COOK ISLANDS MARINE PARK

Coral reef survey of Aitutaki, Manuae, Mitiaro, Takutea, and Atiu in the southern Cook Islands

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This research was a collaboration between the Office of the Prime Minister of the Cook Islands (Climate Change Division), Te Ipukarea Society, Oceans 5, Waitt Institute, Pacific Islands Conservation Initiative, Cook Islands National Environment Service, Secretariat of the Pacific Community, European Union, and the Global Climate Change Alliance.

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EXECUTIVE SUMMARY

From 28 July – 9 August 2013, a research team consisting of individuals from the Office of the Prime Minister of the Cook Islands, Te Ipukarea Society, Oceans 5, Pacific Islands Conservation Initiative, Cook Islands National Environment Service, and local volunteers travelled aboard the vessel *Plan B* of the Waitt Institute to conduct a rapid marine assessment of the fore reefs of the islands of Aitutaki, Manuae, Mitiaro, Takutea, and Atiu in the southern Cook Islands — for the purpose of assessing the health of coral reefs within the proposed Cook Islands Marine Park.

The results of this assessment showed that coral communities on the fore reefs of Manuae, Mitiaro, Takutea, and Atiu were relatively healthy with good coverage of hard corals. Indicators of healthy reefs on these islands also included the dominance and high abundance of the coral-associated fish family Pomacentrids, high cover of crustose coralline algae, and low cover of macro-algae. Coral communities were very similar on these islands in terms of species composition (except Atiu), attributed to the dominance of a few species of hard coral — such as the platy coral *Astreopora expansa* on steeper reef slopes — which thus far appear to be unique to these islands. Despite low abundance of herbivorous fish species noted, this was unlikely the result of overfishing as human population is low on these islands and fishing activities have declined overall. On the other hand, Aitutaki's reefs showed a significant decline in coral health, particularly on the fore reef.

Interestingly, coral reef disturbance (i.e., COTS infestation and coral disease) and recovery (based on coral colony size information) appear to have some geographical pattern, with both occurring in a southeastward direction from Aitutaki towards Manuae, Mitiaro, Takutea, and Atiu. Though limited historical information and baseline data exists for this chain of islands, seemingly these islands have gone through a cycle of disturbance with recovery well underway. Yet, a subsequent round of disturbance has commenced in this southeastward direction, with Aitutaki showing a significant decline in coral cover since the last fore reef survey in 2008, and Manuae (the next island in the chain) showing signs of stress related to coral disease and COTS predation.

Based on this pattern, we suggest that an outbreak of COTS and perhaps the prevalence of coral disease on Aitutaki could potentially cascade down the rest of the island chain. Hydrodynamic studies also support this pattern, particularly from December to March during the spawning months for most marine organisms in the region, where the predominant current flow is south to southeastward. In this regard, a bottom-up control of nutrients in Aitutaki may reduce the impact of anthropogenic stressors such as COTS and coral disease on islands to the southeast. A more detailed study of coral disease and other diseases (i.e., Coralline Lethal Orange Disease recorded on Aitutaki) would be critical to elucidate the causes and the extent of the damage and distribution in this group of islands. Indeed, connectivity studies and information from regular monitoring of these reefs will certainly help us understand how these islands influence each other, which would feed into an effective management plan for these delicate ecosystems within the Cook Islands Marine Park.

1. INTRODUCTION

Coral reefs are structurally important for the protection of low-lying coastal areas from strong wave action and erosion. Reefs also provide food, recreational opportunities, medicinal products, and are a major attraction for the tourism industry. However, there is mounting evidence that marine resources, as well as marine ecosystems around the world, are heading towards a downward trajectory (Jackson et al., 2001; Pandolfi et al., 2003). A report on the status of the reef by the Global Coral Reef Monitoring Network indicated that about 30% of the world's reefs have been degraded, and another 30% is predicted to have the same fate within a few decades (Wilkinson, 2002). Major contributors to the degradation of marine ecosystems are global climate change and other related anthropogenic activities, which threaten ecosystems through changes in ocean chemistry, increased incidence of coral disease, coral bleaching events, ocean acidification, eutrophication, and increased sedimentation (Hoegh-Guldberg, 1999; Kleypas et al., 1999; Lapointe, 1997; Rogers, 1990). These impacts will cause fundamental changes to reef habitats, including reduced coral cover, changes to the composition of coral assemblages and reduced structural complexity (Hughes et al., 2003, Aronson & Precht, 2006; Hoegh- Guldberg et al., 2007). A meta-analysis of coral reefs reveal that over the past 30 years, coral cover on reefs in Southeast Asia, Australia, and the western Pacific Ocean have decreased by around 40% relative to the early 1980s; about 16% of the corals around the world disappeared during the 1998 bleaching event alone (Bruno & Selig, 2007).

In the Cook Islands (Figure 1 *top*), natural disturbances play a major role in influencing the state of coral reef ecosystems. For example cyclones, which have been linked to the El Niño Southern Oscillation (Figure 2), is critical in determining the fate of coral reefs in the southern Cook Islands (Rongo & van Woesik, 2013). Crown-of-thorns starfish (COTS; *Acanthaster planci*), a common coral-eating predator to these reefs and arguably an anthropogenic-induced disturbance (e.g., Birkeland, 1982; Brodie et al., 2005), also play an important role in shifting reef communities in this region from coral-dominated to less desirable states (Figure 3). For example, in the last 40 years, Rarotonga has experienced two major COTS outbreaks (one in the early 1970s and the other in the 1990s), which severely decimated its reefs (Rongo & van Woesik, 2013).

It is important to understand that for the Cook Island's 1.9 million km^2 of total territory area within its Exclusive Economic Zone (Figure 1 *bottom*), over 99.9% is ocean. Yet very little effort in terms of research has been dedicated to understanding how this large area of ocean influences the near shore communities in this group of islands and vice versa. According to the *National Sustainable Development Plan 2011 - 2015* for the Cook Islands, the development of this country must achieve its national vision, which is "to enjoy the highest quality of life consistent with the aspirations of our people and in harmony with our culture and environment". The Government's declaration of half of its Exclusive Economic Zone (~1 million km^2) as a Cook Islands Marine Park (CIMP) in 2012 (see Figure 1 *bottom*) recognizes these global, regional, and local threats, and intends to ensure that these ecosystems and its resources are properly managed to increase not only their resiliency to these threats, but also that of the Cook Islands people that rely on them for food security and economic development.

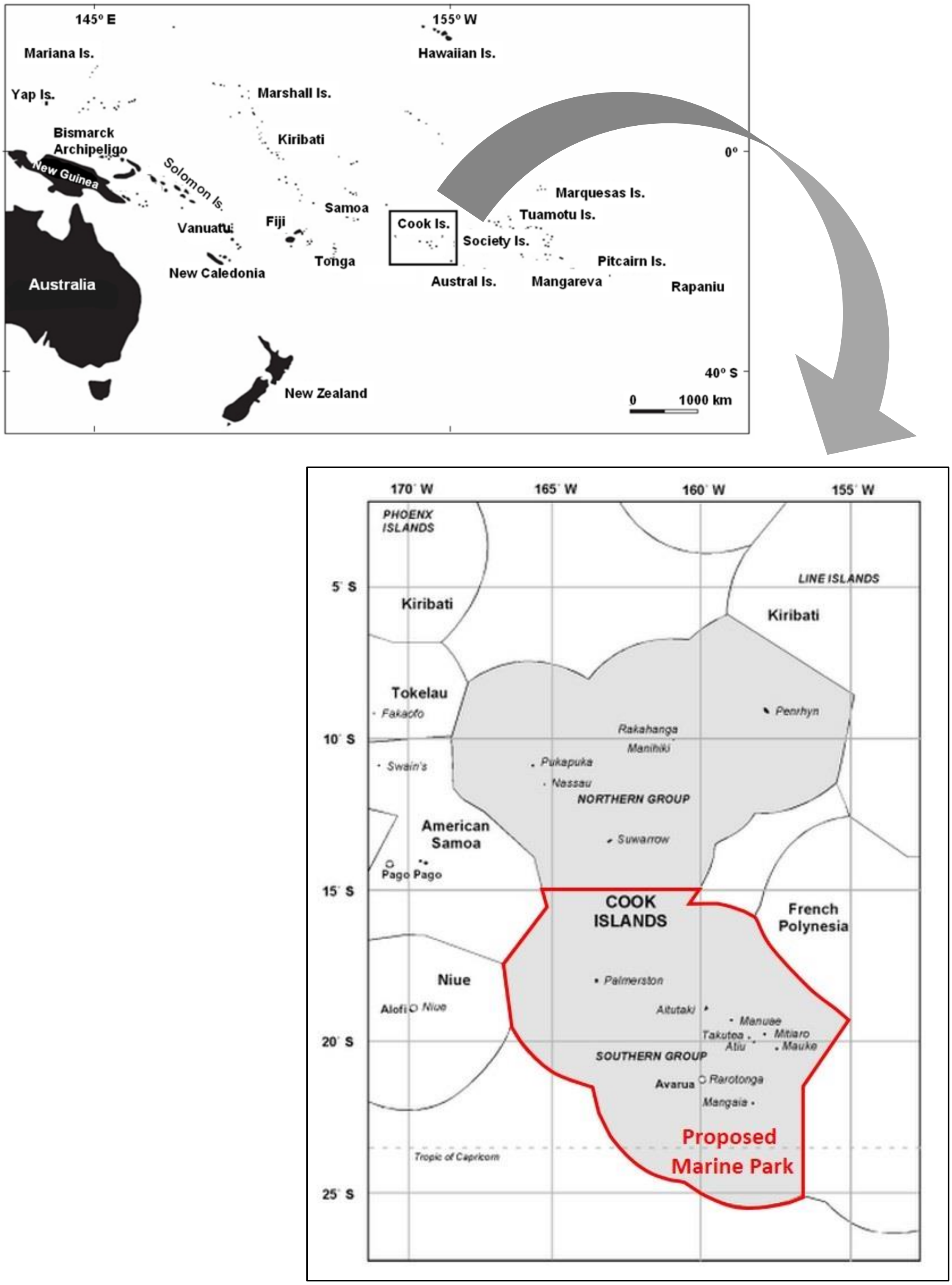


Figure 1. *Top*: Map of the Pacific with the location of the Cook Islands indicated in the boxed region. *Bottom:* the Cook Islands' Exclusive Economic Zone in the shaded grey region, with the red-lined zone indicating the proposed Cook Islands Marine Park encompassing the southern Cook Islands group. Map generated by the Cook Islands Government.

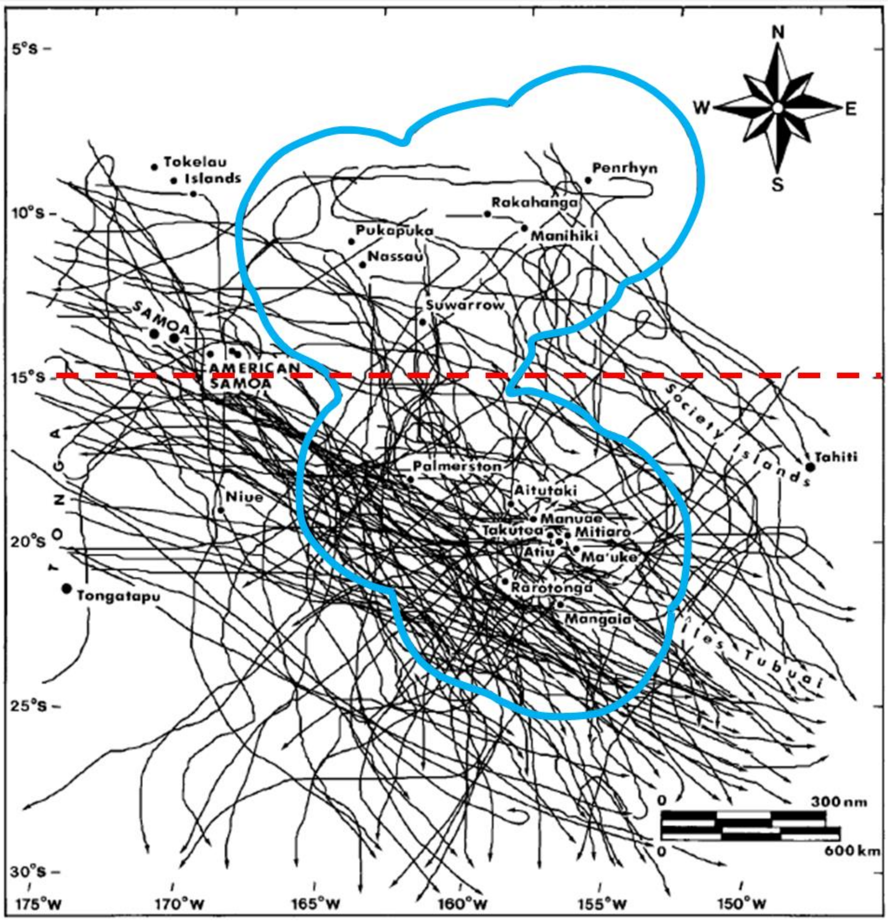
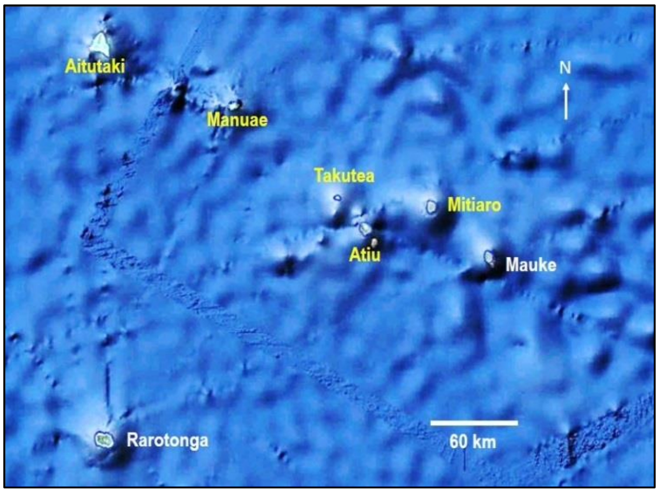


Figure 2. Generalized tracks of 104 cyclones in the Cook Islands, 1820–2006. The origin of cyclones tracking from west of 175ºW longitude is not shown, and many cyclones tracked east or south out of the map area before decaying or undergoing extratropical transition. Solid blue line delineates the Exclusive Economic Zone of the Cook Islands. Dashed red line indicates the boundary of the Cook Islands Marine Park at 15ºS. Figure modified from de Scally (2008).

Figure 3. The crown-of-thorns starfish, *Acanthaster planci*, feeding on a fore reef coral in Amuri, Aitutaki in 2008. About a dozen starfish were noted at depths around 7 – 12 m in an area where the coral community was healthy during this period. Photo taken by Teina Rongo.

1.1. PRIMARY OBJECTIVES

The objectives of this study were to carry out rapid marine assessments on the fore reefs of five islands in the southern Cook Islands – Aitutaki, Manuae, Mitiaro, Takutea, and Atiu (Figure 4 *top*) – as well as to explore a shallow seamount named Te Uapuakaoa located around 200 nautical miles west of Rarotonga, and a supposed shallow reef system named Winslow Reef located east of Te Uapuakaoa. The research expedition took place from 28 July – 9 August 2013, with the research team travelling aboard the vessel *Plan B* to first search for the seamount and Winslow Reef, albeit unsuccessfully (Figure 4 *bottom*), before returning to the southern Cook Islands to conduct reef surveys. The marine assessments largely focused on 1) collecting information on coral reef biodiversity (i.e., fish, macro-algae, corals, and other macro-invertebrates), 2) assessing the status of coral reefs on each island, and 3) establishing reef baseline information for some of the islands. This information will enable stakeholders such as resource managers, political decision-makers, and the general public to plan and make informed decisions pertaining to the management of the CIMP based on scientifically valid, quantitative data. The Office of the Prime Minister of the Cook Islands, Non-Government Organizations Te Ipukarea Society (who coordinated this survey) and Pacific Islands Conservation Initiative, and the National Environment Service were supported by Oceans 5 and the Waitt Institute who generously provided funding and their research vessel, crew, and expertise respectively.



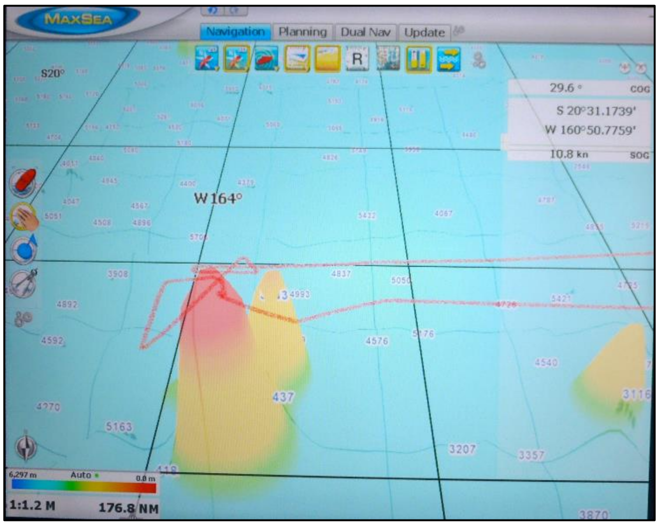


Figure 4. *Top*: Map of islands in the southern Cook Islands. Yellow names indicate islands surveyed on this 2013 expedition. Map modified from Google Earth. *Bottom*: screenshot of *Plan B's* navigation screen indicating the search pattern for Te Uapuakaoa seamount; the depth sounder was limited to 600 m, but no seamount was found within this range. Winslow Reef was also not found, perhaps because it was incorrectly charted. Photo provided by Kelvin Passfield.

1.2. EXPEDITION TEAM

The CIMP research team was composed of individuals from the relevant ministries within the Cook Islands Government (i.e., Climate Change Division and the National Environment Service) as well as from the Non-Government Organizations Te Ipukarea Society and Pacific Islands Conservation Initiative. There were also local avid divers who volunteered their assistance with the field work.

1.3. MATERIALS AND METHODS

1.3.1. Sites

The number of sites and locations surveyed at each island were determined based on accessibility. Because of rough sea conditions experienced during this expedition, most sites were located on the leeward exposure of islands. Sites established in previous reef surveys for Aitutaki (Rongo, 2008), Manuae (Rongo et al., 2005), and Mitiaro (Lyon, 2002) were revisited. For islands that have not been previously surveyed (i.e., Takutea and Atiu), this survey provided baseline information for future monitoring. *Appendix A* provides the Global Positioning System coordinates of sites on each island surveyed during this expedition.

1.3.2. Transect deployment

Three 50-m transects (replicates) were deployed at all sites along the fore reef. Transects were placed following the reef contour at depths around 7 – 10 m parallel to shore and laid consecutively at intervals of 10 m.

1.3.3. Biological surveys

The survey methods used were selected because they are widely accepted protocols for rapid marine assessments. Validation of these methods is their publication in peer-reviewed scientific journals. For example, Houk et al. (2005) contains methodology for coral community and benthic surveys. In addition, the methods selected complement those of previous fore reef surveys conducted in Rarotonga (Miller et al., 1994; Ponia et al., 1999; Rongo et al., 2006, 2009; Rongo & van Woesik, 2013), Aitutaki (Rongo, 2008), Mitiaro (Lyon, 2002), and Manuae (Rongo et al., 2005). A brief description of each general biota or coral survey is described below.

1.3.3.1. Coral communities

Coral population structure and relative abundance are influenced by disturbances (Bak and Meesters, 1998). The point-quadrat method is used to collect data for coral community analysis (Houk et al., 2005). Along each 50-m transect deployed, two teams consisting of four divers used the point-quadrat method to record the benthos with a 1-m^2 quadrat frame tossed haphazardly every 5 m. A total of 20 quadrats (10 per team) were tossed per transect (60 quadrats per site). The quadrat used to record the benthos was partitioned into 25 sections with string, providing 16 points of intersection. The reef benthos under each intercept was recorded to the genus level. The benthic survey focused on measuring the percent cover of hard coral, crustose coralline algae (CCA), pavement (mainly turf algae < 1 cm in height [Steneck, 1988], and carbonate substrate), and macro-algae (>1 cm in height [Steneck, 1988]).

1.3.3.2. Coral colony size

At every 20 m interval, a quadrat was tossed haphazardly to record coral communities for a total of six quadrats per site. Coral colony sizes were measured within each 1-m^2 quadrat. 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 fell within the edges of the quadrat frame. Information obtained from this method included population densities and geometric diameters. For geometric diameter (cm), colonies were grouped into four size classes (see *Section* 1.3.4.2 below); class A colonies were considered new recruits for this survey.

1.3.3.3. Macro-invertebrates & fish

Macro-invertebrates were surveyed using a belt size of 2 m along the 50-m transects (1 m on each side of transect). A belt size of 5 m (2.5 m on each side of transect) was used for fish surveys. Identifications were made to the highest taxonomic resolution possible (i.e., genus and species). Common names were obtained from the Cook Islands Biodiversity website where possible.

1.3.3.4. Biological diversity

For each island, an identification checklist was generated for all coral, macro-invertebrates, and fish identified. Identifications were made to the highest taxonomic resolution possible (i.e., genus and species) for the purposes of adding to the species inventory for the Cook Islands. Photographs were taken of all species when possible, and some samples collected for identification purposes using taxonomic references or outside taxonomic expertise. Species identification were verified using Randall and Myers (1983), Myers (1989, 1999), Veron (2000), Randall (2005), photographs provided by Gustav Paulay, and www.fishbase.com. In addition to the above-mentioned surveys, the team also carried out algal sampling to examine the abundance and distribution of ciguatoxic dinoflagellates among these islands; results of this sampling will be presented in a separate report.

1.3.4. Data analysis

Microsoft Excel spreadsheet, PivotTable, and PivotChart were used for basic computations. PRIMER 6 and STATISTICA 12 software were used for graphical and comparative analysis.

1.3.4.1. Percent cover calculations

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

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

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

1.3.4.2. 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 per m^2) = $n/6\ m^2$

where n is the total number of colonies of any given species and 6 m^2 is the total area surveyed using 6 quadrat tosses per site.

Size classes were sorted into four categories based on geometric diameter: A (< 4 cm), B (4 to < 8 cm), C (8 to < 16 cm), D (16 to < 32cm), and E (≥ 32 cm).

1.3.4.3. Average density

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

$$(7) \qquad \text{Average density} = \frac{\text{Number of individuals per site / number of replicates}}{\text{Belt area (100 m}^2\text{ for invertebrates and 250 m}^2\text{ for fish)}}$$

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

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

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

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:

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

PRIMER 6 software was used to generate these indexes.

1.3.4.5. Statistical analysis

Comparative analysis was carried out on benthic categories, macro-invertebrates, and fish communities to determine relationships between sites. PRIMER 6 was used to generate a Principal Component Analysis (PCA), vector plots, and ordination of data using 2D plots. Bubbles on 2D plots were used for graphical representation of the respective categories. Mean error plots were generated using STATISTICA 12.

