.0433	23
Pomacentrus pavo	O	x		x									
Pomacentrus vaiuli	O	0.0467	21	0.1283	8								
Stegastes albifasciatus	H	0.1150	9	0.0533	19			0.0300	33			x	
Stegastes fasciolatus	H			0.0017	600			x					
Stegastes lividus	H	0.1733	6	0.0100	100					0.0267	38	0.0300	33
SCARIDAE		**0.2733**	**4**	**0.2433**	**4**	**0.0033**	**300**	**0.0183**		**0.0133**	**75**	**0.0150**	**67**
Chlorurus frontalis	H	0.0267	38	0.0183	55			0.0167	60	0.0033	300	0.0033	300
Chlorurus microrhinos	H					0.0017	600						
Chlorurus sordidus	H	0.2117	5	0.1117	9			0.0017	600	0.0050	200	0.0050	200
Scarus altipinnis	H	0.0017	600	0.0050	200								
Scarus frenatus	H	0.0017	600										
Scarus globiceps	H											x	
Scarus psittacus	H	0.0317	32	0.1083	9	0.0017	600	x		0.0050	200	0.0067	150
SERRANIDAE		**0.0133**	**75**	**0.0050**	**200**	**0.0017**	**600**			**0.0017**	**600**	**0.0033**	**300**
Cephalopholis argus	C			0.0017	600	0.0017	600					0.0033	300
Epinephelus hexagonatus	C			x		x		x				x	
Epinephelus macrospilos	C	0.0100	100	0.0017	600								
Epinephelus merra	C	0.0033	300										
Grammistes sexlineatus	C	x		0.0017	600	x				0.0017	600		
SIGANIDAE				**0.0167**	**60**	**0.0033**	**300**						
Siganus argenteus	H			x									
Siganus spinus	H	x		0.0167	60	0.0033	300	x				x	
SYNGNATHIDAE						**0.0050**	**200**	**0.0017**					
Corythoichthys spp.	P					0.0050	200	0.0017	600			x	
TETRADONTIDAE		**0.0233**	**43**	**0.0083**	**120**	**0.0117**	**86**	**0.0033**		**0.0083**	**120**		
Arothron hispidus	B	x											
Arothron meleagris	Co	0.0050	200	x								x	
Arothron nigropunctatus	Co	x											
Canthigaster amboinensis	H					0.0017							
Canthigaster solandri	H	0.0183	55	0.0083	120	0.0100		0.0033	300	0.0083	120	x	
OSTRACIIDAE		**0.0017**	**600**			**0.0017**	**600**						
Ostracion cubicus	B	x				0.0017	600	x		x			
Ostracion meleagris	O	0.0017	600										
ZANCLIDAE		**0.0083**	**120**	**0.0100**	**100**			**0.0050**					
Zanclus cornutus	O	0.0083	120	0.0100	100	x		0.0050	200			x	
TOTAL # OF SPECIES OBSERVED:		**77**		**99**		**63**		**60**		**40**		**53**	
TOTAL # OF FAMILIES OBSERVED:		**21**		**27**		**22**		**23**		**15**		**19**	

Appendix R. Average density of fish (ind. per m^2) for lagoon sites based on trophic levels for the present survey. Percent contribution of trophic level at each site are also included.