2. PROFILE AND RESULTS BY ISLAND

2.1. AITUTAKI

2.1.1. Site characteristics

Aitutaki (Figure 5) is located around 18º 53' S and 159º 46' W, and approximately 263 km north of Rarotonga. In 2011, the total population was 2,038, which has remained relatively stable in the last 10 years; Aitutaki is the second most populated island in the southern Cook Islands after Rarotonga, who has a population of 13,095 (Cook Islands Census, 2011). Geologically, the island is an almost-atoll around 18 km^2 in area, with a substantial residual volcano about 124 m high aged ~8.1 million years. The mainland is about 16 km^2 in area with a moderate-sized lagoon and 15 small islands (*motu*) around its perimeter. This predominantly sandy lagoon, which hosts a range of marine organisms, is one of the most beautiful lagoons in the world that provides many benefits to the people of Aitutaki. These benefits include food resources, recreational activities, and ecotourism. Increasing development in the last twenty years to meet the demand of the tourism industry, along with reef disturbances (e.g., global warming, COTS outbreaks, coral disease, and cyclones), pose threats to the existence of this delicate ecosystem.

Over the last 20 years, several coral reef surveys have been conducted in Aitutaki that have been critical in our understanding of temporal changes on these reefs. During the 1990s, the reefs of Aitutaki went through several natural disturbances; a bleaching event in the early 1990s followed by a COTS outbreak, which degraded the reef to its current state (Rongo, 2008; Bruckner, 2013). On the CIMP research team's visit to Aitutaki on 29 July 2013, two of the sites surveyed in 2008 were re-surveyed to serve as a practice for the team. Aitutaki was not a focus on this trip because a previous research team from the Living Oceans Foundation had extensively surveyed the fore reefs of Aitutaki a few months prior to our visit in May (although the majority of their information has not yet been submitted to the relevant ministries in the Cook Islands Government). Only benthic communities and macro-invertebrate data from the research team's practice surveys were included in this report.

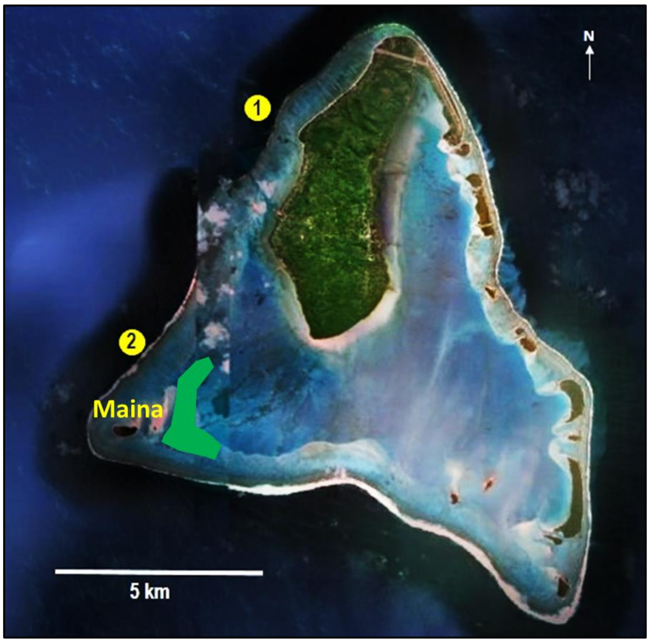


Figure 5. Map of Aitutaki with yellow dots indicating the two sites surveyed during this expedition; these two sites were established in 2008 (see Rongo, 2008). Green area near *motu* Maina indicates the area where the team conducted a snorkeling tour as part of the survey preparation. Taken from Google Earth.

2.1.2. Benthic communities

Hard coral cover and crustose coralline algae (CCA) in this survey were compared with results from two sites established in the 2008 survey (Rongo, 2008). A significant decline in hard coral cover was noted when compared with survey data from 2008 (Figure 6); cover at Site 1 declined from 34 % ± 0.01 (SE) to < 1 % ± 0.16 (SE) in 2013, while Site 2 declined from 14 % ± 1.44 (SE) to 1 % ± 0.55 (SE) in 2013. However, CCA at both sites did not show a significant change over time.

Figure 6. Comparison of the average percent cover of crustose coralline algae (CCA) and hard coral from two fore reef sites surveyed in Aitutaki in 2008 (see Rongo, 2008), and resurveyed in 2013. Site 1 is off of Pacific Resort and Site 2 is off of the *Alexander* wreck.

2.1.3. Macro-invertebrate communities

Site 1 had significantly higher densities of the pale burrowing urchin (*Echinometra mathaei*) when compared with Site 2 (Figure 7). The giant clam (*Tridacna* spp.) was uncommon on the fore reef, with the average density < 1 individual per 100 m^2 at Site 2. The average density of the great worm-snail (*Dendropoma maxima*) was 14 ± 8 (SE) individuals per 100 m^2 at Site 2, and 8 ± 3 (SE) individuals per 100 m^2 at Site 1. Other invertebrates not plotted because of low numbers on the transects included trochus (*Tectus niloticus*), COTS (*Acanthaster planci*), and flatworms (*Pseudobiceros* spp.).

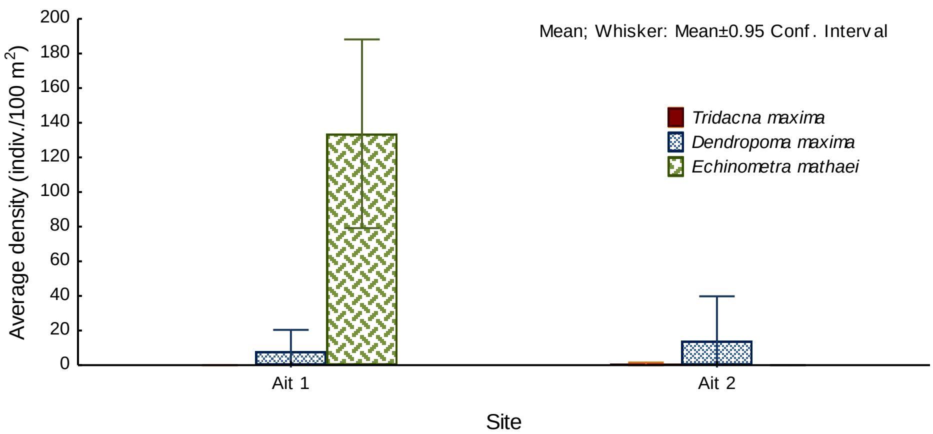


Figure 7. Average density of macro-invertebrates from two fore reef sites surveyed in Aitutaki in 2013. *Ait 1* is a site off of Pacific Resort, and *Ait 2* is a site off of the *Alexander* wreck.

2.1.4. Discussion

While the 2008 survey indicated that Aitutaki's reefs were recovering from previous reef disturbances in the 1990s and 2000s (Rongo, 2008), recovery appeared to be limited to shallow fore reef slopes (< 10 m) and reefs on the deeper slopes (> 15 m) had not recovered. The average coral cover at Site 1 (referred to as the Pacific Resort in 2008) was reported at 34% (Rongo, 2008), but declined to < 1% in 2013. Figure 8 shows a much healthier coral community in 2008 (*top left*) than that observed in 2013 (*top right*); most corals at this site were destroyed with the exception of a few encrusting type species. This decline in coral cover was likely a result of the impact of Cyclone Pat in 2010, and to a larger extent COTS infestation over the years (Rongo, 2008; Bruckner, 2013). The lagoon area of Aitutaki close to the main island was observed to be dominated by a variety of algal species (Figure 8 *bottom left*); extensive areas of the lagoon around Arutanga and the habour site were dominated by the green alga *Boodlea* spp. (Figure 8 *bottom right*). Also, coral species that thrive in turbid environments were commonly observed within the lagoon (Figure 9 *left*). In support, Total Suspended Solids (TSS; a parameter to measure water clarity; data obtained from MMR) were above the threshold level considered detrimental to coral reefs (e.g., Larcombe et al., 1995; see also George et al. [2007] and reference therein) in most of the coastal waters around the main island of Aitutaki (Figure 9 *right*); high TSS were likely attributed to past dredging activities within the lagoon of Aitutaki.

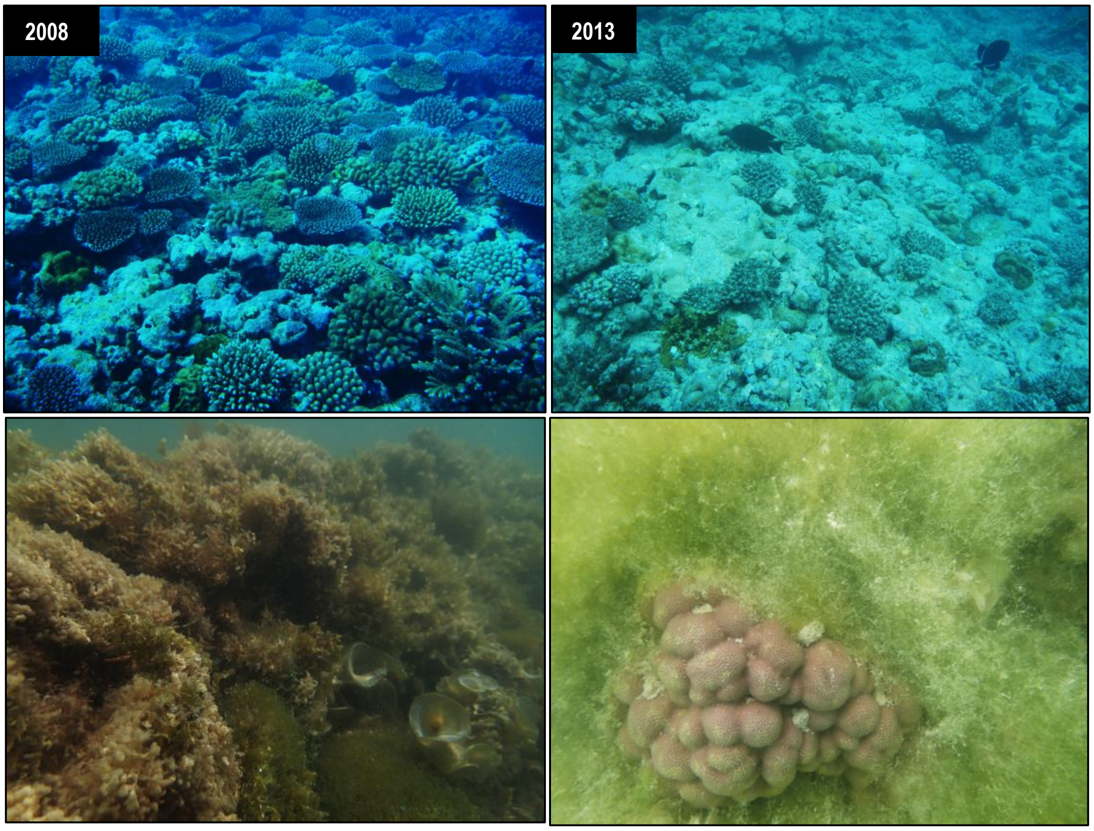


Figure 8. *Top*: Fore reef site off of Pacific Resort (Site 1), photographed in 2008 and 2013 by Teina Rongo. Note: pictures were not taken from the same location, but were from the same general area. *Bottom left*: algal assemblages of a variety of algae that dominated the benthos in well-flushed lagoon areas around the harbor in 2013. *Bottom right*: a *Porites* coral getting overgrown by a green alga, *Boodlea* spp.; this alga covered an extensive area within the lagoon that was relatively sheltered in 2013. Photo taken by Teina Rongo.

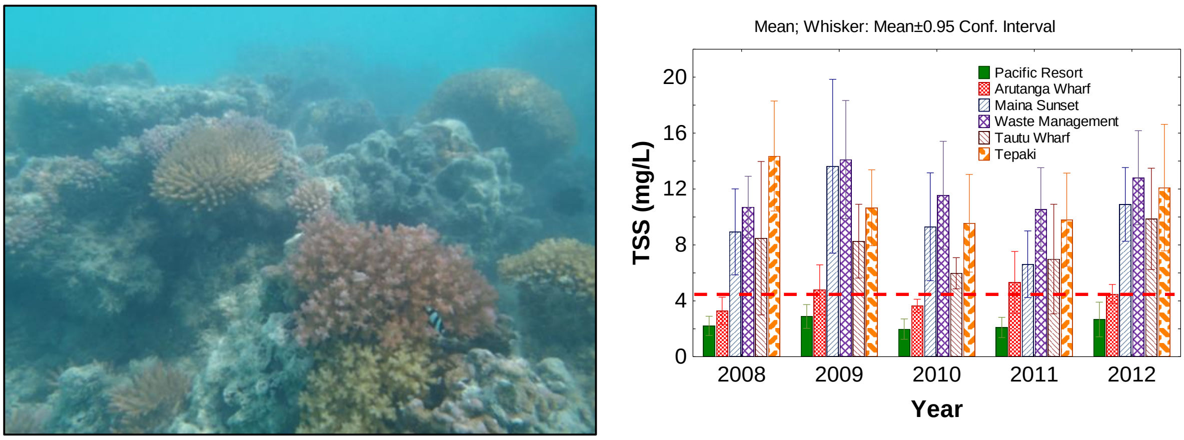


Figure 9. *Left:* Coral communities consisting of species that thrive in turbid environments. Photo taken by Teina Rongo. *Right*: Total Suspended Solids (TSS [mg/L]) recorded for selected sites along the coast of the Aitutaki main island monitored by the Ministry of Marine Resources; dotted red line indicates the threshold level of TSS (4 mg/L) considered detrimental for coral reefs.

Incidentally, Coralline Lethal Orange Disease (CLOD) was noted occasionally on coralline algae at Site 2 (Figure 10). CLOD was first identified in Aitutaki in 1992 by Littler and Littler (1995), which was reported to have affected an extensive area of Aitutaki's reef slopes. Crustose coralline algae (CCA) was the most dominant substrate on the fore reef at Site 2 in 2008 as well as in 2013; this is an indication that conditions are set for recovery to occur (e.g., Harrington et al., 2004). However, CLOD is a concern given the role that CCA plays in cementing together sand, dead corals, and debris to create a stable substrate for coral recruits. Furthermore, Littler and Littler (1995) indicated that reefs affected by CLOD have a tendency to shift from being CCA- and coral-dominated to being dominated by turf and fleshy algae. Because of time constraints, the team was unable to examine the severity of CLOD on Aitutaki during this trip. It would be useful to carry out a follow-up study on this disease, not only on Aitutaki but also the other islands in the southern Cook Islands group.

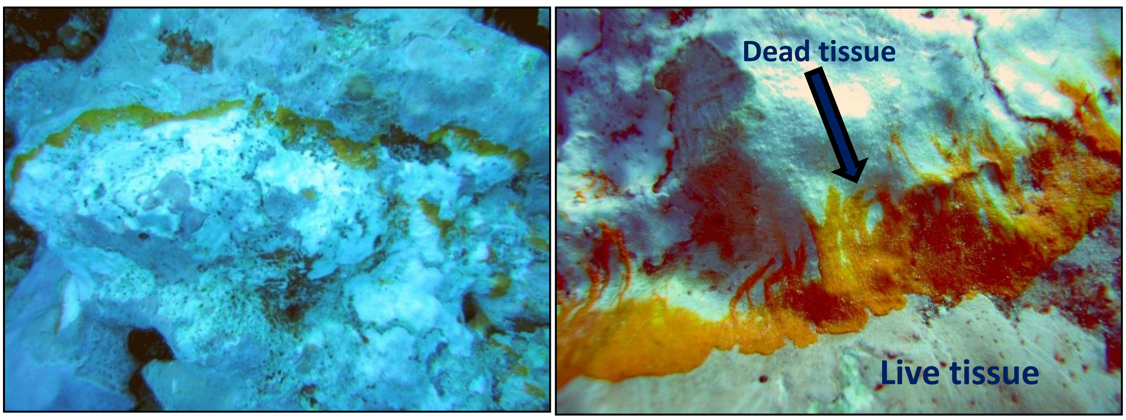


Figure 10. Coralline Lethal Orange Disease (CLOD) found on the fore reef of Aitutaki; in both photos, white area indicates dead tissue of the coralline algae *Porolithon onkodes*, with the orange band indicating the active area of the disease. Photos taken by Mareike Sudek.

A recent reef survey conducted in Aitutaki by the Living Oceans Foundation in May 2013, indicated that COTS predation has decimated fore reef corals on the leeward side of Aitutaki and advanced to the windward side. In our observations, the COTS damage appeared to be limited to the fore reef. A few COTS were noted (Figure 11) in a brief snorkel tour into the lagoon area along the entire western back reef (see Figure 5; near Maina). However, healthy reef communities still exist in the lagoon (Figure 12), which could serve as source populations for the recovery of fore reef areas around the island. COTS in the lagoon may become problematic in the future, therefore the people of Aitutaki should continue to physically remove them from areas where healthy coral communities still exist.

Figure 11. Crown-of-thorns starfish (*Acanthaster planci*) were found within the back reef area of Maina on the western side of the Aitutaki lagoon during a brief snorkel trip conducted by the team. Photo taken by Barbara Hanchard.

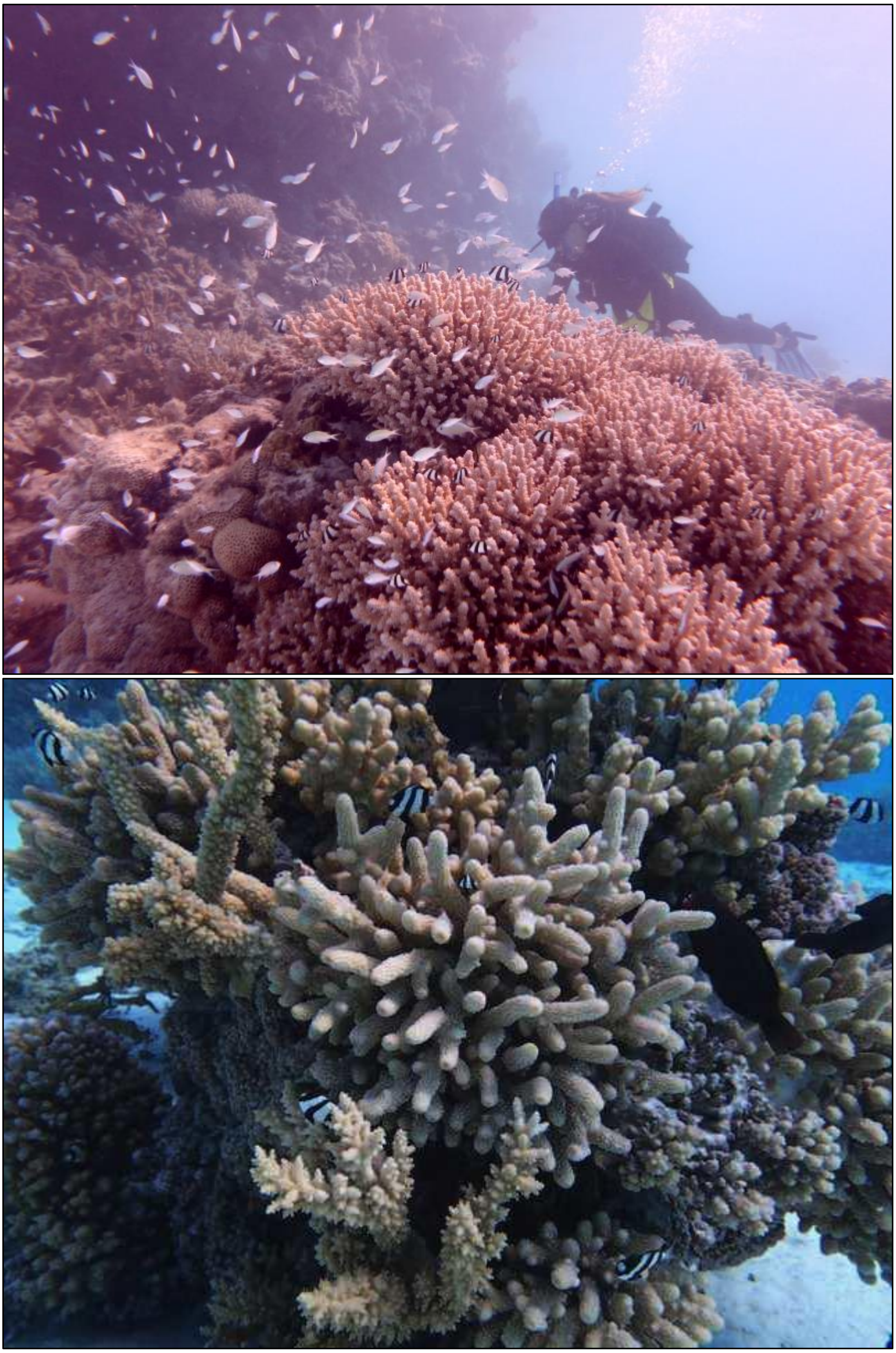


Figure 12. Back reef of the Maina area. *Top*: branching *Acropora* spp. with clouds of blue-green chromis (*Chromis viridis*) and some humbug dascyllus (*Dascyllus aruanus*) hovering above the coral colonies. Photo taken by Graham McDonald. *Bottom*: diverse community of branching coral *Acropora* spp. Photo taken by Teina Rongo.

2.2. MANUAE

2.2.1. Site characteristics

Manuae (Figure 13) is a small atoll approximately 16 km^2, located about 87 km southeast of Aitutaki (19º 16'S 158º 57'W). Although Manuae is currently uninhabited with minimal anthropogenic stresses, the island in the earlier part of the 1990s was inhabited and exporting copra. The pristine coral reef ecosystem on Manuae invites the development of the island as a tourist destination. As an effort to develop Manuae for ecotourism, a dirt airstrip that could cater for small aircraft was established. However, this idea did not come to fruition. Today, the island's marine resources (in particular reef fishes and marine invertebrates) are intermittently exploited by local fishing parties from Aitutaki and, to lesser extent, from Rarotonga. Manuae is now the only remaining island in the southern Cook Islands with very high densities of *Tridacna* clams.

Several reef surveys have been carried out on Manuae. The Ministry of Marine Resources conducted an assessment from 1994 – 1997 (Ponia et al., 1998a) to identify ideal sites for establishing Marine Protected Areas on the island, while the National Environment Service carried out a coral reef survey in 2005 to establish baseline information for the island (Rongo et al., 2005). According to the 2005 report, Manuae's fore reefs were depauperate of corals (e.g., 7% and 8% cover on windward and leeward exposures respectively). However, the complexity of reef structure — particularly on the leeward exposure — suggested that a much healthier and diverse reef community existed here in the past, possibly destroyed by COTS outbreaks. Because the prevailing ocean current around Manuae is westward (towards Aitutaki), it was suggested that Manuae is a potential source population for Aitutaki, and its establishment as a Marine Protected Area may be critical for the recovery of Aitutaki's reefs (see Rongo et al., 2005).

Previous studies examined both the fore reef and the lagoon areas of Manuae, however this survey was limited to fore reef areas due to accessibility issues into the lagoon from the research vessel. In addition, much of the survey was limited to the leeward exposure of the island because of large swells experienced during the visit. Consequently, only one of the two fore reef sites established in 2005 (Rongo et al., 2005) was resurveyed (Site 1 in Figure 13).

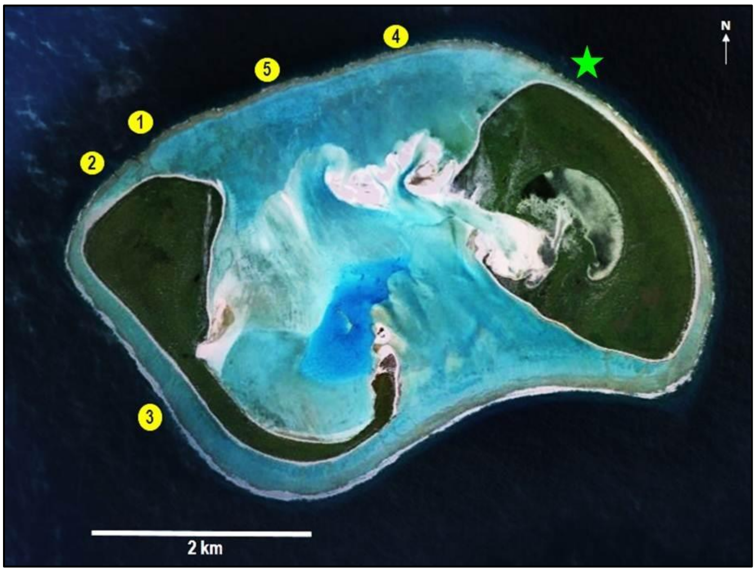


Figure 13. Map of Manuae with yellow dots indicating the fore reef sites surveyed during this expedition. Green star indicates one of the fore reef sites established in 2005 (Rongo et al., 2005) that could not be resurveyed in 2013 due to rough conditions on this expedition. Taken from Google Earth.

2.2.2. Benthic communities

Average hard coral cover on Manuae ranged from 28% ± 2 (SE) at Site 5 to 41% ± 4 (SE) at Site 1 (Figure 14). *Halimeda* spp. (Figure 15) was the most common macro-algae recorded, with large patches of this species reported at Site 5. The average cover for macro-algae ranged from 3% ± 1 (SE) at Site 3 to 16% ± 4 (SE) at Site 5. Although filamentous turf algae were not recorded in a separate category (grouped into the 'pavement' category in this survey), turf algae were particularly common at Site 4, where corals recently killed by the yellow-band disease and COTS predation were recorded.

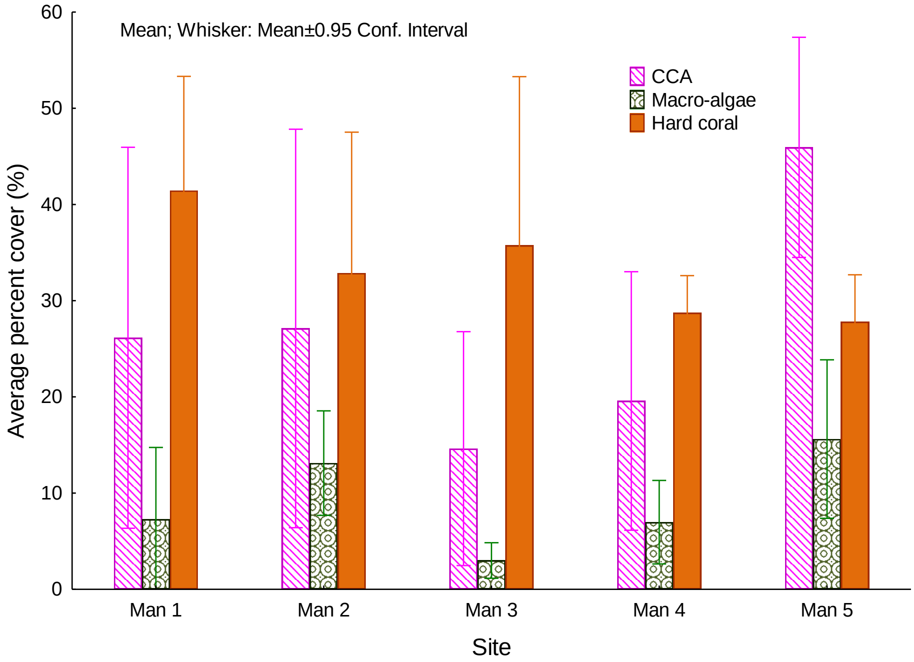


Figure 14. Average percent cover of crustose coralline algae (CCA), macro-algae, and hard coral from five fore reef sites surveyed in Manuae in 2013.

Figure 15. *Halimeda* spp., the most common macro-algae on the fore reefs of Manuae. Photo taken by Teina Rongo at Site 5.

At Site 1, average hard coral cover of 41% ± 5 (SE) in this survey was significantly higher than the 10% ± 2 (SE) recorded in 2005 (Figure 16). On the contrary, pavement (called turf algae in 2005) showed a significant decline from 80% ± 1 (SE) to 24% ± 5 (SE) in 2013, while CCA cover showed no significant difference between 2005 and 2013.

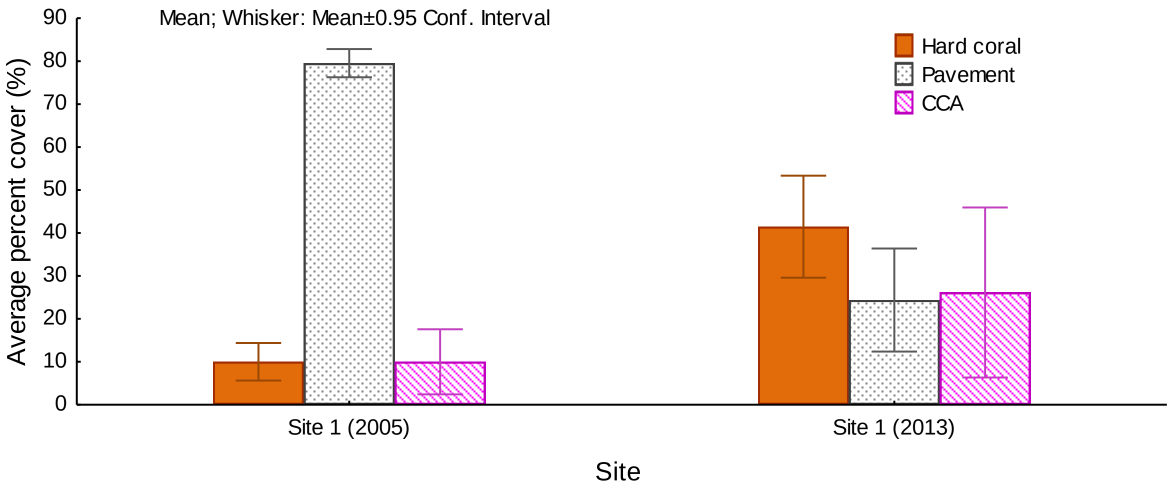


Figure 16. Comparison of the average percent cover of hard coral, pavement, and crustose coralline algae (CCA) from one fore reef site surveyed in Manuae in 2005 (Rongo et al., 2005), and resurveyed in 2013.

A total of 25 species of hard corals representing 8 families were recorded (*Appendix B*). Because of rough conditions, only Site 2, 4, and 5 were used to gather information on coral diversity (i.e., total number of species, number of individuals, species richness, evenness, and species diversity). All categories were the highest at Site 5 (Table 1). *Acropora schmitti* (Figure 17 *a,b*) was one of the most common coral species on shallow fore reef slopes of Manuae; *A. schmitti* is a more fragile coral species, and broken branches reattaching to the substrate were observed in some areas. The ability of this species to reproduce via fragmentation may explain its high density at some locations on Manuae. *Astreopora expansa* was the dominant coral species on steeper reef slope areas (Figure 17 *c,d*).

Table 1. Species diversity of hard corals at Sites 2, 4, and 5 in Manuae surveyed in 2013. S is the total number of species; N is the number of individuals; d is the Margalef's species richness; J` is Pielou's evenness; H` is the Shannon-Wiener diversity index. Red number indicates highest in each category

Site	S	N	d	J'	H'(loge)
Man 2	21	137	4.065	0.8392	2.555
Man 4	22	146	4.214	0.8547	2.642
Man 5	25	149	4.796	0.8556	2.754

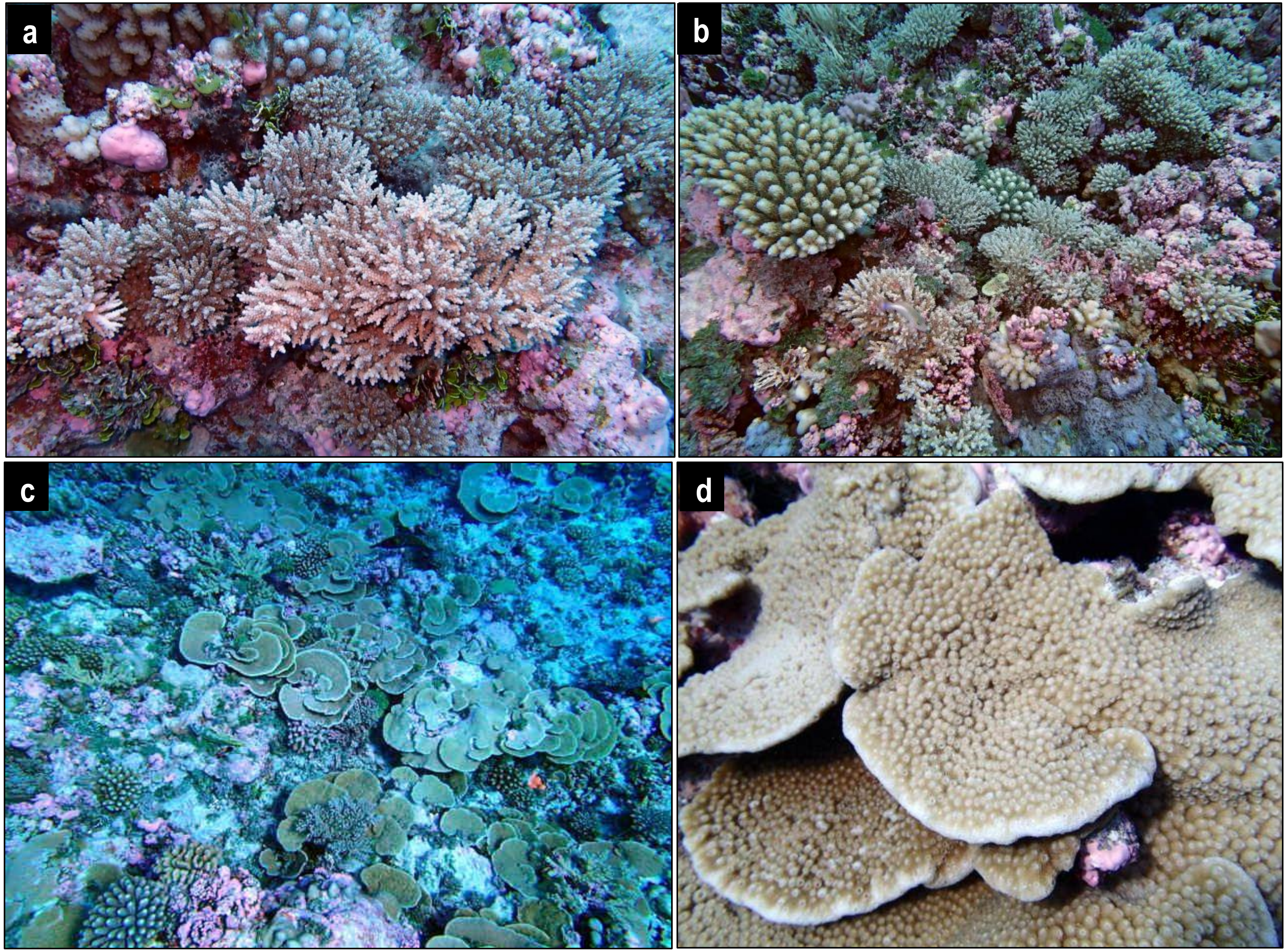


Figure 17. *a & b*) *Acropora schmitti*, one of the most common coral species on the shallow fore reef slopes of Manuae; *c & d) Astreopora expansa*, a hard coral that was dominant on the steeper reef slope areas. Photos taken by Teina Rongo.

2.2.3. Macro-invertebrate communities

Although highly variable, the giant clam (*Tridacna maxima*) were frequently recorded on the fore reef. The average density of *Tridacna* clams ranged from 8 ± 6 (SE) individuals per 100 m^2 at Site 4 to 36 ± 6 (SE) individuals per 100 m^2 at Site 5 (Figure 18). With the exception of Site 5 where the average density of the pale burrowing urchin (*Echinometra mathaei*) was recorded at 88 ± 32 (SE) individuals per 100 m^2, urchins were not common at all sites. Interestingly, COTS (*Acanthaster planci*) were observed at Site 4, with a dozen recorded in a 5-minute swim at depths of around 12 – 20 m. Other invertebrates recorded but not plotted because of low numbers include the great worm-snail (*Dendropoma maxima*), the Christmas-tree worm (*Spirobranches* spp.), the spider conch (*Lambis lambis*), the esculator urchin (*Echinostrephus aciculatus*), and the daytime octopus (*Octopus cyanea*) (*Appendix C*).

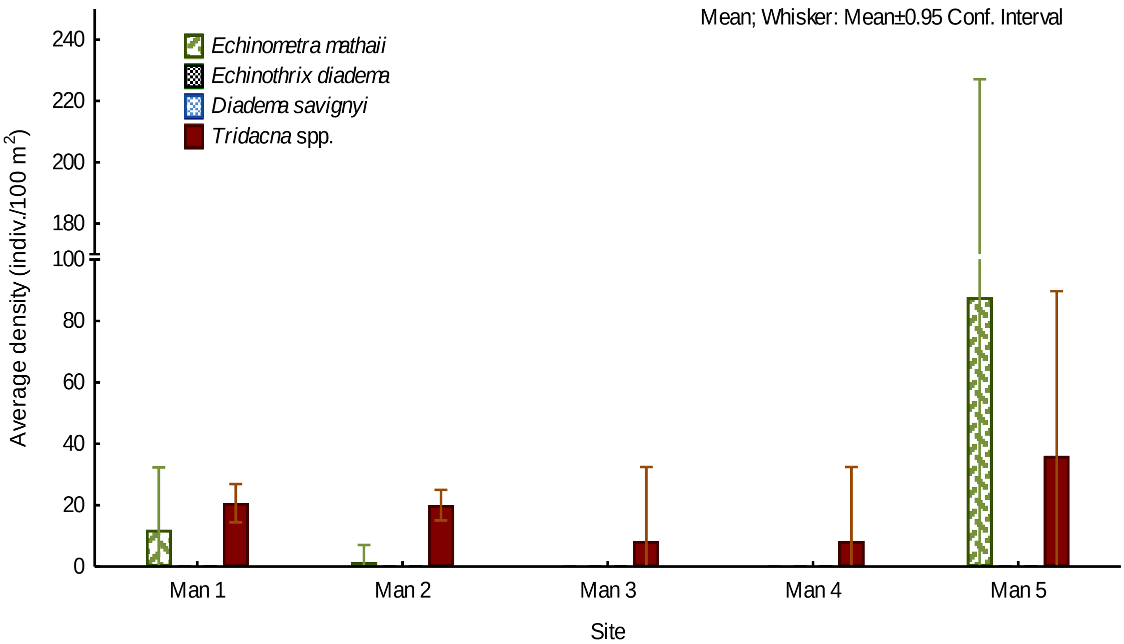


Figure 18. Average density of macro-invertebrates from five fore reef sites surveyed in Manuae in 2013. Only the common invertebrates were included in the plot. Note: a break in the y-axis was implemented between 100 and 170 individuals per 100 m^2.

2.2.4. Fish communities

A total of 66 fish species representing 17 families were recorded on Manuae (*Appendix D*). Site 1 had the highest number of species, number of individuals, and species richness. Site 3 had the highest evenness and Site 5 had the highest diversity index (Table 2). Pomacentrids were most abundant, with average density ranging from 56 ± 10 (SE) individuals per 250 m^2 at Site 3 to 617 ± 9 (SE) individuals per 250 m^2 at Site 1 (Figure 19). Average density of Labrids ranged from 15 ± 1 (SE) individuals per 250 m^2 to 44 ± 15 (SE) individuals per 250 m^2. Average density of Acanthurids ranged from 0 to 19 ± 6 (SE) individuals per 250 m^2. Average density of Cirrhitids were below 14 individuals per 250 m^2 at all sites. Bigeye trevally (*Caranx sexfasciatus*) was one of the larger schooling fish species observed on Manuae at Site 1 (Figure 20 *top*); a similar school was also reported at this site in 1995, but not in 2005. The purple queen anthias (*Pseudanthias pascalus*) were also very common, particularly on steeper fore reef slopes (Figure 20 *bottom*).

Table 2. Species diversity of fish at sites surveyed in Manuae in 2013. S is the total number of species; N is the number of individuals; d is the Margalef's species richness; J' is Pielou's evenness; H' is the Shannon-Wiener diversity index. Red number indicates highest in each category.

Site	S	N	d	J'	H'(loge)
Man 1	41	2152	5.212	0.4467	1.659
Man 2	36	1135	4.976	0.4091	1.466
Man 3	14	258	2.341	0.7143	1.885
Man 4	38	1582	5.023	0.4185	1.522
Man 5	31	886	4.420	0.5491	1.886

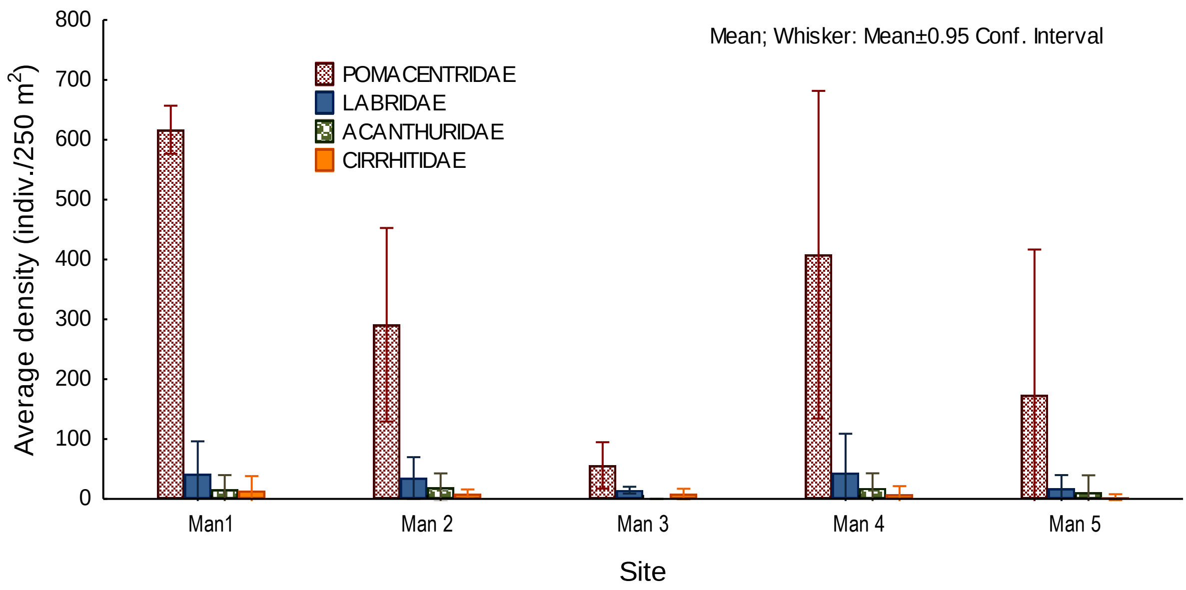


Figure 19. Average density of fish by family (Pomacentridae, Labridae, Acanthuridae, and Cirrhitidae) from five fore reef sites surveyed in Manuae in 2013.

Figure 20. *Top:* Bigeye trevally (*Caranx sexfasciatus*) at the main passage at Site 1. A similar school of this size was observed in 1995, but not recorded in the 2005 survey. *Bottom:* Aggregates of the purple queen anthias (*Pseudanthias pascalus*) at Site 5. Photos taken by Graham McDonald.

2.2.5. Discussion

Due to rough sea conditions experienced on Manuae, the team could not survey the windward exposure of the island. However, spot checks indicated that hard coral cover was similar to that of the leeward side, with *Astreopora expansa* dominant particularly on steeper fore reef slopes. A comparison with the 2005 survey indicated a 30% increase in coral cover, which suggests that this reef has been recovering. A compilation of surveys from 2,667 Indo-Pacific coral reefs showed that average hard coral cover was 22.1% in 2003 (Bruno & Selig, 2007); Manuae's average coral cover at all sites ranged from 28% to 41%, which is considered above average based on this Indo-Pacific study.

Pomacentrids were the most abundant fish family on the fore reefs of Manuae, which was comparable to the average density estimated in 2005 (see Rongo et al., 2005). In 2005, Pomacentrids averaged over 500 individuals per 250 m^2 at Site 1, while the current survey estimated over 600 individuals per 250 m^2 at the same site. However, there was a noted difference in Acanthurid abundance where the average density was approximately 44 individuals per 250 m^2 at Site 1 in 2005, but decreased to around 16 individuals per 250 m^2 in 2013. These changes in Acanthurid abundance may be attributed to changes in reef state that has seen a significant increase in hard coral cover and decrease in turf algal cover (see Figure 16).

Interestingly, *Tridacna* clam density seemed to have increased at fore reef sites in 2013 compared with 2005 (Rongo et al., 2005). For example, clam density at Site 1 was estimated at 4 individuals per 100 m^2 in 2005, which increased to 21 individuals per 100 m^2 in 2013. However, the results of this survey are not enough to suggest that clam density on the fore reef has increased significantly since 2005, considering that only one site was resurveyed. A brief snorkel trip into the lagoon around the main channel entrance indicated that *T. maxima* were abundant (Figure 21). In 2005, there were concerns raised that marine resources on Manuae may be experiencing heavy fishing pressure from frequent visits by Aitutaki fishermen (Rongo et al., 2005). Ciguatera poisoning may have prompted these visits in the mid-1990s to 2000s as ciguatera was problematic in Aitutaki during this period, and Manuae's reef fish were unaffected. However, these visits may have declined in recent years due to the decline in the incidence of ciguatera in Aitutaki (Rongo & van Woesik, 2013), considering that trips to Manuae are risky and expensive.

Despite the improvement of Manuae's reefs since 2005, there were signs of stress in 2013 that could potentially be a serious concern. For example, an extensive area at Site 4 was observed to have coral disease (likely yellow-band disease; Figure 22 *a – d*) and COTS. While the disease was more apparent on the most dominant species *Astreopora expansa*, it was also found on other corals (i.e., *Millepora platyphylla, Acropora schmitti, Montastrea curta, Acropora humilis, Pocillopora meandrina, Pavona maldivensis*, and *Cyphastrea chalcidicum*). This site also had the highest number of COTS noted during a 5-minute swim (covering an area of approximately 5000 m^2) where nine starfish were counted (approximately 1800 starfish per km^2), which may be an indication of an outbreak occurring. For example, Moran & De`ath (1992) suggested that a density of 1500 starfish per km^2 is an indication of an outbreak.

The loss of coral on Manuae prior to 2005 is unknown, and there are no reliable records of any major outbreaks of COTS in the past. Considering that COTS outbreaks and, in particular, coral disease are normally associated with anthropogenic influences (e.g., Ward & Lafferty, 2004; Brodie et al., 2005), with Manuae being uninhabited it will be critical at this point to carry out a more detailed survey on COTS and coral disease to help us understand the natural variables that are causing it.

Figure 21. High densities of the small giant-clam (*Tridacna maxima*) were observed within Manuae's lagoon. Photo taken by Teina Rongo.