AVERAGE DENSITY	NIKAO	NIKAO-C	ARORANGI	ARORANGI-C	KAVERA	KAVERA-C	VAIMA`ANGA	VAIMA`ANGA-C	TITIKAVEKA	TITIKAVEKA-C	TA`AKOKA	TA`AKOKA-C
BENTHIC INVERTIVORES	0.3750	0.6133	0.4383	0.2850	0.3783	0.5250	0.6267	0.4917	0.2583	0.1750	0.1667	0.2000
CARNIVORES	0.0033	0.0333	0.0283	0.0317	0.0267	0.0433	0.0000	0.0117	0.0133	0.0083	0.0000	0.0100
CORALLIVORES	0.0183	0.0317	0.0283	0.0433	0.1600	0.1800	0.0000	0.0517	0.0400	0.0567	0.0250	0.0517
HERBIVORES	0.3517	0.2533	0.3117	1.2317	1.0017	0.9317	0.0800	2.0333	1.4117	1.4333	1.0750	0.9383
OMNIVORES	0.1967	0.2983	0.2567	0.0867	0.0617	0.1817	0.1933	0.1633	0.0967	0.0283	0.0350	0.1917
PLANKTIVORES	0.0000	0.0000	0.0200	0.0017	0.1067	0.2917	0.0000	0.1000	0.0700	0.0000	0.0000	0.0383
SUM	0.9450	1.2300	1.0833	1.6800	1.7350	2.1533	0.9000	2.8517	1.8900	1.7017	1.3017	1.4300
PERCENTAGE	%	%	%	%	%	%	%	%	%	%	%	%
BENTHIC INVERTIVORES	39.7	49.9	40.5	17.0	21.8	24.4	69.6	17.2	13.7	10.3	12.8	14.0
CARNIVORES	0.4	2.7	2.6	1.9	1.5	2.4	0.0	0.4	0.7	0.5	0.0	0.7
CORALLIVORES	1.9	2.6	2.6	2.6	9.2	8.4	0.0	1.8	2.1	3.3	1.9	3.6
HERBIVORES	37.2	20.6	28.8	73.3	57.7	42.9	8.9	71.3	74.7	84.2	82.6	65.6
OMNIVORES	20.8	24.3	23.7	5.2	3.6	8.4	21.5	5.7	5.1	1.7	2.7	13.4
PLANKTIVORES	0.0	0.0	1.8	0.1	6.1	13.5	0.0	3.5	3.7	0.0	0.0	2.7

Appendix S. ANOSIM and SIMPER results for lagoon fish species.

ANOSIM

Global Test
Sample statistic (Global R): 0.846
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 1352078)
Number of permuted statistics greater than or equal to Global R: 0

SIMPER

Standardise data: No
Transform: Log(X+1)
Cut off for low contributions: 90.00%
Factor name: Lagoon width (Narrow and Wide)

Group Narrow
Average similarity: 51.99

Species	*Av.Abund*	*Av.Sim*	*Sim/SD*	*Contrib%*	*Cum.%*
Acanthurus triostegus	27.92	5.59	2.17	10.75	10.75
Thalassoma lutescens	19.25	5.46	4.16	10.50	21.25
Acanthurus nigrofuscus	39.75	4.86	3.52	9.34	30.59
Halichoeres trimaculatus	10.17	4.01	3.24	7.72	38.31
Chrysiptera glauca	24.25	3.96	1.22	7.62	45.93
Coris variegata	18.50	3.22	1.02	6.19	52.11
Chrysiptera unimaculata	7.25	2.85	1.82	5.48	57.60
Naso lituratus	5.25	2.53	1.79	4.87	62.46
Stethojulis bandanensis	9.92	2.49	1.01	4.79	67.25
Chaetodon citrinellus	3.67	2.08	1.73	4.01	71.26
Parupeneus bifasciatus	3.92	1.90	1.23	3.65	74.91
Coris aygula	2.33	1.37	1.30	2.64	77.55
Plectroglyphidodon imparipennis	3.67	1.18	0.79	2.26	79.81
Chaetodon auriga	2.08	1.15	0.83	2.21	82.02
Ctenochaetus striatus	23.08	1.06	0.47	2.04	84.06
Thalassoma purpureum	2.50	0.74	0.61	1.42	85.48
Stegastes lividus	2.83	0.67	0.42	1.28	86.77
Labroides dimidiatus	1.42	0.65	0.63	1.26	88.03
Gomphosus varius	1.50	0.64	0.65	1.23	89.26
Parupeneus multifasciatus	1.25	0.58	0.63	1.11	90.37