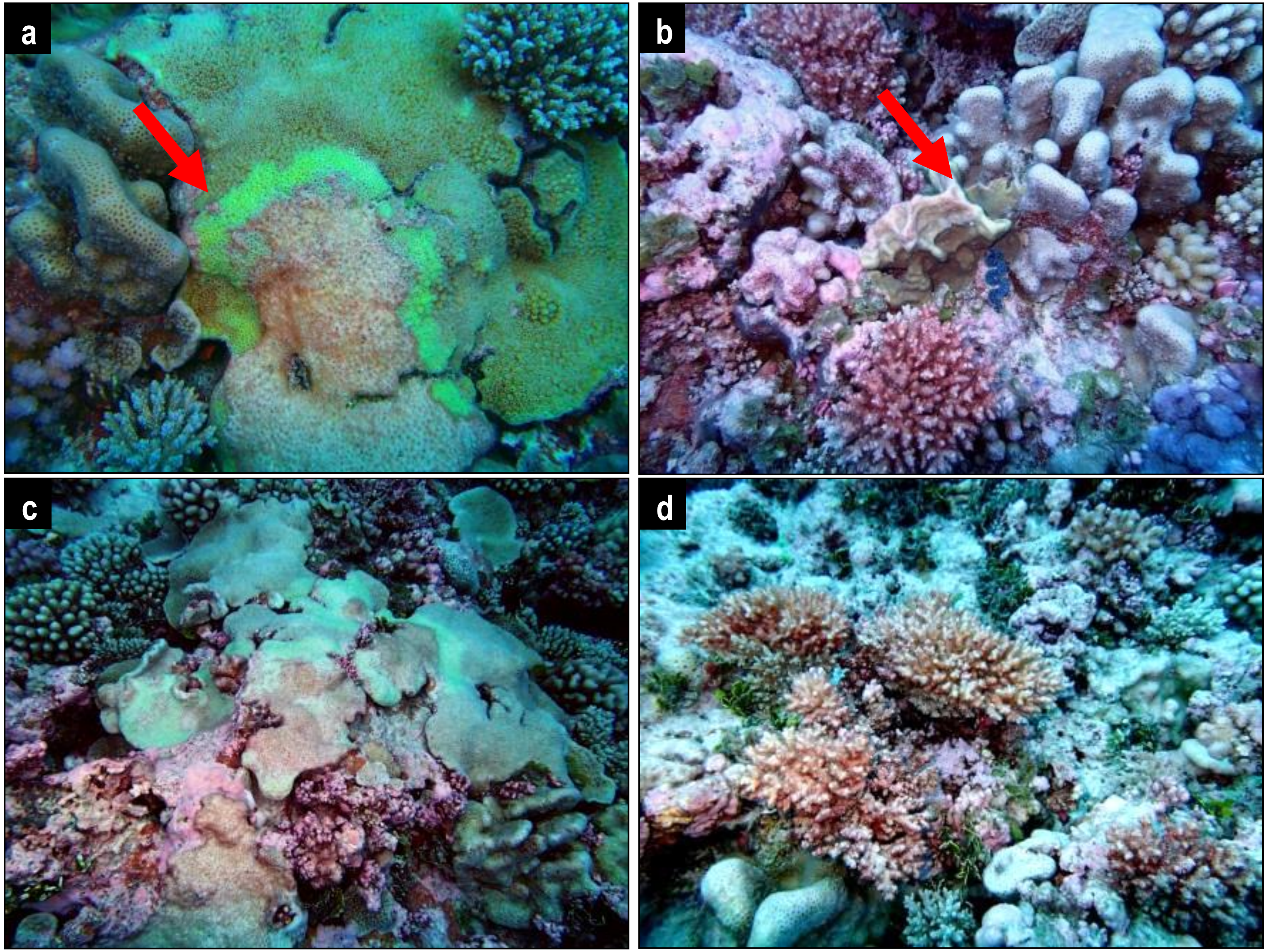


Figure 22. Coral disease was noted at Site 4 on Manuae, where an extensive area was affected. Disease lesions were apparent on large, platy *Astreopora* colonies (a & c). Other species were also infected, such as *Millepora platyphyla* (b) and *Acropora* spp. (d) where turf algae have overgrown the recently killed colony. Red arrow indicates area of the disease. Photos taken by Teina Rongo.

2.3. MITIARO

2.3.1. Site characteristics

Mitiaro (Figure 23), located at 19º 52'S 157º 41'W, is one of three sister islands in the southern group that includes Mauke and Atiu, with the three commonly referred to as *Ngaputoru*. This sunken island, dated around 12.3 million years old, was uplifted by tectonic activity associated with the formation of Rarotonga. During this period of uplift, the raised coral island, or *makatea*, reached a maximum elevation of around 11 m. The reefs of Mitiaro are fringed with places partially overlain by a sequence of late Pleistocene reef limestone. The total land area of the island is approximately 22 km^2 and the circumference of the bench reef is approximately 18 km. Mitiaro has a population of under 300 people, residing mainly in the village of Taka`ue.

To date there has been limited amount of marine research that has been conducted on Mitiaro. In 1998, a baseline assessment was carried out by the Ministry of Marine Resources (Ponia et al., 1998b) to quantify exploitable marine resources on the reef flat area. In 2002, a coral reef assessment was conducted on the fore reef (Lyon 2002) as part of an Environmental Impact Assessment undertaken by the National Environment Service for a proposal by Government to upgrade the harbour. Both surveys were important in providing some baseline information for the island.

A total of six sites were surveyed on Mitiaro on this expedition (see Figure 23). Rough sea conditions experienced limited the survey to the leeward exposure, and only spot checks could be carried out on the windward exposure. Sites established in 2002 were revisited (Site 3, 5, & 6) at the request of the island mayor to assess the damage, if any, to reef communities as a result of the recent upgrade of Mitiaro Harbour in 2011.

Figure 23. Map of Mitiaro with yellow dots indicating the sites surveyed during this expedition. Site 3, 5, and 6 were established in 2002 (Lyon, 2002) and were revisited in 2013. Image taken from Google Earth.

2.3.2. Benthic communities

The average hard coral cover on Mitiaro ranged from 24 % ± 3 (SE) at Site 3 to 42% ± 5 (SE) at Site 6 (Figure 24). Although *Halimeda* spp. was the most common macro-algae recorded on Mitiaro with cover ranging from 2% ± 1 (SE) to 7% ± 2 (SE), these were not recorded at the harbour sites. Cover of CCA ranged from < 1% to 7% ± 2 (SE) at all sites.

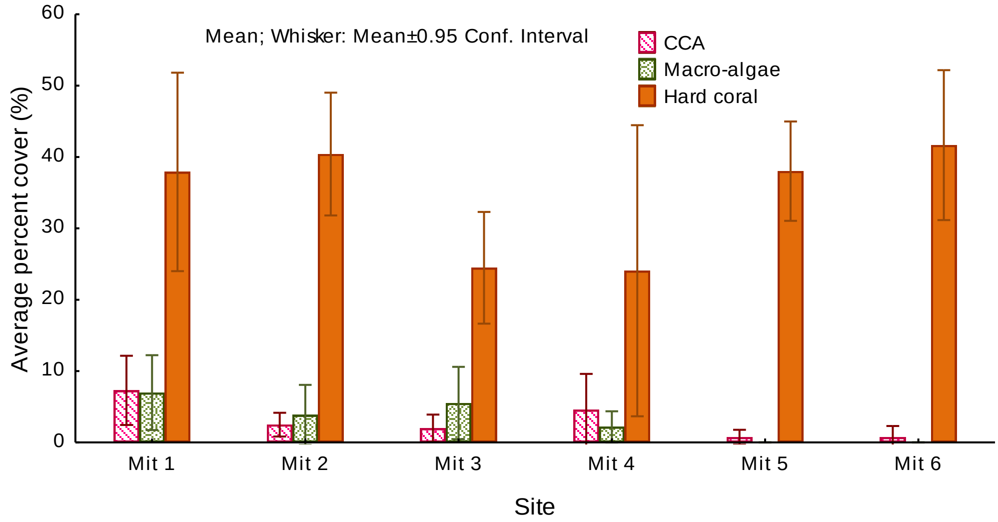


Figure 24. Average percent cover of crustose coralline algae, macro-algae, and hard coral from six fore reef sites surveyed in Mitiaro in 2013.

Comparison of results with 2002 showed a 20% increase in hard coral cover at Site 5, and a 23% increase at Site 6 (Figure 25); these sites are located on either side of the harbour entrance. However, no significant change in coral cover was noted at the control site (Site 3), established on the northern exposure of Mitiaro away from the harbour sites. Recently killed coral colonies were only recorded at the harbour sites (Site 5 and 6), with an average percent cover of 6% and 3% respectively (see Figure 25).

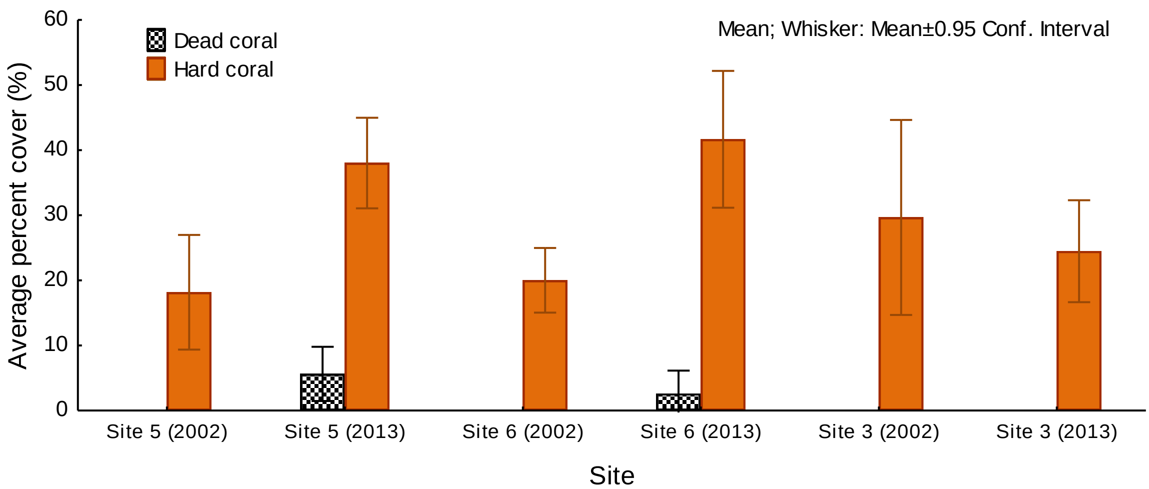


Figure 25. Comparison of the average percent cover of hard coral and dead coral from two fore reef sites off Mitiaro Harbour surveyed in 2002 (Lyon, 2002), and resurveyed in 2013.

Dead coral colonies noted at the harbour sites (Sites 5 & 6) were largely from one of the most dominant genera *Pocillopora* (Figure 26*a*) (with some species of *Acropora* as well) that were in close proximity to the harbour entrance. Dead colonies at this location were covered by turf or cyanobacteria. Mats of the same cyanobacteria were observed at shallow depths in this area, particularly around the harbour entrance.

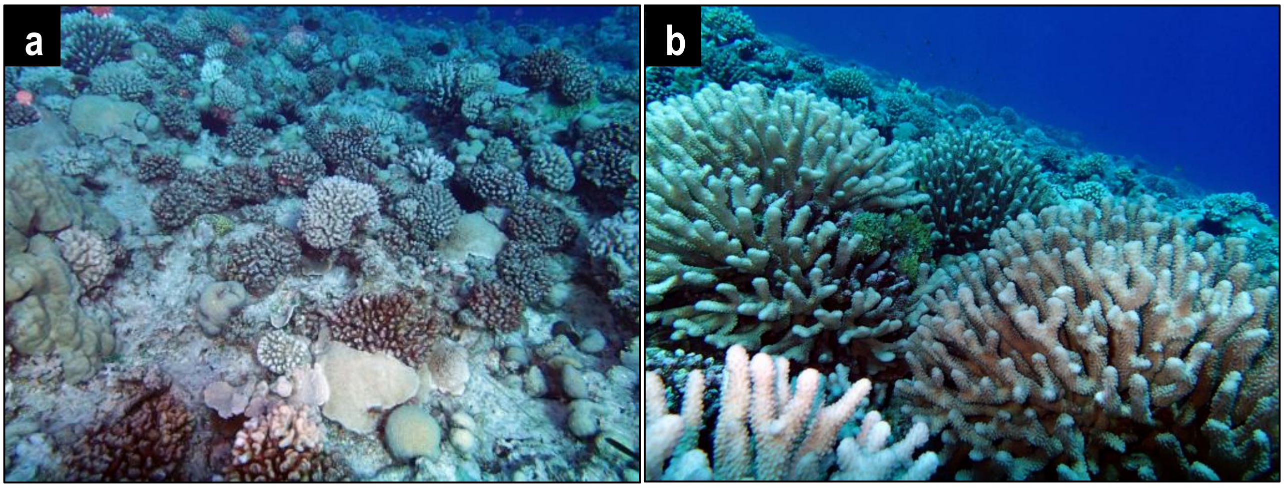


Figure 26. *a*) Dead coral species predominantly from the genera *Pocillopora*, noted in close proximity to the harbour entrance. *b*) Large colonies of *Pocillopora* spp., which is one of the most dominant hard coral on the leeward exposure of Mitiaro; photo taken on the northern side of the harbour by Teina Rongo.

A total of 25 species of hard corals representing 8 families were recorded on Mitiaro (see *Appendix B*). Site 1 on the leeward exposure had the highest total number of species, species richness, and species diversity, whereas Site 3 had the highest number of individuals and evenness (Table 3). Large colonies of *Pocillopora* spp. (Figure 26*b*) were common at depths < 12 m on the western exposure, with some colonies reaching a diameter of close to 1 m. On the steeper reef slopes (> 12 m), impressive plate-like growth forms of *Astreopora expansa* were dominant. This pattern of distribution was observed at all fore-reef locations on the island.

Table 3. Species diversity of hard corals at Sites 1, 2, and 3 in Mitiaro surveyed in 2013. S is the total number of species; N is the number of individuals; d is the Margalef's species richness; J` is Pielou's evenness; H` is the Shannon-Wiener diversity index. Red number indicates highest in each category.

Site	**S**	**N**	**d**	**J'**	**H'(loge)**
Mit 1	22	145	4.220	0.8130	2.513
Mit 2	18	138	3.450	0.7801	2.255
Mit 3	17	206	3.003	0.8278	2.345

Astreopora expansa (Figure 27*a*) was the most dominant coral species on the steeper reef-slopes of Mitiaro, forming terraces of thick plates. Figure 27*b* shows both *A. expansa* and *Acropora schmitti,* which are the two most dominant coral species at the Airport site (Site 3).

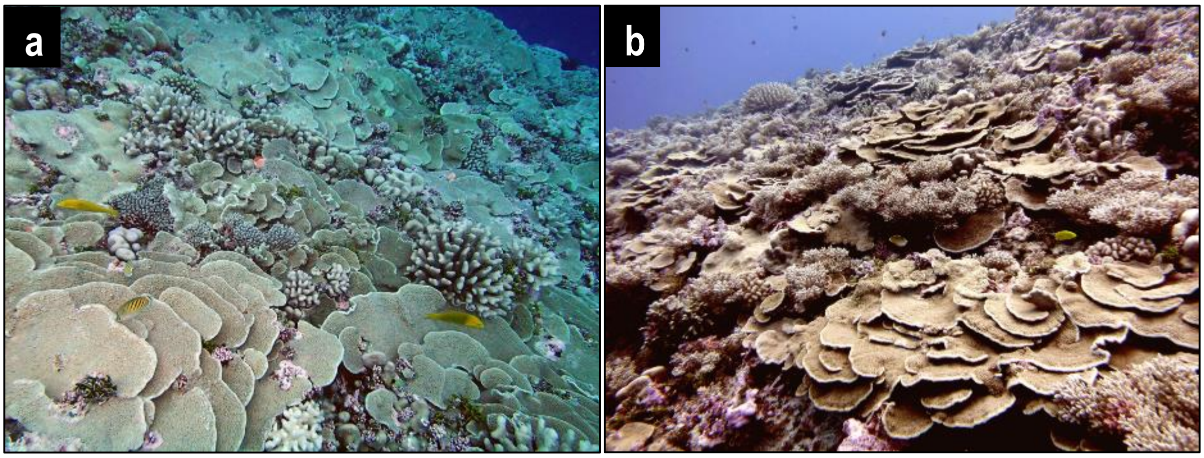


Figure 27. a) *Astreopora expansa*, the dominant coral species on fore reef slopes of Mitiaro; photo taken by Teina Rongo at Site 4. b) *Acropora expansa* and *A. schmitti*, the dominant corals off the airport at Site 3; photo taken by Graham McDonald.

2.3.3. Macro-invertebrate communities

The moderate long-spined urchin (*Echinothrix diadema*) was the most common invertebrate on the fore reef of Mitiaro, particularly around the harbour, where the average density ranged from 100 ± 24 (SE) individuals per 100 m^2 at Site 5 to 94 ± 9 (SE) individuals per 100 m^2 at Site 6 (Figure 28). The extreme long-spined urchin (*Diadema savignyi*) was also recorded at the harbour area (Site 6), while the pale burrowing urchin (*Echinometra mathaei*) was only recorded at Site 3 and 6. Other invertebrates recorded but not plotted due to low numbers included the great worm-snail (*Dendropoma maxima*), the esculator urchin (*Echinostrephus aciculatus*), the prickly redfish (*Thelenota ananas*), the black brittle star (*Ophiomastix janualis*), the hidden sea urchin (*Tripneustes gratilla*), and the daytime octopus (*Octopus* cyanea) (see *Appendix C*).

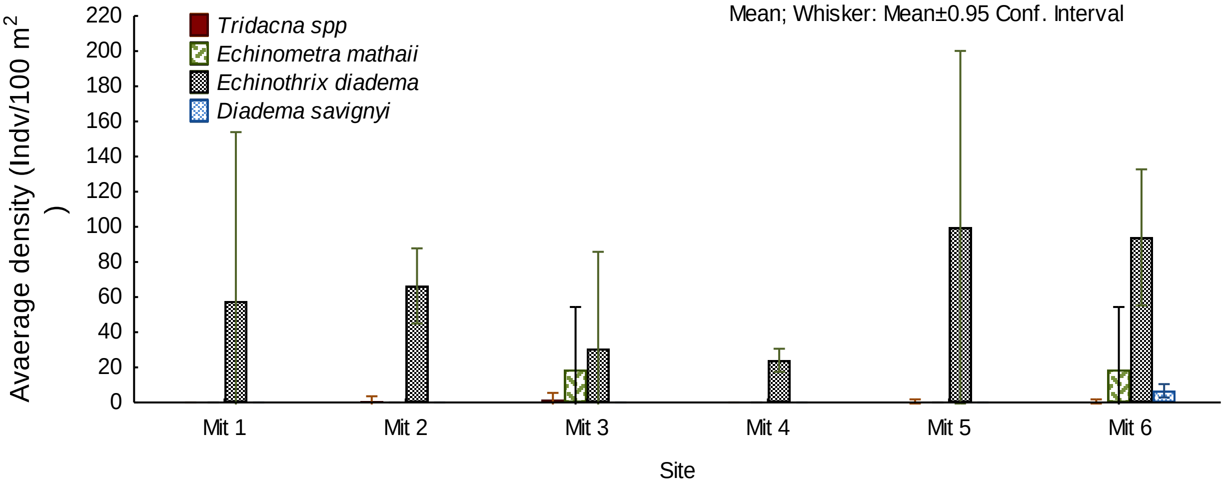


Figure 28. Average density of macro-invertebrates from six fore reef sites surveyed in Mitiaro in 2013. Only the common invertebrates were included in the plot.

2.3.4. Fish communities

A total of 62 fish species representing 16 families were recorded on Mitiaro (see *Appendix D*). Site 5 had the highest number of species and number of individuals, whereas Site 6 had the highest species richness, and Site 4 had the highest evenness and species diversity index (Table 4). Although Pomacentrids were the most abundant, these were highly variable on the transects with the average abundance ranging from 50 ± 9 (SE) individuals per 250 m^2 at Site 4 to 202 ± 40 (SE) individuals per 250 m^2 at Site 5 (Figure 29). The average abundance of Labrids ranged from 22 ± 2 (SE) individuals per 250 m^2 at Site 2 to 51 ± 10 (SE) individuals per 250 m^2 at Site 5.The average abundance of Acanthurids ranged from 7 ± 3 (SE) individuals per 250 m^2 at Site 5 to 16 ± 9 (SE) individuals per 250 m^2 at Site 4. The average density of Cirrhitids ranged from 6 ± 0.3 (SE) individuals per 250 m^2 at Site 4 to 51 ± 2 (SE) individuals per 250 m^2 at Site 5.

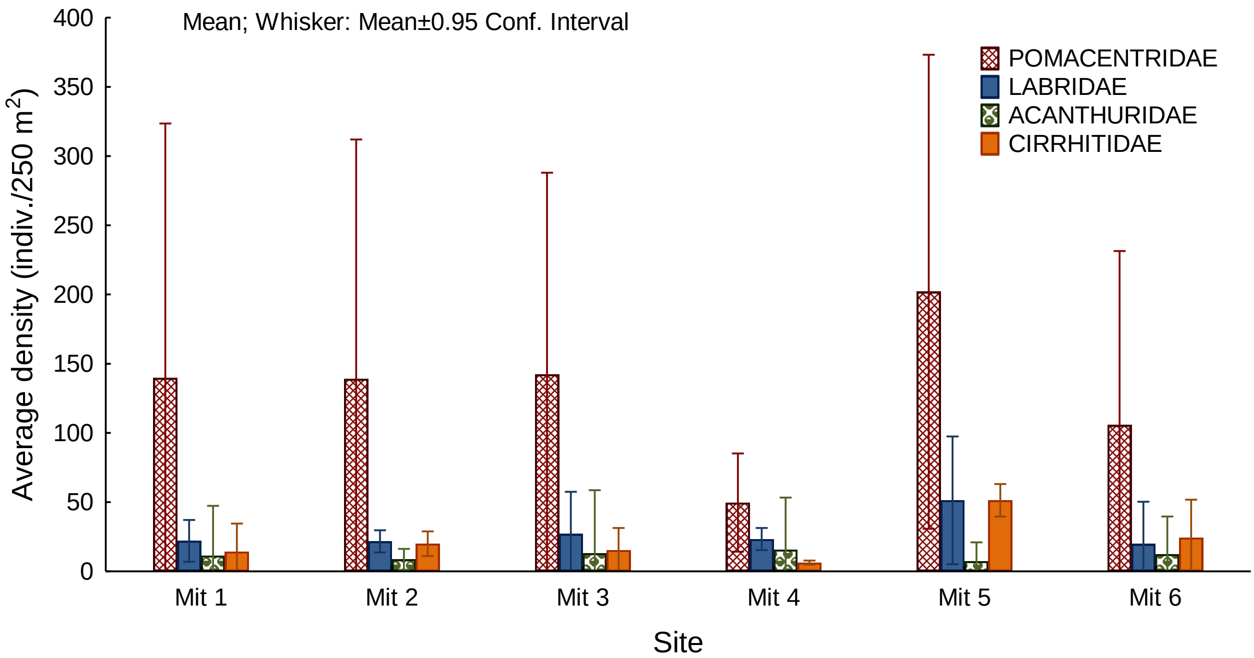


Figure 29. Average density of fish by family (Pomacentridae, Labridae, Acanthuridae, and Cirrhitidae) from six fore reef sites surveyed in Mitiaro in 2013.

Table 4. Species diversity of reef fish communities on the fore reef of Mitiaro in 2013. S is the total number of species; N is the number of individuals; d is the Margalef's species richness; J' is Pielou's evenness; H' is the Shannon-Wiener diversity index. Red numbers indicate highest in each category.

Site	S	N	d	J'	H'(loge)
Mit 1	33	791	4.795	0.6765	2.366
Mit 2	33	626	4.969	0.7350	2.570
Mit 3	35	638	5.265	0.6781	2.411
Mit 4	30	370	4.904	0.8725	2.968
Mit 5	40	1072	5.590	0.7456	2.751
Mit 6	39	539	6.042	0.7401	2.712

2.3.5. Discussion

Weather was a constraint to the team's ability to survey the entire island of Mitiaro; almost all sites surveyed were located on the leeward exposure. The reef health of Mitiaro was certainly on the healthy side with hard coral cover ranging from 24% to 42% at all sites (well above the Indo-Pacific average of 22.1% in 2003; see Bruno and Selig, 2007), and likely above 70% at locations deeper than where transect lines were deployed. Average hard coral cover around the harbour (Site 5 & 6) were estimated at 18% and 20% respectively in 2002, and increased significantly to 38% and 42% respectively in 2013. However, no change in hard coral cover was recorded at the Airport site (Site 3; used as the control site in 2002), which was 29% in 2002 and 24% in 2013. Based on the results of both the 2002 and 2013 surveys, it was estimated that the rate of recovery for coral cover at the harbour sites were around 2% annually.

Damage that may have resulted from the harbour upgrade in 2011 appeared to be limited to areas in close proximity to the harbour entrance; dead colonies of *Pocillopora* and *Acropora* were recorded within 50 m of the entrance. Interestingly, observations made in the shallower areas (around 6 m and less) at Site 3 indicated high cover of turf algae and high density of urchins (i.e., *Echinothrix diadema*). In addition, this site was the only site with poor visibility and low coral cover in the shallower areas, especially on the western side of Site 3. Because the general current on the western side of Mitiaro flows northward (according to locals), it is possible that sediments and associated nutrients originating from the residential area (Taka`ue) and the harbour site on the western side may collect here. Although the western side of Mitiaro may be experiencing some level of human disturbance (as noted from the high density of urchins and dead colonies around the harbour), the leeward side of the island certainly was diverse in terms of fish communities (see Table 4), and likely corals as well, although no diversity information was collected at these sites.

It was interesting to note that Scarids were not common on Mitiaro, and none were recorded on transects. Reef fishing on Mitiaro is largely bottom fishing with drop-lines for snappers and groupers, and bamboo rod fishing on the reef flat for groupers and soldierfish (Holocentridae); spearfishing and gillnet fishing are uncommon. Therefore it is unlikely that low numbers of Scarids were due to overfishing, but rather a recruitment limitation issue. However, there were concerns of overfishing raised by the elders of Mitiaro during a community meeting (Figure 30). According to the elders, target species such as their favorite deep water Serranids (i.e., *Variola louti* and *Epinephalus fasciatus*) caught via bottom fishing are getting harder to catch.

Figure 30. Community meeting held on Mitiaro to discuss the purpose of the research expedition. Presenters: Teina Rongo of the Office of the Prime Minister and Jacqueline Evans of NGO Te Ipukarea Society. Photo taken by Jessica Cramp.

2.4. TAKUTEA

2.4.1. Site characteristics

Takutea (Figure 31) is a small sand cay island (19°48' S and 158° 17' W), located 22 km northwest of Atiu. The island has a land area of around 1.2 km^2 with a maximum elevation of around 6 m above sea level. The island is surrounded by a narrow and shallow fringing reef flat often exposed during low tide. Takutea is one of two uninhabited islands in the southern group, considered an important nesting ground for turtles and a variety of sea bird species in the Cook Islands, and is a wildlife sanctuary. Administratively, the island is considered part of Atiu and is owned equally by all inhabitants. Currently, the wildlife sanctuary is administered by a Trust consisting of the traditional leaders of Atiu, with the High Chief Rongomatane as the chairman of the Trust; visits to the island have to seek the permission of the trustees.

Although marine-related information on Takutea is limited, a survey was conducted in 1998 by the Ministry of Marine Resources (MMR; Ponia et al., 1998c) to identify and quantify common reef resources on the island. This survey was commissioned by the Takutea trustees to provide an estimate of a sustainable harvest quota for the main exploitable marine resources (i.e., *Tridacna maxima*) as overfishing was becoming a concern. Coincidentally, the MMR also facilitated the introduction of the trochus (*Tectus niloticus*) to the island in hopes that these will establish and serve as reserve stock for the island of Atiu. Because the MMR survey was limited to reef flat habitats of Takutea, our survey in 2013 provided baseline information on fore reef communities. A total of four sites were established on the fore reef, with two located on the leeward exposure (Sites 1 & 4 in Figure 31) and two on the windward exposure (Sites 2 & 3).

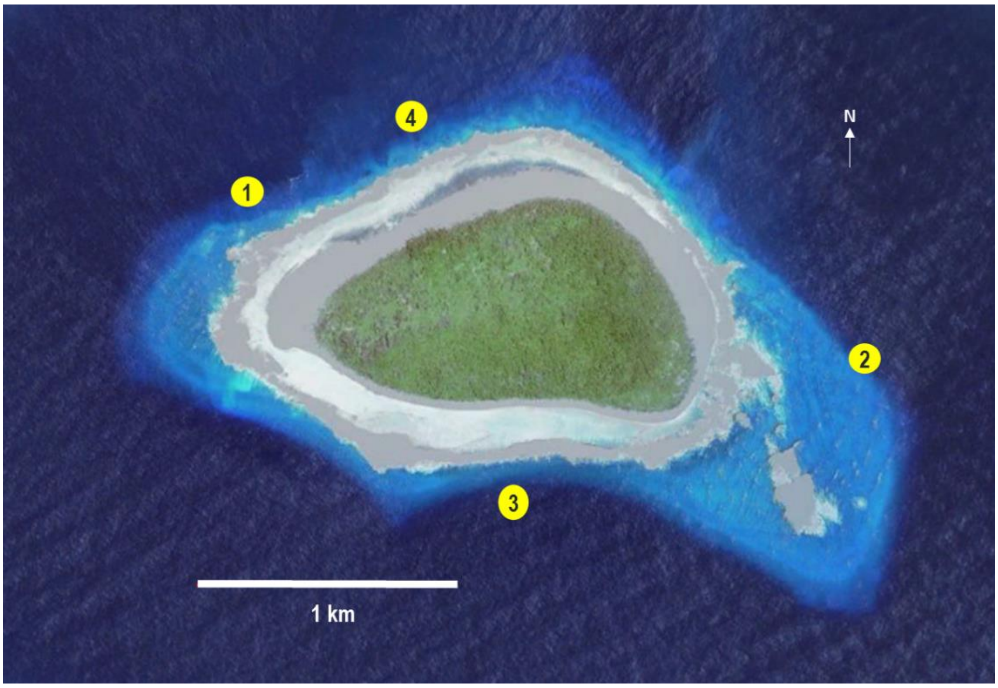


Figure 31. Map of Takutea with yellow dots indicating the sites surveyed during this expedition. Taken from Google Earth.

2.4.2. Benthic communities

The average hard coral cover on Takutea ranged from 16 % ± 2 (SE) at Site 3 to 29% ± 3 (SE) at Site 1 (Figure 32). Cover of CCA ranged from 6% ± 2 (SE) at Site 4 to 27% ± 5 (SE) at Site 2. Pavement cover ranged from 40% ± 8 (SE) at Site 2 to 71% ± 4 (SE) at Site 4.

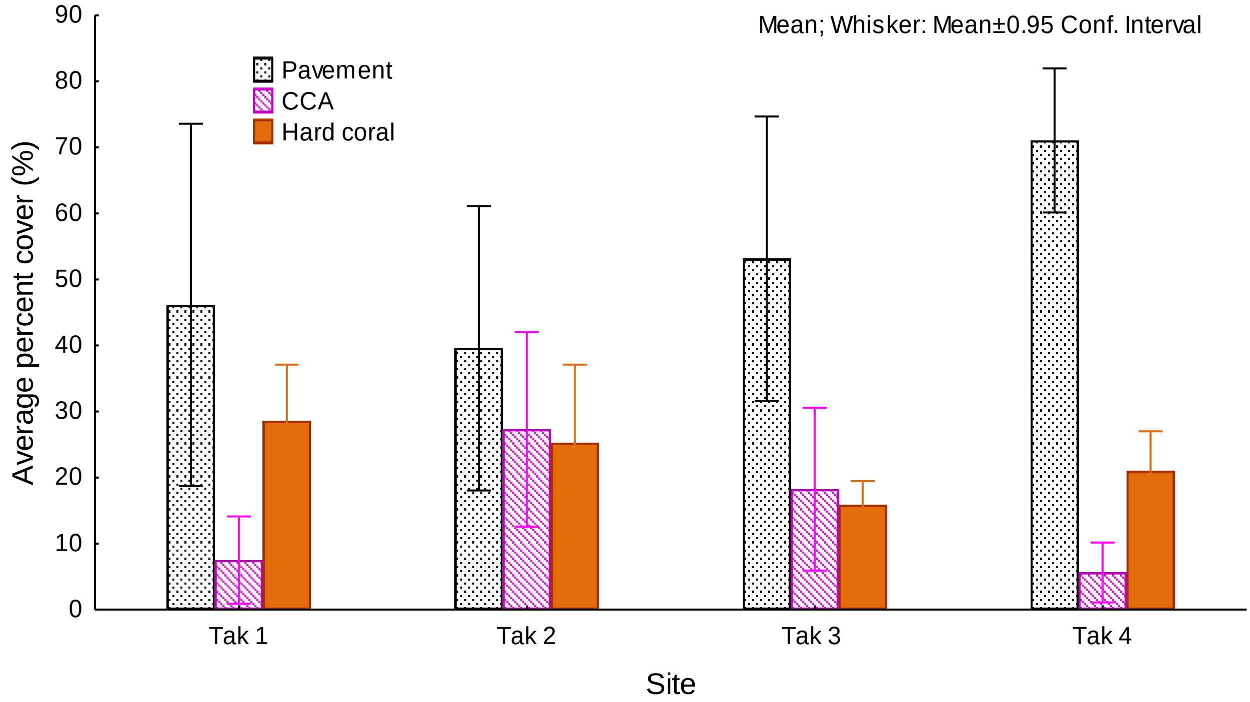


Figure 32. Average percent cover of pavement, crustose coralline algae (CCA), and hard coral from four fore reef sites surveyed in Takutea in 2013.

Only two sites (Sites 1 & 4) were used to generate information on species diversity as conditions were not favourable to collect that information at the other sites. A total of 21 species of corals representing 6 families were recorded on Takutea (see *Appendix B*). Between the two sites, Site 1 had the higher numbers in all categories (Table 5); coral communities on this leeward exposure were more diverse (Figure 33 *top*). With the exception of some channels traversing the fore reef slope (from the reef crest towards the deeper slope on the leeward exposure), reef complexity on the fore reef was poor with some areas appearing flattened (Figure 33 *bottom*).

Table 5. Species diversity of hard corals from the fore reefs of Takutea in 2013. S is the total number of species; N is the number of individuals; d is the Margalef's species richness; J' is Pielou's evenness; H' is the Shannon-Wiener diversity index. Red number indicates highest in each category.

Site	S	N	d	J'	H'(loge)
Tak 1	17	169	3.119	0.8160	2.312
Tak 4	16	144	3.018	0.7337	2.034

Figure 33. *Top:* Diverse community of hard corals on the leeward exposure of Takutea at Site 1. *Bottom:* Fore reef on the windward exposure of Takutea at Site 3, with poor reef rugosity. There were many broken branches of *Acropora* and *Pocillopora* spp. on this exposure, a likely result of large swells associate with a low pressure system in the region the week prior to the survey. Members of the team are seen here carrying out their surveys. Photos taken by Teina Rongo.

2.4.3. Macro-invertebrate communities

The pale burrowing urchin (*Echinometra mathaei*) was abundant, especially at Site 4, with average density recorded at 104 ± 6 individuals per 100 m^2 at this site (Figure 34). The extreme long-spined urchin (*Diadema savignyi*; Figure 35) was noticeably one of the most common invertebrates on the fore reef. Their average density was particularly high at Sites 2 & 4 with 22 ± 2 (SE) individuals per 100 m^2 and 58 ± 7 (SE) individuals per 100 m^2 respectively (see Figure 34). Interestingly, Site 3 had low numbers of macro-invertebrates (see *Appendix C*); the moderate long-spined urchin (*Echinothrix diadema*) was the most common macro-invertebrate recorded on transects at this site. There were no trochus (*Tectus niloticus*) recorded on the fore reef.

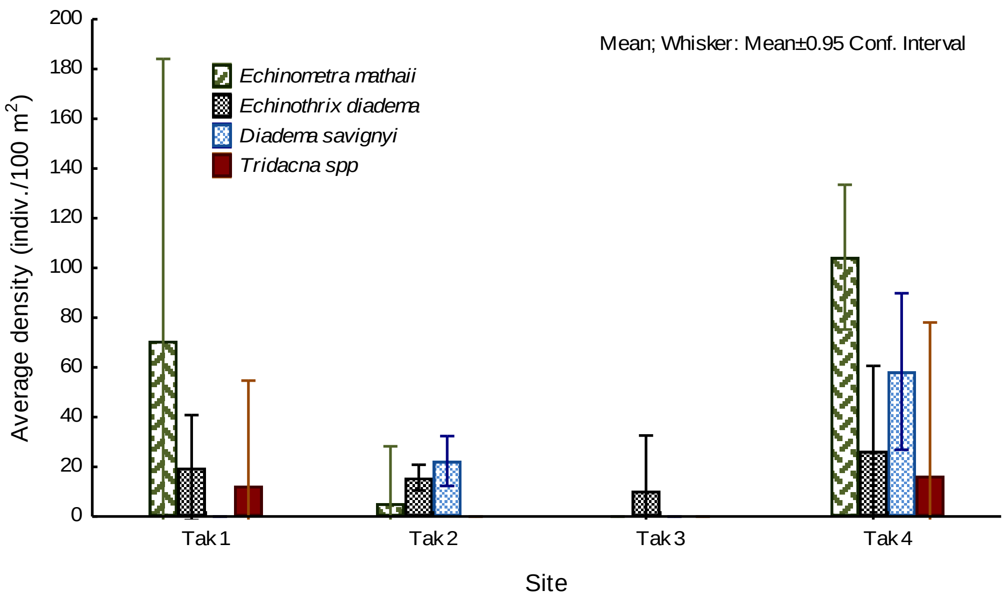


Figure 34. Average density of macro-invertebrates from the four fore reef sites surveyed in Takutea in 2013.

Figure 35. The extreme long-spined urchin (*Diadema savignyi*) was one of the most common macro-invertebrates noted at Site 2 & 4 on the fore reef of Takutea. Photo taken by Teina Rongo.

2.4.4. Fish communities

A total of 55 fish species representing 17 families were recorded on Takutea (see *Appendix D*). Pomacentrid numbers were relatively low on Takutea compared with other islands surveyed, ranging from 31 ± 2 (SE) individuals per 250 m^2 at Site 2 to 191 ± 78 (SE) individuals per 250 m^2 at Site 1 (Figure 36). Average density of other families (i.e., Labridae, Acanthuridae, and Cirhitidae) did not exceed 30 individuals per 250 m^2 at all sites. Large solitary *Lutjanus bojar* (Figure 37) were frequently encountered on the fore reefs of Takutea. In terms of the diversity index, Site 4 had the highest number of species, species richness, and species diversity, while Site 1 had the highest number of individuals and Site 3 the highest evenness (Table 6).

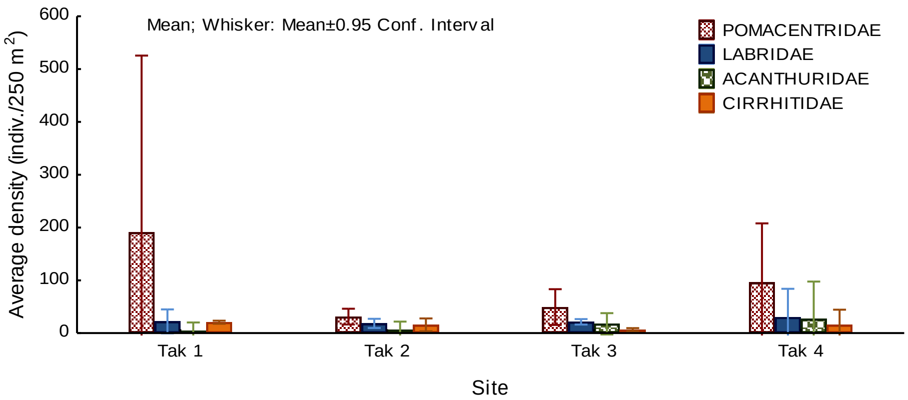


Figure 36. Average density of fish by family (Pomacentridae, Labridae, Acanthuridae, and Cirrhitidae) from four fore reef sites surveyed in Takutea in 2013.

Figure 37. Large solitary *Lutjanus bojar* were frequently encountered on the fore reefs of Takutea. Photo taken by Teina Rongo at Site 2.

Table 6. Species diversity of reef fish communities on the fore reef of Takutea in 2013. S is the total number of species; N is the number of individuals; d is the Margalef's species richness; J' is Pielou's evenness; H' is the Shannon-Wiener diversity index. Red number indicates highest in each category.

Site	S	N	D	J'	H'(loge)
Tak 1	30	847	4.302	0.7004	2.382
Tak 2	28	265	4.839	0.7809	2.602
Tak 3	27	332	4.479	0.7959	2.623
Tak 4	33	571	5.041	0.7569	2.647

2.4.5. Discussion

The coral community of Takutea was less diverse than most of the other islands visited, and generally had lower hard coral cover. The average hard coral cover ranged from 16% on the windward exposure to 29% on the leeward exposure. While it could be argued that these differences are a result of more sites established on the leeward exposure, spot checks on the windward exposure also confirmed this outcome. *Astreopra expansa*, *Acropora schmitti*, *Pocillopora* spp., and *Montastrea curta* were the most common coral species on Takutea. Although reef complexity was generally poor, some areas on the leeward exposure provided some structural complexity for a more diverse community to exist. Poor reef complexity on this island suggests that the reefs of Takutea have been in a coral-depauperate state for an extended period; recruitment limitation may also be an issue because of the remoteness and size of the island. However, it is difficult to determine this provided that no previous data on these fore reef communities exist. Nevertheless, the higher percent contribution in the smaller size classes of hard corals (geometric diameter of 16 cm and less) suggest that recovery is taking place, with much of these colonies barely a decade old (assuming that growth rate is around 1 cm/year).

Macro-invertebrates were more diverse on the leeward exposure of Takutea, with some species not observed on the windward exposure (e.g., *Diadema savignyi*). Although urchins were the most common invertebrate on the fore reef, some small giant-clams (*Tridacna maxima*) were recorded particularly on the leeward exposure. The results of this survey were contrary to the 1998 survey on the reef flat (Ponia et al., 1998c), where a higher density and diversity of exploitable resources were recorded on the windward exposure. According to that report, these differences were due to accessibility; rough conditions on the windward exposure may have minimized the effect of fishing pressure by people visiting the island. Although our team did not carry out any survey on the reef flat, a brief assessment on the leeward exposure showed very few target species (i.e., *Turbo setosus*, *Tridacna maxima*, and *Heterocentrotus trigonarius*). The trochus (*Tectus niloticus*) were not recorded on the fore reef or observed on the reef flat, suggesting that the introduction conducted by MMR in 1998 was unsuccessful.

Fish communities on Takutea were also more abundant on the leeward exposure, with Pomacentrids having the highest density at all sites. The highest density of Pomacentrids at Site 1 may be attributed to good coral cover (29%; the highest for all sites) and possibly the topography of this site. Transects at Site 1 were deployed near a drop-off where several Pomacentrid species were recorded (e.g., *Chromis* v*anderbilti*, *Chromis acares*, and *Pomachromis fuscidorsalis*). Although not recorded on transects, solitary species of trevally (i.e., *Caranx melampygus* and *Caranganoides orthogrammus*) and the red snapper (*Lutjanus bojar*) were frequently encountered on the fore reef. Only one shark (grey-reef; *Carcharhinus amblyrhynchos*) was recorded on the windward exposure during a spot check.

2.5.ATIU

2.5.1. Site characteristics

Atiu (Figure 38) is an uplifted *makatea* island located at latitude 19°58' S and longitude 158° 06' W, about 23 km southeast of Takutea and around 200 km southeast of Aitutaki. Atiu is the biggest (27 km^2 of land area) and the highest (72 m) of the *Ngaputoru* islands, which is dated around 8 - 9 million years old. Atiu has a narrow fringing reef with the widest reef flat area located on the southern exposure of the island (~ 120 m wide). In 2011, there were less than 500 people living on Atiu (Cook Islands Census, 2011), with the population declining since 1996 from migration to Rarotonga and beyond for job opportunities.

While people on Atiu still practice a subsistence lifestyle (many individuals were observed bamboo rod fishing in the surf zone during our visit), Atiu is one of the islands in the southern group that occasionally have reported cases of ciguatera poisoning from consuming Acanthurids (i.e., *Ctenochaetus striatus*). Notably, the first cases of ciguatera poisoning in the southern Cook Islands were reported from Atiu in the early 1980s (Losacker, 1992). According to locals, these poisonings tend to occur from consuming reef fishes caught on the leeward exposure of the island, particularly around the harbour site. Because ciguatera poisoning has been linked to reef state and the abundance of herbivorous reef fishes density (Rongo and van Woesik, 2013), information from this survey will contribute to our understanding of this problem on Atiu.

To date, information on the coral reefs of Atiu, particularly on the fore reef, is scant. Although the Ministry of Marine Resources has carried out an assessment of exploitable reef resources on Atiu in 1998 to gather information on their abundance and distribution (Ponia et al., 1998d), the assessment was limited to the reef flat areas of the island. Because weather conditions improved during our time on Atiu, the team was able to establish sites all around the island, surveying a total of 6 sites (see Figure 38).

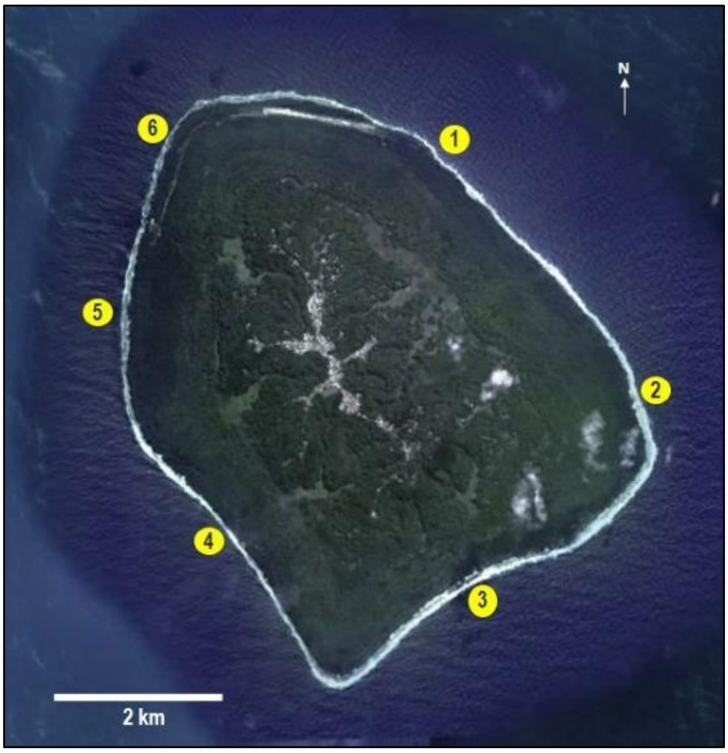


Figure 38. Map of Atiu with yellow dots indicating the sites surveyed during this expedition. Taken from Google Earth.