Group Wide
Average similarity: 54.72

Species	*Av.Abund*	*Av.Sim*	*Sim/SD*	*Contrib%*	*Cum.%*
Ctenochaetus striatus	64.67	6.48	4.92	11.83	11.83
Thalassoma lutescens	33.50	5.13	8.38	9.37	21.20
Scarus psittacus	21.00	3.13	1.95	5.72	26.93
Chlorurus frontalis	14.50	3.13	1.94	5.72	32.65
Pomacentrus vaiuli	11.67	2.84	2.72	5.19	37.84
Chlorurus sordidus	40.92	2.69	0.87	4.91	42.75
Chaetodon auriga	11.75	2.47	1.59	4.51	47.26
Acanthurus triostegus	66.83	2.29	0.90	4.18	51.44
Chaetodon citrinellus	3.83	2.16	5.48	3.94	55.39
Naso lituratus	5.58	2.01	1.74	3.68	59.07
Halichoeres trimaculatus	7.25	1.75	1.24	3.20	62.27
Gomphosus varius	3.00	1.66	3.34	3.04	65.30
Cheilinus chlorourus	3.58	1.62	2.77	2.96	68.27
Stegastes lividus	13.08	1.36	0.77	2.49	70.75
Stethojulis bandanensis	4.08	1.32	1.23	2.41	73.16
Rhinecanthus aculeatus	4.08	1.25	1.23	2.28	75.44
Stegastes albifasciatus	8.58	1.10	0.67	2.00	77.44
Zebrasoma scopus	3.25	1.07	0.91	1.96	79.41
Parupeneus multifasciatus	2.33	1.02	1.23	1.86	81.26
Dascyllus aruanus	24.92	0.97	0.53	1.78	83.04
Centropyge flavissimus	2.83	0.96	0.82	1.75	84.79
Parupeneus bifasciatus	3.58	0.92	0.77	1.68	86.48
Labroides dimidiatus	1.92	0.85	1.01	1.56	88.04
Parupeneus cyclostomus	1.58	0.70	1.05	1.28	89.32
Zanclus cornutus	1.33	0.62	0.81	1.13	90.45

Groups Narrow & Wide
Average dissimilarity = 63.56

Species	*Group N Av.Abund*	*Group W Av.Abund*	*Av.Diss*	*Diss/SD*	*Contrib%*	*Cum.%*
Ctenochaetus striatus	23.08	64.67	2.70	1.50	4.24	4.24
Chlorurus sordidus	0.58	40.92	2.49	1.42	3.92	8.17
Chrysiptera glauca	24.25	2.17	2.21	1.48	3.48	11.64
Coris variegata	18.50	0.00	2.18	1.49	3.43	15.07

Scarus psittacus	0.67	21.00	2.17	1.93	3.42	18.49
Pomacentrus vaiuli	0.00	11.67	2.13	2.93	3.34	21.83
Acanthurus nigrofuscus	39.75	8.08	2.09	1.69	3.29	25.12
Chlorurus frontalis	1.17	14.50	1.96	1.78	3.09	28.21
Acanthurus triostegus	27.92	66.83	1.78	1.46	2.80	31.01
Chrysiptera unimaculata	7.25	0.00	1.71	2.20	2.69	33.70
Dascyllus aruanus	0.00	24.92	1.56	0.95	2.46	36.16
Stegastes lividus	2.83	13.08	1.48	1.27	2.33	38.50
Stegastes albifasciatus	1.50	8.58	1.40	1.13	2.21	40.70
Chaetodon auriga	2.08	11.75	1.40	1.57	2.21	42.91
Stethojulis bandanensis	9.92	4.08	1.26	1.51	1.99	44.90
Zebrasoma scopus	0.08	3.25	1.09	1.32	1.71	46.61
Plectroglyphidodon imparipennis	3.67	0.00	1.05	1.16	1.66	48.27
Cheilinus chlorourus	0.67	3.58	1.04	1.68	1.64	49.91
Halichoeres trimaculatus	10.17	7.25	1.02	1.21	1.61	51.51

Appendix T. MDS plot by lagoon width for fish species.