2.5.2. Benthic communities

The average hard coral cover on Atiu ranged from 14 % ± 3 (SE) at Site 4 to 29% ± 2 (SE) at Site 6 (Figure 39). Average cover of CCA was significantly higher at Site 4 at 38 % ± 5 (SE) compared with all other sites. Pavement cover ranged from 40% ± 5 (SE) at Site 4 to 71% ± 3 (SE) at Site 5. Soft coral (see Figure 39) was recorded at all sites, but more so on the leeward exposure with cover ranging from < 1% at the other sites to 6 % ± 3 (SE) at Site 4.

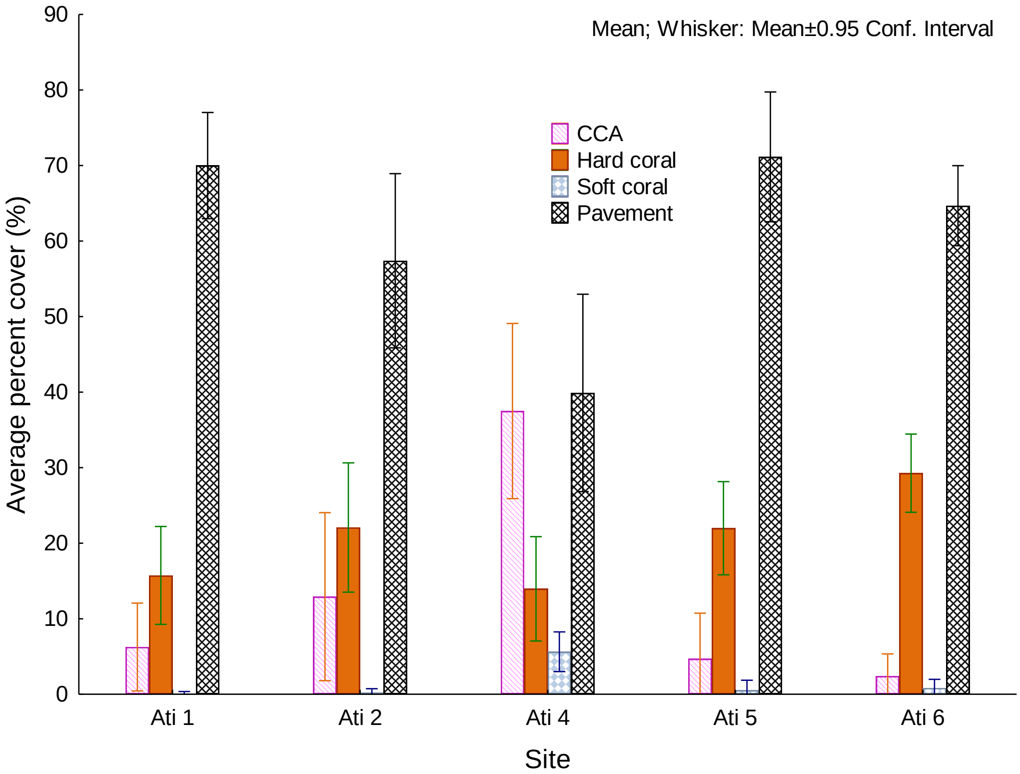


Figure 39. Average percent cover of crustose coralline algae (CCA), hard coral, soft coral, and pavement from six fore reef sites surveyed in Atiu in 2013.

A total of 35 species of corals representing 10 families were recorded on Atiu (see *Appendix B*). Site 4 on the leeward exposure (see Figure 38) had the highest in all diversity categories except for number of individuals, which was highest at Site 6 (Table 7). Reef complexity was good at this site with many of these large structures of dead coral indicating that a much healthier reef used to exist here. Site 4 on the leeward exposure had high cover of soft corals (Figure 40). Notably, large skeletal structures of what used to be colonies of *Lobophyllia hemprichii* (Figure 41) that were covered by CCA, were unusually common at this site. *Pocillopora* spp. and *Acropora* spp. were the most dominant genera on Atiu at all sites. Occasionally, extremely large colonies of *Pocillopora* were observed within the vicinity of the transect (Figure 42).

Table 7. Species diversity of hard corals at sites surveyed in Atiu in 2013. S is the total number of species; N is the number of individuals; d is the Margalef's species richness; J' is Pielou's evenness; H' is the Shannon-Wiener diversity index. Red number indicates highest in each category.

Site	S	N	d	J'	H'(loge)
Ati 1	24	169	4.484	0.7345	2.334
Ati 2	17	172	3.108	0.7600	2.153
Ati 3	21	152	3.981	0.6405	1.950
Ati 4	26	141	5.052	0.8199	2.671
Ati 6	22	187	4.014	0.6975	2.156

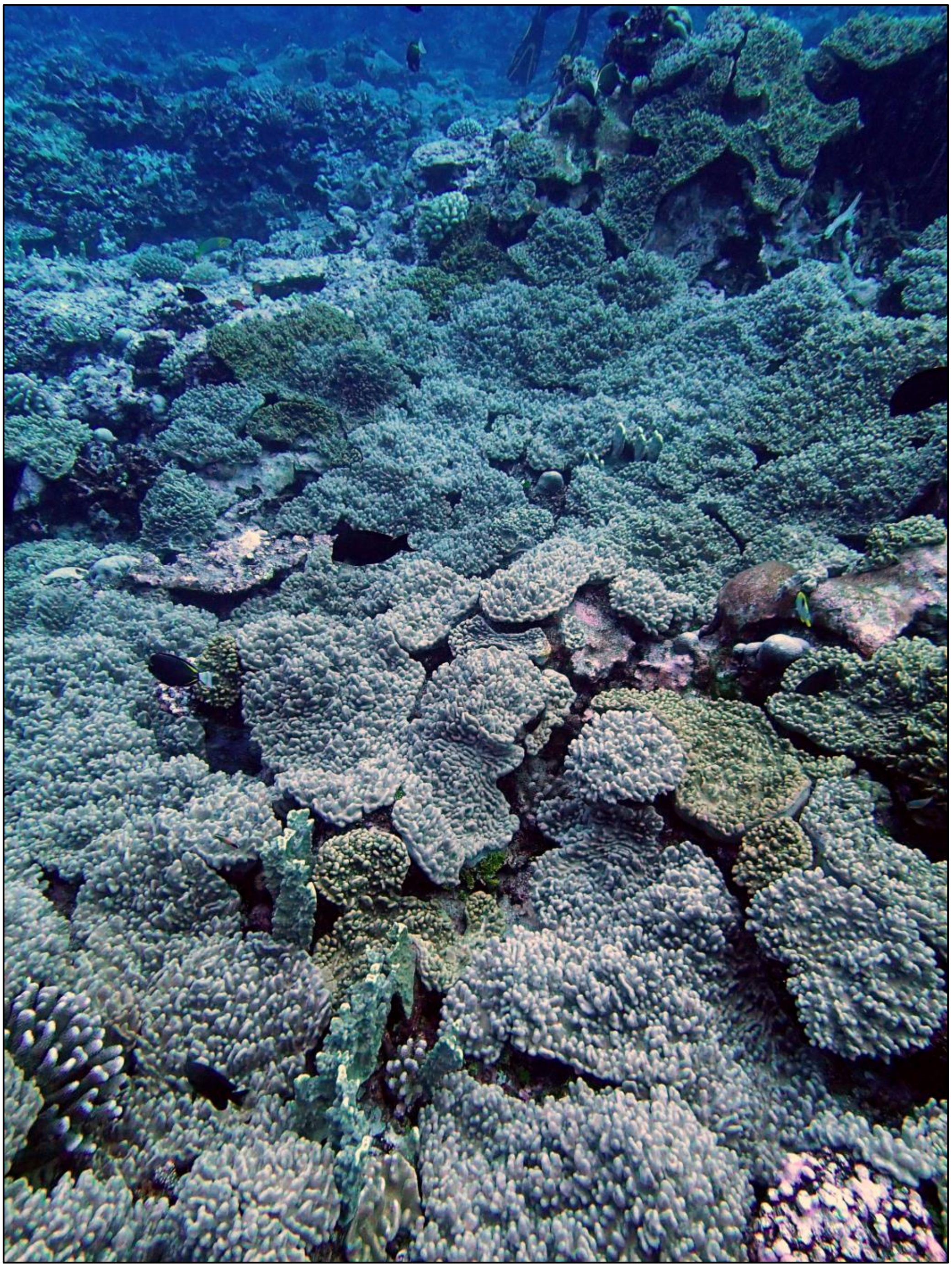


Figure 40 Soft coral was observed at all sites on Atiu, but more dominant at some locations on the leeward exposure. *Sinularia* spp. was the most dominant genera of soft coral on the fore reef of Atiu. Photo was taken by Teina Rongo at Site 4 on the leeward exposure.

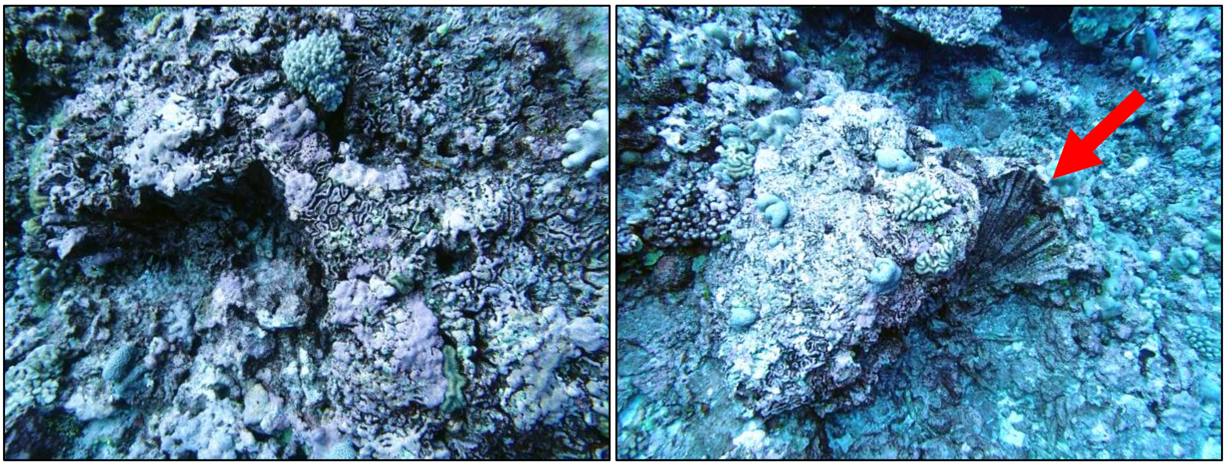


Figure 41. Large colonies of dead *Lobophyllia hemprichii* covered by CCA at Site 4 on the leeward exposure of Atiu. These dead skeletons provided some reef complexity on the fore reef for coral settlement as well as refuge for other organisms. Red arrow indicates sections of the dead colony that have broken off. Photos taken by Teina Rongo.

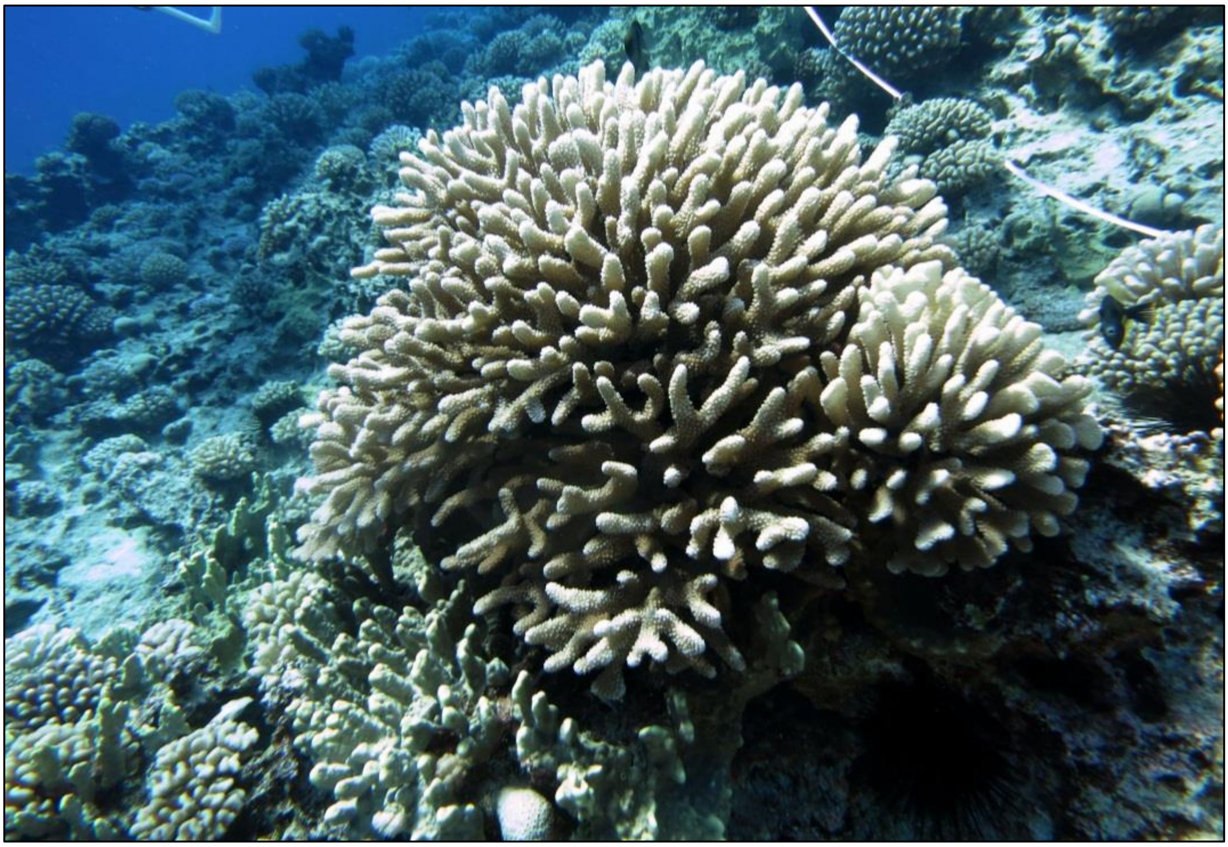


Figure 42. Large colonies of *Pocillopora* spp. were occasionally sighted along transects. The colony pictured was measured at around 2 m in diameter. Photo taken by Graham McDonald at Site 6 on the leeward exposure of Atiu.

2.5.3. Macro-invertebrate communities

The moderate long-spined urchin (*Echinothrix diadema*) (Figure 43) was abundant at all sites, with average density ranging from 51 ± 19 (SE) individuals per 100 m^2 at Site 4 to 104 ± 21 (SE) individuals per 100 m^2 at Site 5 (Figure 44). The extreme long-spined urchin (*Diadema savignyi*) had higher densities at Site 5 & 6 compared with all other sites, with average density at 66 ± 21 (SE) individuals per 100 m^2 and 62 ± 12 (SE) individuals per 100 m^2 respectively. The great worm-snail (*Dendropoma maxima*) had values below 22 ± 6 (SE) individuals per 100 m^2. Other invertebrates recorded but not plotted due to low numbers included the banded long-spined urchin (*Echinothrix calamaris*), the esculator urchin (*Echinostrephus aciculatus*), flatworms (*Pseudobiceros* spp.), the prickly redfish (*Thelenota ananas*), the trochus (*Tectus niloticus*), the hidden sea urchin (*Tripneustes gratilla*), the drupe (*Drupella* spp.), the daytime octopus (*Octopus cyanea*), and the fluted giant clam (*Tridacna squamosa*; Figure 45 *left*) (see *Appendix C*). While a few black teatfish (*Holothuria whitmaei;* Figure 45 *right*) were recorded on transects, these were occasionally sighted at depths > 10 m along reef slopes, with higher abundance observed on the leeward exposure.

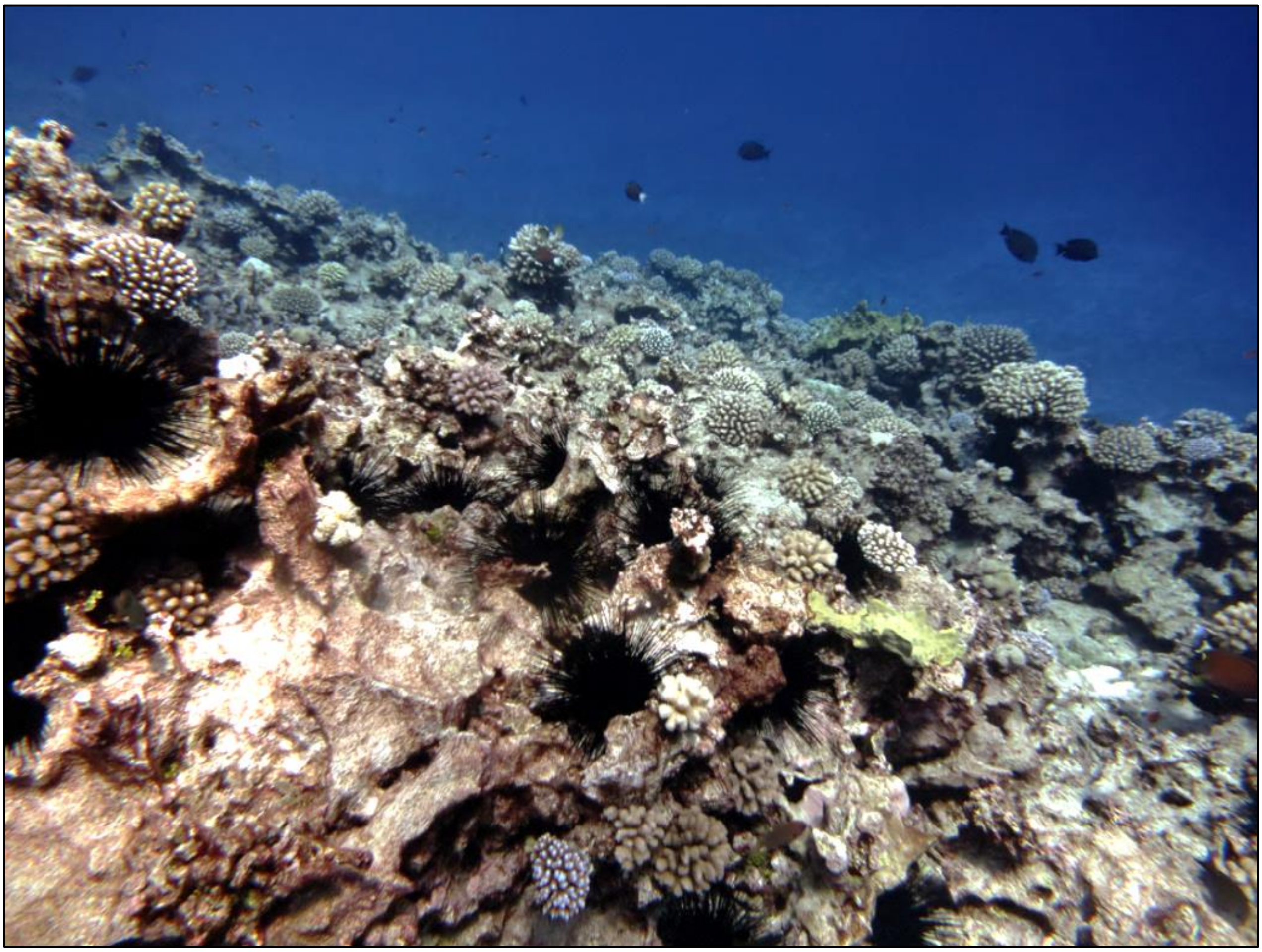


Figure 43. The moderate long-spined urchin (*Echinothrix diadema*) was one of the most common invertebrates on the fore reef of Atiu. Photo taken by Graham McDonald at Site 6 on the leeward exposure of Atiu.

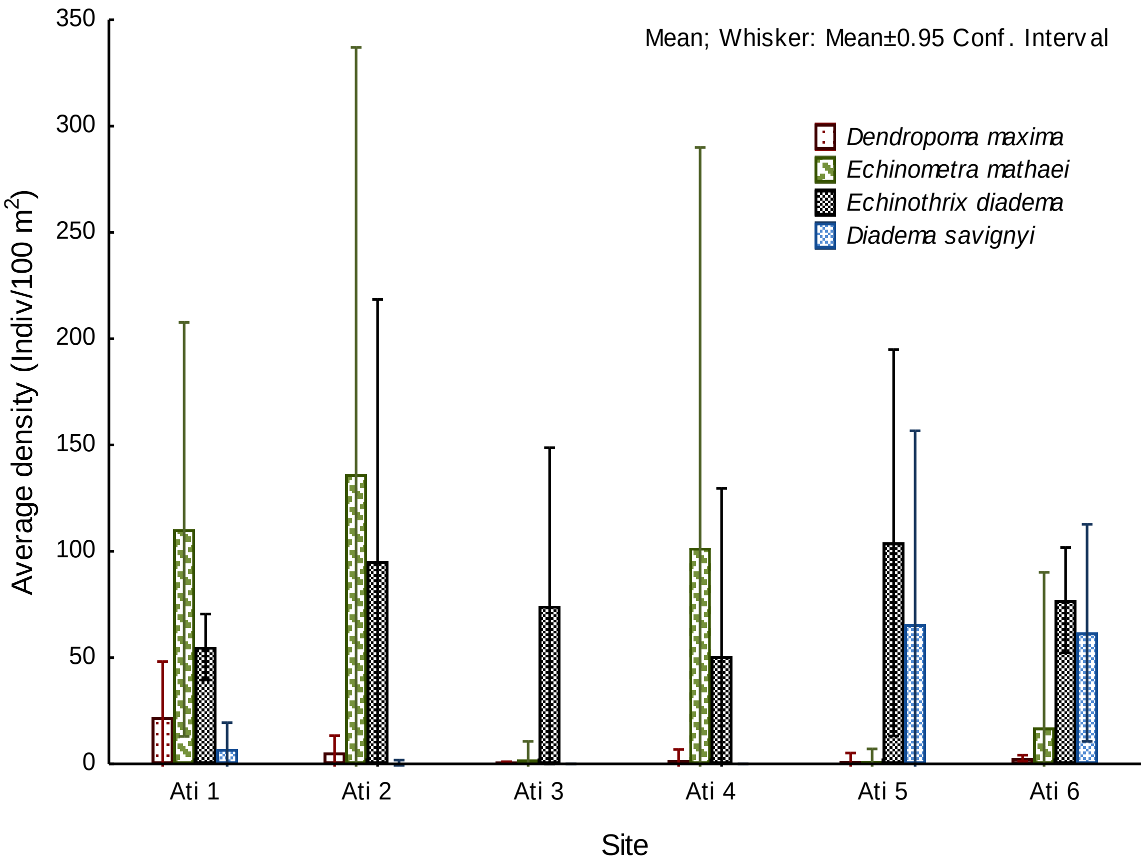


Figure 44. Average density of macro-invertebrates from six fore reef sites surveyed in Atiu in 2013.

Figure 45. *Left:* The fluted giant clam (*Tridacna squamosa*) wedged between two coral colonies of *Astreopora* and *Porites. Right:* The black teatfish (*Holothuria whitmaei*) was occasionally observed along the reef slopes of Atiu; the black teatfish is a commercially important sea cucumber to Asian markets. Photos taken at Site 2 by Teina Rongo.

2.5.4. Fish communities

Pomacentrids were the most common family at all sites, ranging from 115 ± 16 (SE) individuals per 250 m^2 at Site 3 to 205 ± 32 (SE) individuals per 250 m^2 at Site 5 (Figure 46). Acanthurids were also recorded at each site with an average density of 16 ± 5 (SE) individuals per 250 m^2 at Site 2 to 41 ± 9 (SE) individuals per 250 m^2 at Site 5. The average density of Labrids ranged from 21 ± 2 (SE) individuals per 250 m^2 at Site 1 to 53 ± 11 (SE) individuals per 250 m^2 at Site 6. A total of 76 fish species representing 19 families were recorded on Atiu (see *Appendix D*). Site 6 had the highest number of species, number of individuals, species richness, evenness, and species diversity (Table 8).

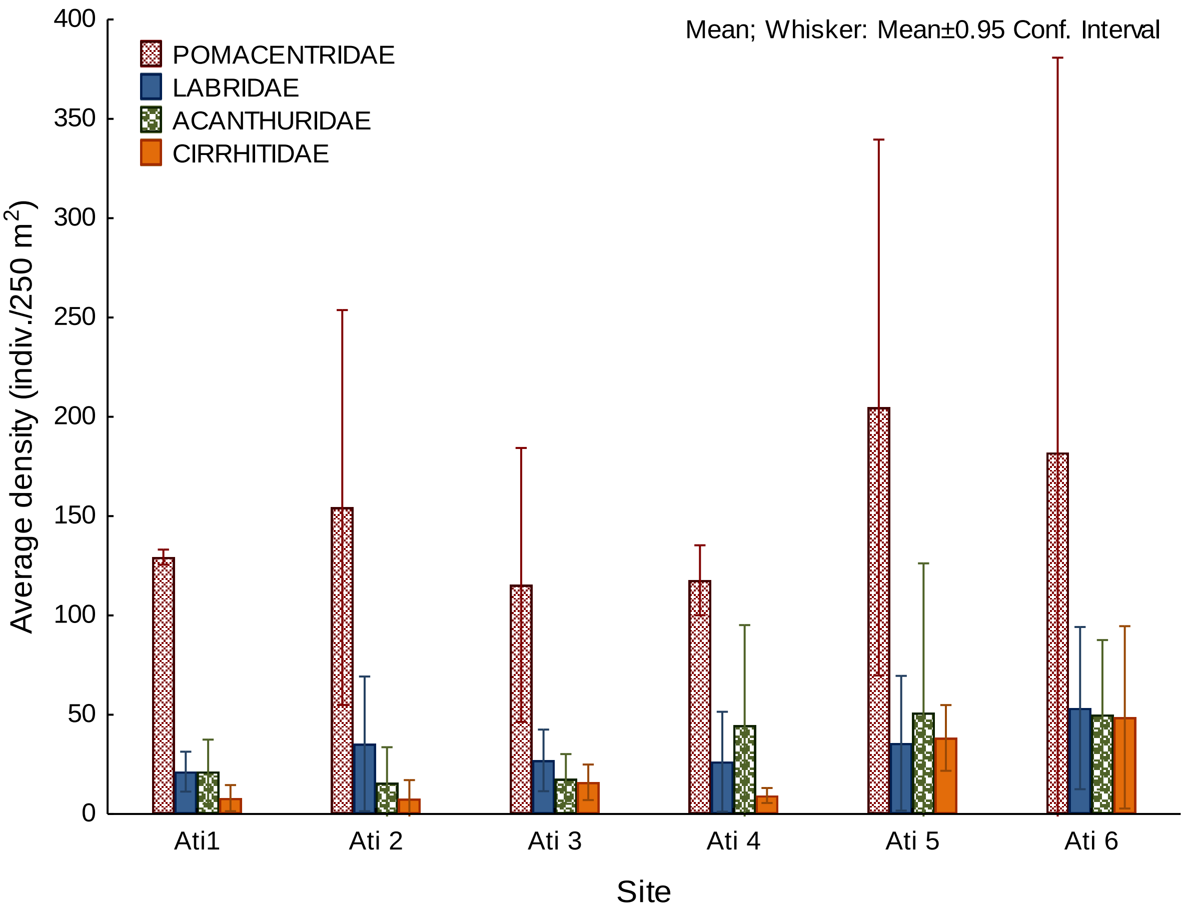


Figure 46. Average density of fish by family (Pomacentridae, Labridae, Acanthuridae, and Cirrhitidae) from six fore reef sites surveyed in Atiu in 2013.

Table 8. Species diversity of fish at sites surveyed in Atiu in 2013. S is the total number of species; N is the number of individuals; d is the Margalef's species richness; J' is Pielou's evenness; H' is the Shannon-Wiener diversity index. Red number indicates highest in each category.

Site	S	N	D	J'	H'(loge)
Ati 1	33	599	5.004	0.713	2.493
Ati 2	40	685	5.973	0.6785	2.503
Ati 3	35	581	5.342	0.6692	2.379
Ati 4	38	754	5.585	0.7188	2.615
Ati 5	35	1075	4.871	0.7208	2.563
Ati 6	51	1179	7.070	0.7666	3.014

2.5.5. Discussion

Although Atiu's fore reefs appear to be recovering, with no prior knowledge of these reefs, we could only make inferences based on our data about the former state of these reefs and what might have impacted them in the past. Yet, complex reef structures noted on the leeward exposure of the island suggest that a much healthier reef used to exist. While the genus *Pocillopora* was recorded as the most common coral, with some colonies reaching an impressive diameter of 2 m, *Acropora* species were also common. However, there was a disparity in colony sizes between the two families (most Acroporids were < 16 cm in diameter while large colonies of Pocilloporids were common), which suggests that a COTS outbreak may have occurred within the last decade (assuming the growth rate of these coral species is 1 cm/year). COTS have been reported to have a lower preference for Pocilloporids because they host a species of crab (e.g., *Trapezia*) that aggressively defend their coral host from COTS predation (e.g., Weber & Woodhead 1970; Glynn 1976; Pratchett & Vytopil, 2000). This may explain the large colonies of *Pocillopora* observed on the fore reefs of Atiu. Although COTS outbreaks tend to be associated with high nutrient levels from anthropogenic sources (Birkeland, 1982; Brodie, et al., 2005), such a scenario is unlikely for Atiu considering the small human population on the island. Monitoring these reefs may help us understand the natural variables that may trigger an outbreak of COTS to occur on such an island with minimal human impacts.

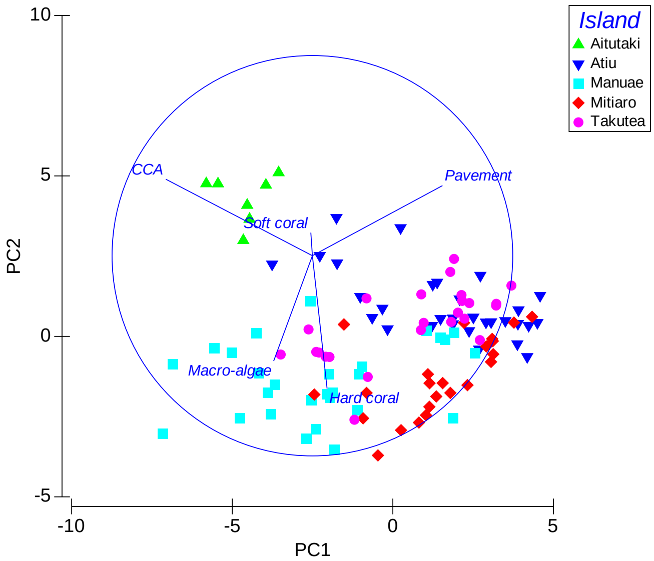
The high abundance of herbivorous fish species (Scarids and Acanthurids) recorded on Atiu is of interest. In particular, there were more *Ctenochaetus striatus* on the fore reef of Atiu than the other islands surveyed on this expedition. *C. striatus* has been reported as an important primary vector for ciguatoxin into the food web (Yasumoto et al., 1971), and their abundance on the fore reef could lead to higher incidence of ciguatera poisoning, especially after major disturbances such as cyclones (e.g., Rongo & van Woesik, 2013). Notably, Atiu is the only island of the *Ngaputoru* group that has continued (although in low numbers) to report cases of ciguatera poisoning since initial reporting on this island in the early 1980s (Losaker, 1992).

The high abundance of the black teatfish (*Holothuria whitmaei*) found on the deeper slopes, particularly on the leeward exposure of Atiu, was interesting. This commercially important species was not common on the other islands surveyed. Urchins were the most abundant macro-invertebrate on Atiu, with densities ranging from 51 to 104 individuals per 100 m^2 for the moderate long-spined urchin (*Echinothrix diadema*) alone. The moderate long-spined urchin (*Echinothrix diadema*) and the extreme long-spined urchin (*Diadema savignyi*) were particularly common at both sites around Atiu Harbour on the leeward exposure. This was similar to what was observed on Mitiaro where most of these species were recorded around Mitiaro Harbour on the leeward exposure. In the outer islands, harbours are important sites for recreational and commercial activities (e.g., boating, shipping, fishing, and swimming) that could potentially impact the health of the reefs in the surrounding area.

3. OVERALL COMPARISON

3.1. BENTHIC COMMUNITIES

Principle Component Analysis for benthic communities revealed that Mitiaro was the island with the highest hard coral cover (Figure 47 *left*). Manuae had the highest cover of macro-algae, and Aitutaki the highest cover of crustose coralline algae. Eigenanalysis of the PCA for all categories of benthic communities showed that 98% of the variation was explained in the first three axes (Table 9). The average coral cover for each island was estimated at 21% for Atiu, 33% for Manuae, 34% for Mitiaro, and 22% for Takutea (Figure 46 *right*). In 2011, the average coral cover for Rarotonga was 10% (Rongo & van Woesik, 2013). Using the average coral cover of 22.1% in 2003 estimated from 2,667 reefs within the Indo-Pacific (Bruno & Selig, 2007), we see that Atiu and Takutea were close to this average while Manuae and Mitiaro were well above; Rarotonga's reefs were still recovering in 2011 (Figure 47 *right*).



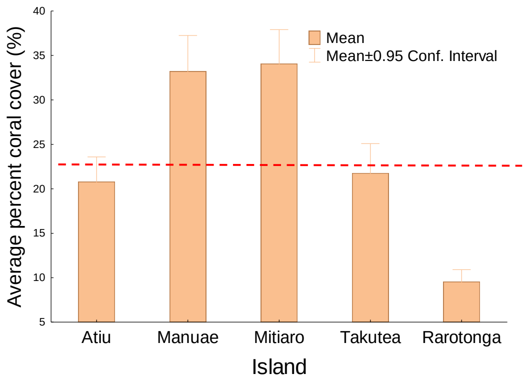


Figure 47. *Left*: Principle Component Analysis (PCA) for benthic communities using all replicates for all islands. Ordination of replicates were superimposed on the vector plot. Square root transformation was carried out on the data before PCA. Islands are colour-coded for better graphical representation. *Right*: Average percent coral cover for all islands in 2013. Coral cover for Rarotonga was taken from the 2011 survey (Rongo & van Woesik, 2013); all replicates from each site were used to generate this plot for each island. Dotted red line represents the Indo-Pacific average coral cover of 22.1% in 2003 (Bruno & Selig. 2007).

Table 9. Eigenvalues and Eigenvectors for the Principle Component Analysis for benthic communities using all replicates for all islands. Red number indicates highest value in each axis.

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	813	68.4	68.4
2	276	23.2	91.7
3	72.5	6.1	97.8

Eigenvectors

Variable	PC1	PC2	PC3
Crustose coralline algae	-0.616	-0.572	0.540
Pavement	0.784	-0.436	0.422
Macro-algae	-0.080	0.142	-0.007
Soft coral	-0.007	-0.017	0.001
Hard coral	0.001	0.680	0.728

Principle Component Analysis for hard corals by genus indicated that Mitiaro's reefs were dominated by the hard coral *Astreopora* (mainly *A. expansa*), while branching corals from the genus *Pocillopora* as well as *Millepora* species dominated the reefs of Takutea and Atiu (Figure 48). Manuae had high cover of corals from the genera *Favia*, *Montipora*, and *Porites*, primarily the massive growth forms. Eigenanalysis of the PCA for all coral families showed that 78% of the variation was explained in the first four axes (Table 10). Eigenvector results showed that *Astreopora* had the most weight on the first axis, *Favia* on the second axis, *Pocillopora* on the third axis, and *Porites* on the fourth axis.

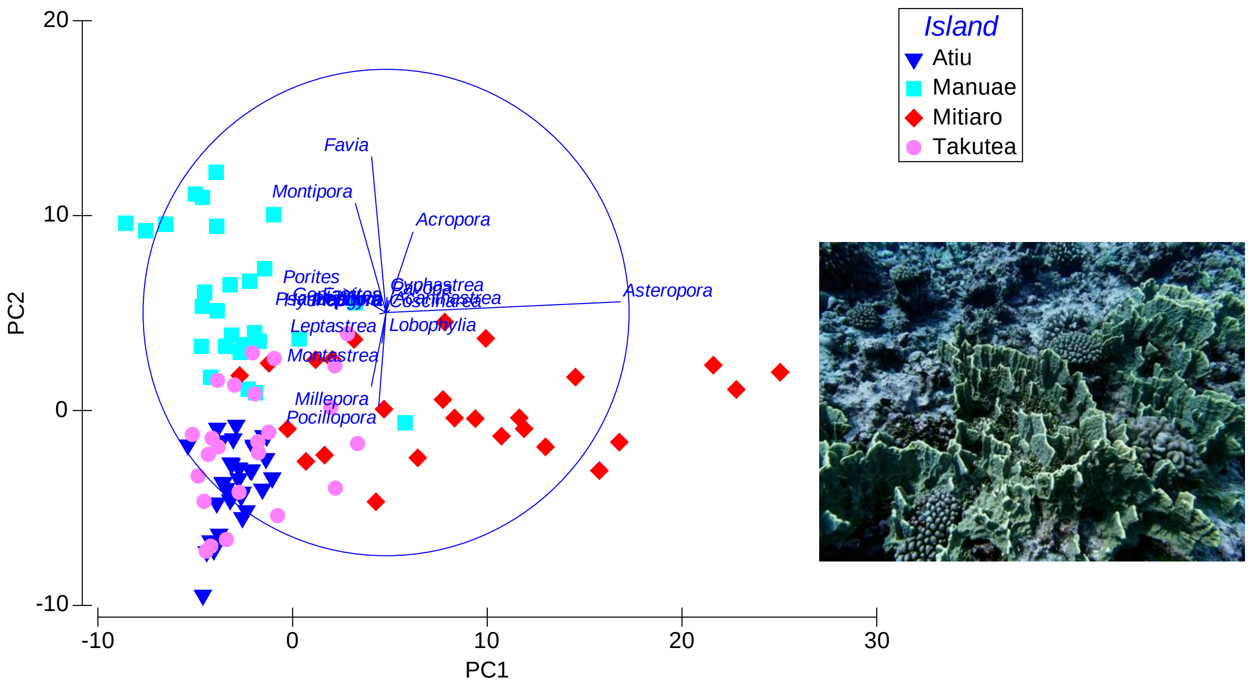


Figure 48. Principle Component Analysis (PCA) for hard corals by genus using all replicates for all islands. Ordination of replicates were superimposed on the vector plot. No transformation was carried out on the data before PCA. All coral genera from the point quadrat data was used to generate this PCA. Islands are colour-coded for better graphical representation. *Insert*: Colony of *Millepora platyphylla* (fire coral), common on the fore reefs of Atiu and Takutea; taken by Teina Rongo.

Table 10. Eigenvalues and Eigenvectors for the Principle Component Analysis for hard corals by genus using all replicates for all islands. Red number indicates highest value in each axis.

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	40.4	33.9	33.9
2	20.5	17.2	51.1
3	18.2	15.3	66.4
4	13.8	11.5	77.9

Eigenvectors (Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3	PC4
Pocillopora	0.030	0.384	-0.858	0.304
Acropora	-0.111	-0.332	-0.206	-0.066
Asteropora	-0.965	-0.044	0.028	0.202
Porites	0.175	-0.099	0.256	0.910
Favia	0.060	-0.641	-0.355	-0.038
Montipora	0.127	-0.450	-0.020	0.154
Millepora	0.061	0.305	0.158	-0.010
Montastrea	0.018	0.127	-0.009	0.046

Size class percent contribution for all islands showed a right-skew distribution (predominantly smaller colonies < 16 cm) for Atiu, Takutea, and Mitiaro, and a left-skew distribution (predominantly larger colonies, and very few recruits < 4 cm) for Manuae (Figure 49). Notably, Atiu showed a higher contribution in the smaller size classes (see Figure 49; Figure 50). The PCA bubble vector plot clearly indicates this shift in size class distribution (Figure 51). Class A colonies (< 4 cm in geometric diameter) were dominant in Atiu, Takutea, and Mitiaro (see Figure 51*a*), while Manuae had the highest densities of class D colonies (16 to < 32 cm in geometric diameter) (see Figure 51*b*). Eigenanalysis of the PCA for all size classes showed that 96% of the variation was explained in the first three axes (Table 11).

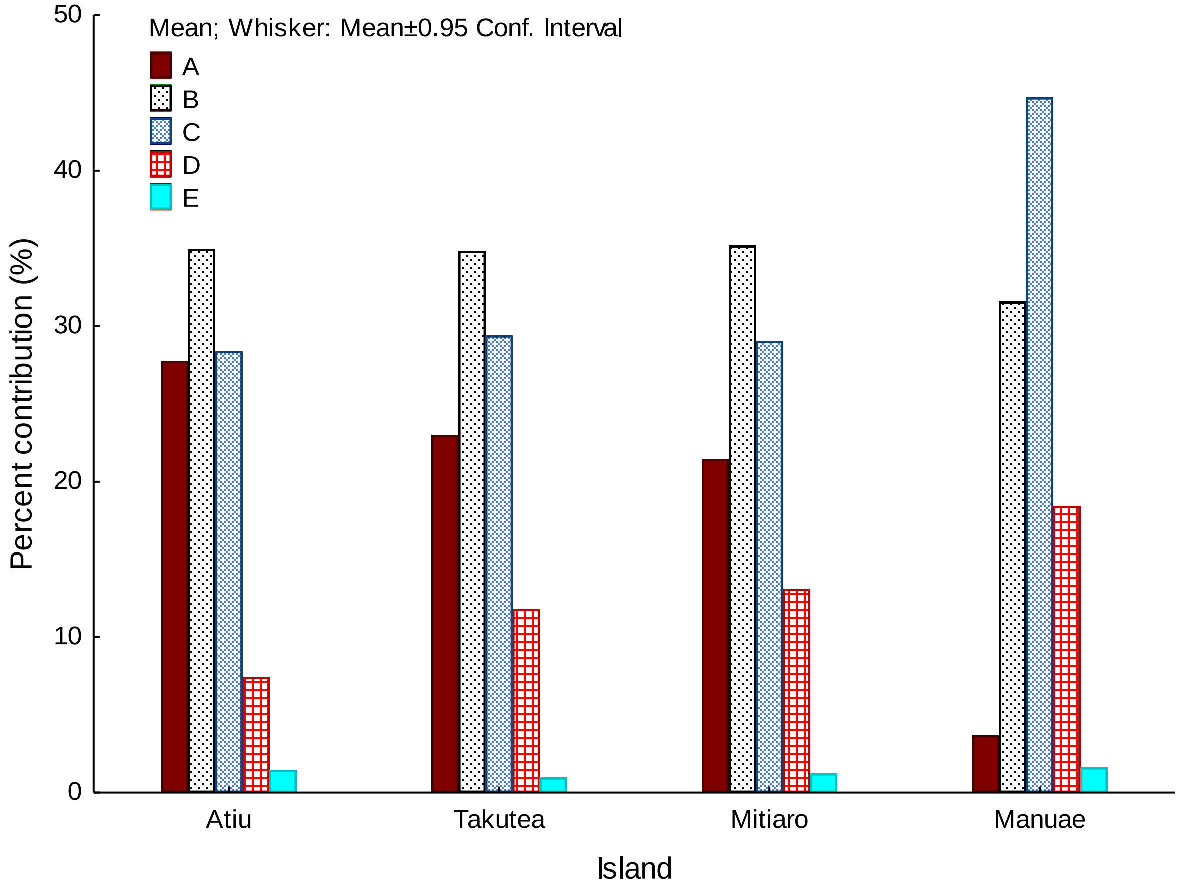
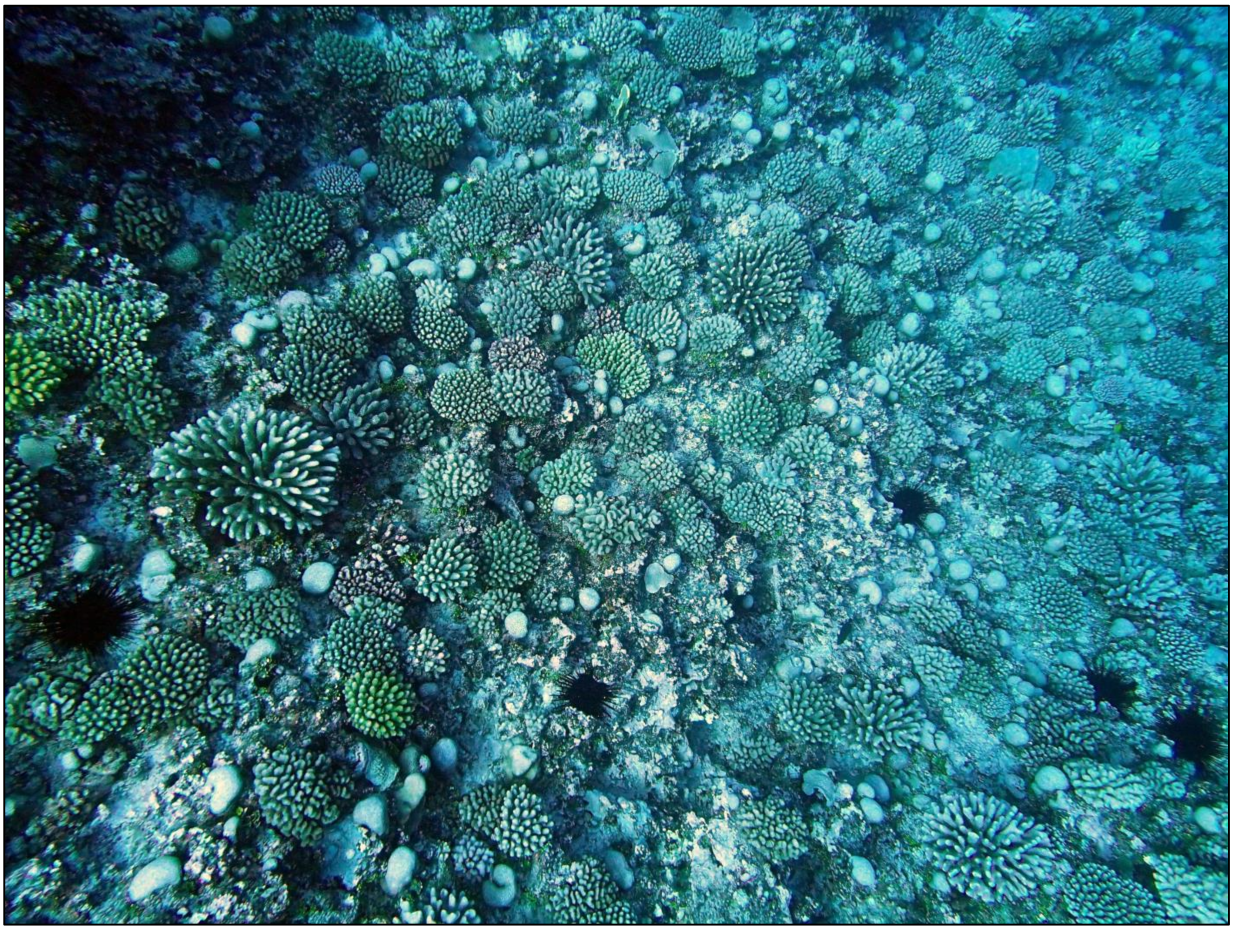


Figure 49. Average coral density by size class; A (< 4 cm), B (4 to < 8 cm), C (8 to < 16 cm), D (16 to < 32 cm) and E (≥ 32 cm) for hard corals using all replicates for all islands.



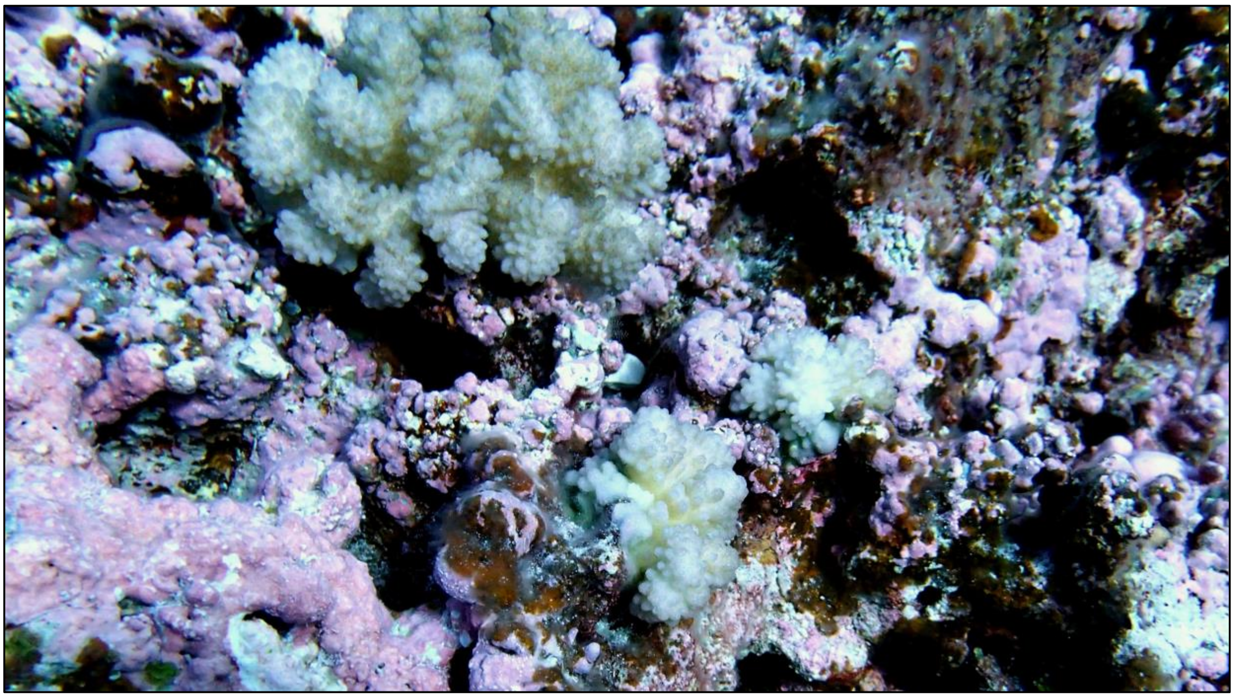


Figure 50. *Top:* Fore reef of Atiu showing dense community of smaller colonies of predominantly *Acropora* cohorts at Site 3 (depth of ~ 11 m), indicated here as the smaller digitate colonies. Larger digitate colonies are species of *Pocillopora*, and smaller massive colonies are *Montastrea curta*. *Bottom: Pocillopora* spp. recruits at Site 2. Photos taken by Teina Rongo.

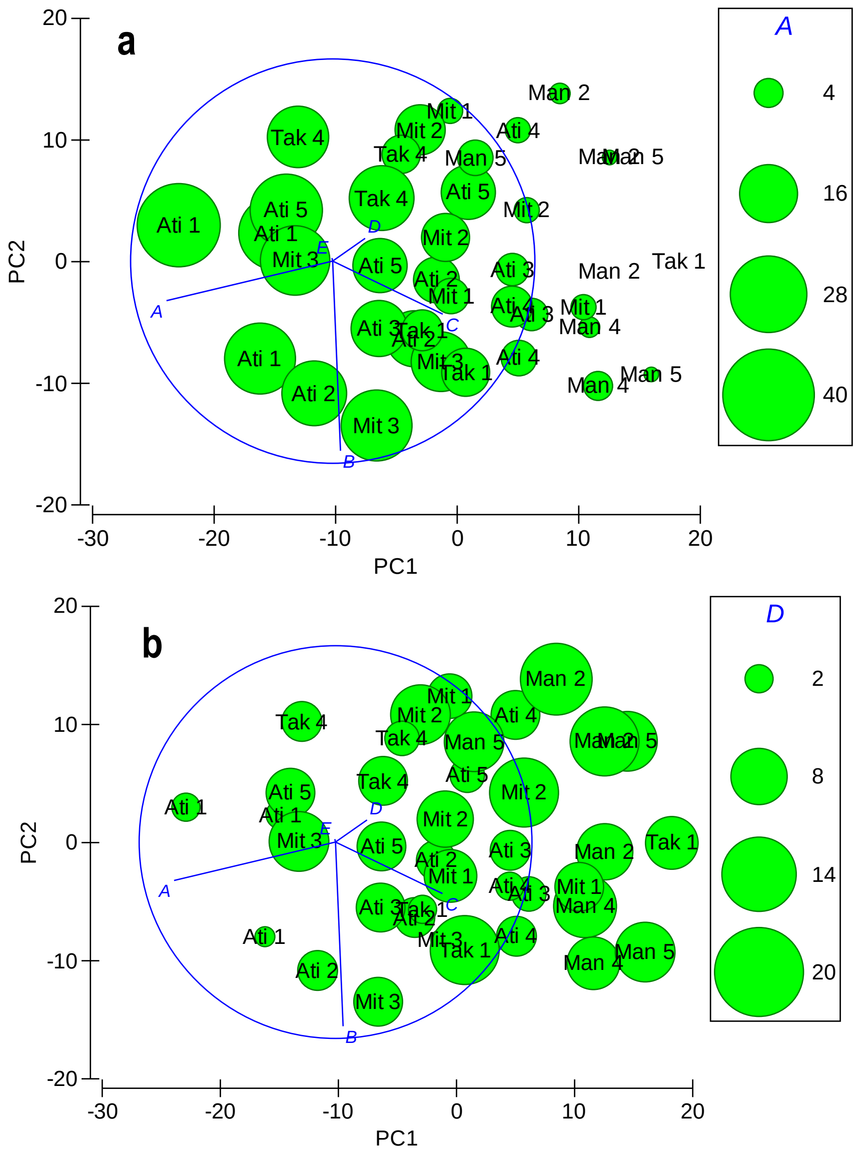


Figure 51. Principle Component Analysis (PCA) for the size classes of hard corals using all replicates for all islands. Ordination of replicates were superimposed on the vector plot. The relative size of each bubble represents the relative density (individuals per 36 m^2) of colonies in: (a) size class A (< 4 cm in geometric diameter), and (b) size class D (16 to < 32 cm in geometric diameter) for each transect. No transformation was carried out on the data.

Table 11. Eigenvalues and Eigenvectors for the Principle Component Analysis for the size classes of hard corals using all replicates for all islands. Size classes were sorted into four categories based on geometric diameter: A (< 4 cm), B (4 to < 8 cm), C (8 to < 16 cm), D (16 to < 32 cm), and E (≥ 32 cm). Red number indicates highest value in each axis.

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	98.2	49.4	49.4
2	55.6	28.0	77.3
3	36.9	18.6	95.9

Eigenvectors (Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3
A	-0.822	-0.196	0.506
B	0.038	-0.938	-0.332
C	0.545	-0.262	0.795
D	0.161	0.112	-0.028
E	-0.003	0.015	-0.026

3.2. MACRO-INVERTEBRATE COMMUNITIES

Principle Component Analysis with vector plot superimposed indicated that giant clam *Tridacna* spp. were dominant on Manuae (Figure 52). The moderate long-spined urchin (*Echinothrix diadema*) and the extreme long-spined urchin (*Diadema savignyi*) had more weight on Atiu and Mitiaro; Eigenvector values indicated that both macro-invertebrates had more weight on the second and third axes respectively (Table 12). Eigenanalysis of the PCA for all invertebrate groups showed that 83% of the variation was explained in the first three axes (Table 12).

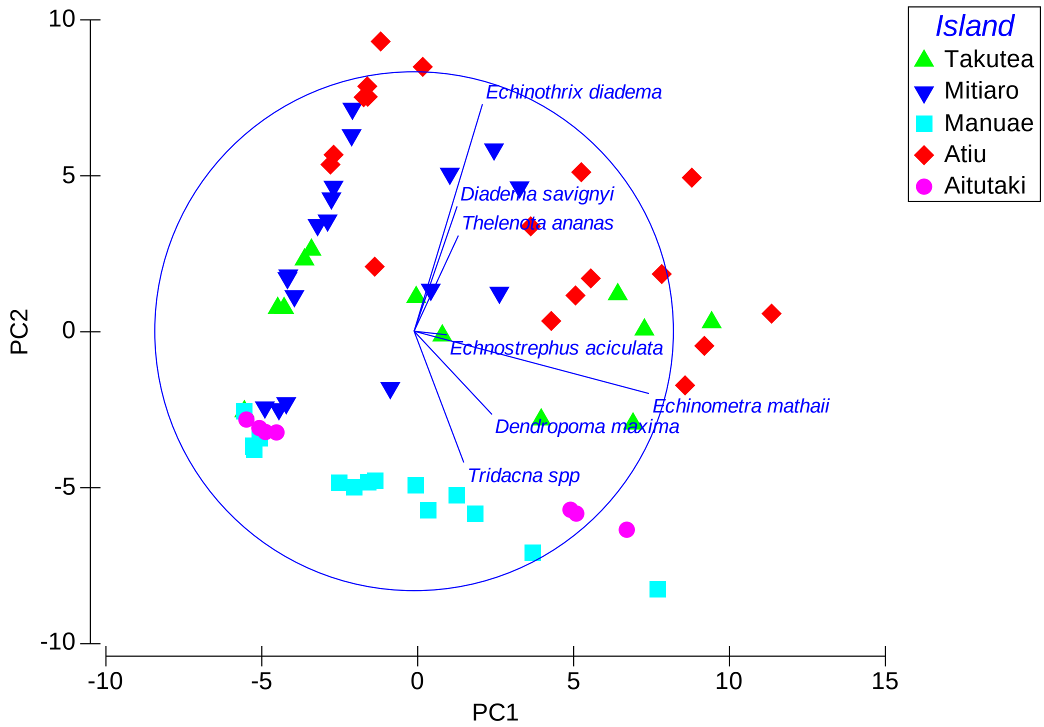


Figure 52. Principle Component Analysis (PCA) for macro-invertebrates using all replicates for all islands. Ordination of replicates were superimposed on the vector plot. Square root transformation was carried out on the data before PCA. Islands are colour-coded for better graphical representation.

Table 12. Eigenvalues and Eigenvectors for the Principle Component Analysis for macro-invertebrates using all replicates for all islands. Red number indicates highest value in each axis.

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	22.2	39.2	39.2
2	18.7	33.0	72.3
3	6.04	10.6	82.9

Eigenvectors (Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3
Tridacna spp.	0.066	-0.261	-0.182
Dendropoma maxima	0.169	-0.111	-0.100
Echinometra mathaei	0.925	-0.269	0.120
Echinostrephus aciculata	0.134	0.027	-0.434
Echinothrix diadema	0.276	0.856	0.302
Thelenota ananas	0.016	0.036	-0.011
Diadema savignyi	0.132	0.335	-0.814

3.3. FISH COMMUNITIES

Principle Component Analysis for fish by family indicated that Pomacentrids and Anthiinids were most important on Manuae and Mitiaro (Figure 53, 54*a*). Acanthurids were most important on Atiu, Takutea, and Mitiaro (see Figure 54*b*). Eigenanalysis of the PCA for all families showed that 79% of the variation was explained in the first three axes (Table 13). For all islands, *Ctenochaetus striatus* was the most common, particularly on Atiu (Figure 55; see also *Appendix D*).

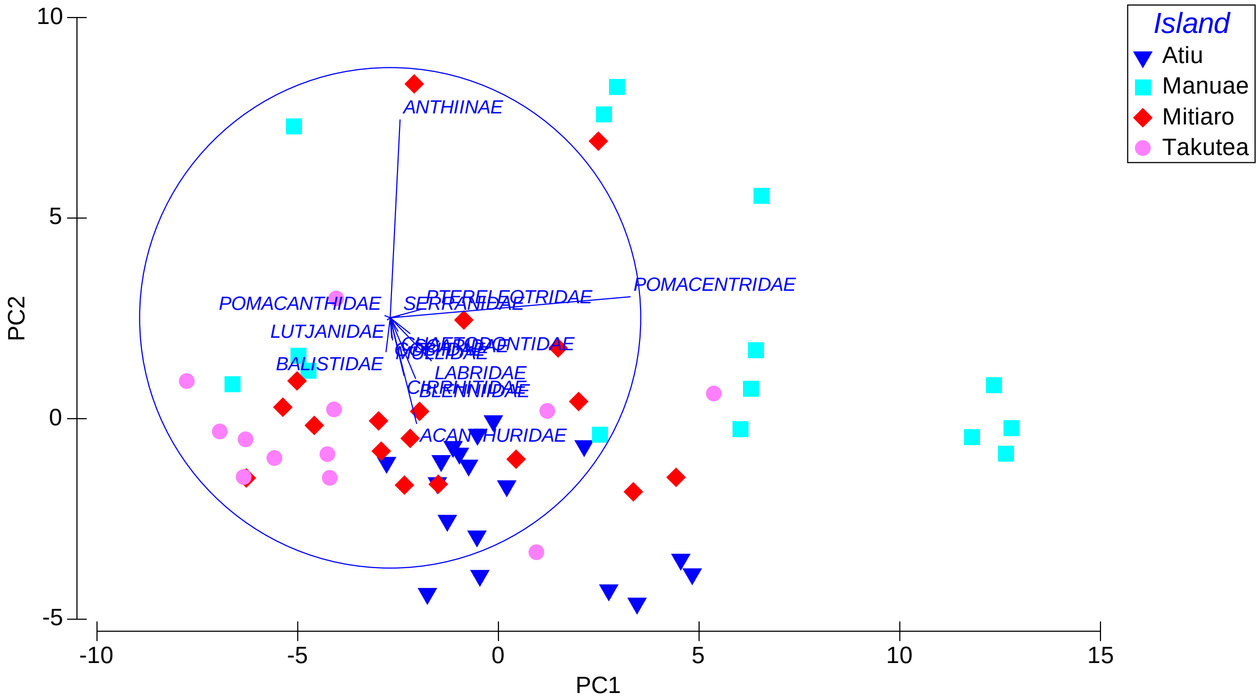


Figure 53. Principle Component Analysis (PCA) for fish by family using all replicates for all islands. Ordination of replicates were superimposed on the vector plot. Square root transformation was carried out on the data before PCA. Islands are colour-coded for better graphical representation.

Table 13. Eigenvalues and Eigenvectors for the Principle Component Analysis for fish families using all replicates for all islands.

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	24.5	51.0	51.0
2	8.35	17.4	68.4
3	5.07	10.6	79.0

Eigenvectors (Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3
POMACENTRIDAE	0.959	0.084	-0.148
LABRIDAE	0.166	-0.173	0.121
ACANTHURIDAE	0.106	-0.424	0.669
CIRRHITIDAE	0.055	-0.231	0.155
ANTHIINAE	0.039	0.793	0.581
BLENNIIDAE	0.102	-0.244	0.227
POMACANTHIDAE	-0.023	0.010	0.105
CHAETODONTIDAE	0.032	-0.055	0.194
SERRANIDAE	0.038	0.009	-0.067
PTERELEOTRIDAE	0.127	0.035	-0.030
BALISTIDAE	-0.017	-0.137	0.183
SCARIDAE	0.080	-0.063	0.011

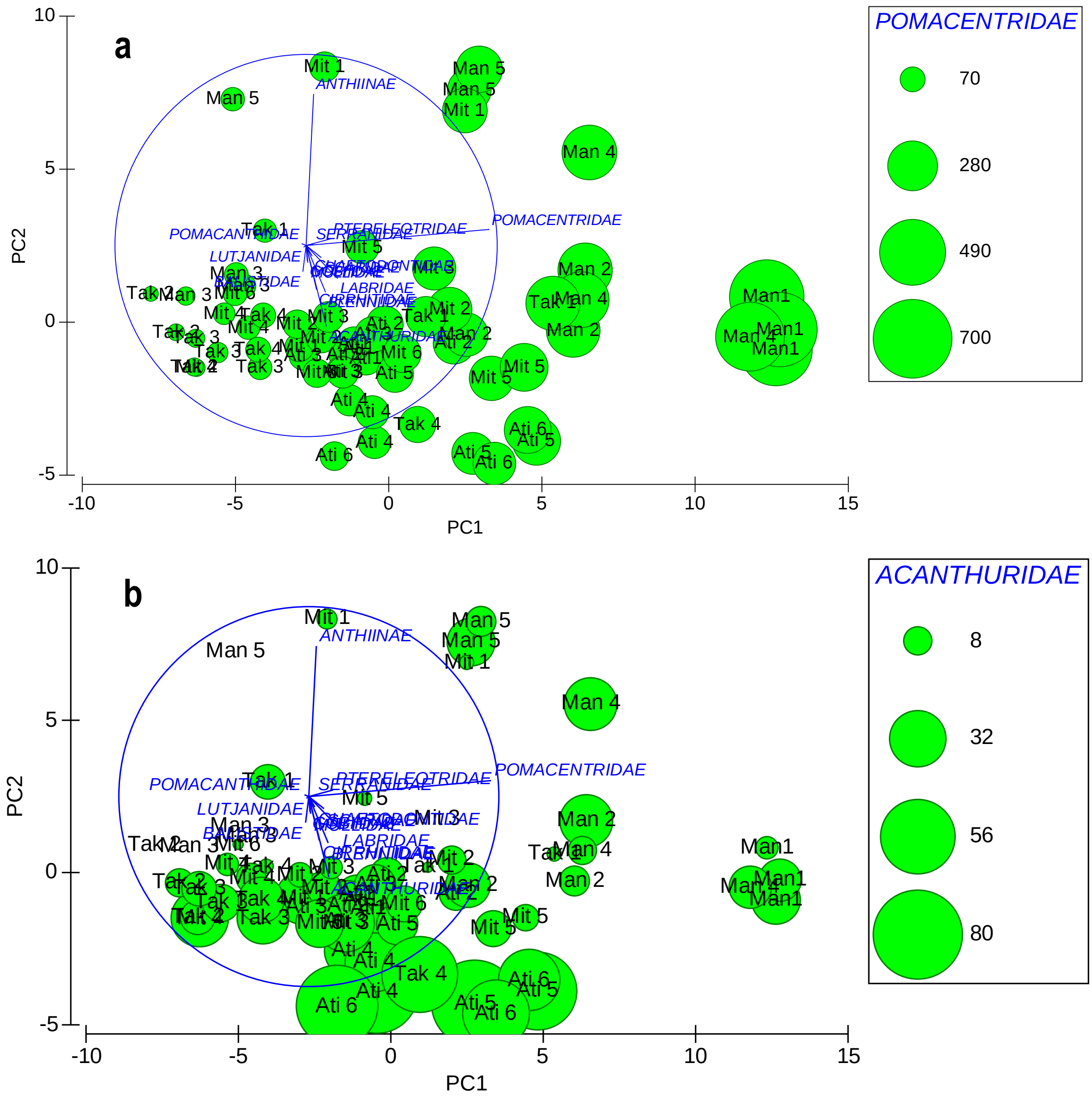


Figure 54. Principle Component Analysis (PCA) for fish families using all replicates on each islands. Ordination of replicates were superimposed on the vector plot. The size of bubbles indicate the relative abundance (individuals per 250 m^2) of: a) Pomacentrids, and b) Acanthurids for each replicate. Replicates are identified by the first three letters of each island followed by the site number. Square root transformation was implemented before PCA construction.

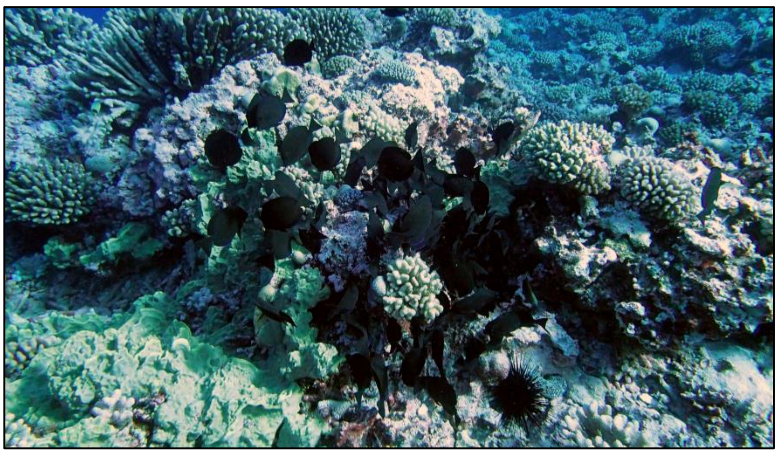


Figure 55. School of *Ctenochaetus striatus* grazing at Site 4 on the leeward exposure of Atiu. Photo taken by Graham McDonald.

4. SUMMARY

The coral communities on the fore reefs of Manuae, Mitiaro, Takutea, and Atiu were relatively healthy, showing good coverage of hard corals. Recovery on Atiu and Takutea's reefs were well underway, with average hard coral cover around the Indo-Pacific average of 22.1% estimated from 2,667 coral reefs in 2003 (Bruno & Selig., 2007); average cover on Manuae and Mitiaro were well above this average. Indicators of healthy reefs on these islands also included the abundance of the coral-associated fish family Pomacentrids, high cover of crustose coralline algae, and low cover of macro-algae. Coral communities were very similar on these islands in terms of species composition (except Atiu), attributed to the dominance of a few species of hard coral – such as the platy coral *Astreopora expansa* on steeper reef slopes – which thus far appear to be unique to these islands. Despite low abundance of herbivorous fish species noted, this was unlikely the result of overfishing as human population is low on these islands and fishing activities have declined overall.

Interestingly, coral stressors (i.e., COTS infestation and coral disease) and recovery seem to have some geographical pattern, with both occurring in a southeastward direction from Aitutaki towards Manuae, Mitiaro, Takutea, and Atiu. Though limited historical information and baseline data exists for this chain of islands, seemingly these islands have gone through a cycle of disturbance with recovery well underway. Yet, a subsequent round of disturbance has commenced in this southeastward direction, with Aitutaki showing a significant decline in coral cover since the last fore reef survey in 2008 (Rongo, 2008), and Manuae (the next island in the chain) showing signs of stress related to coral disease and COTS predation.

Coral colony size information followed this southeastward pattern as well, suggesting that recovery is also occurring in this direction. For example, there was a left-skew distribution (higher density of larger, older colonies) in the northernmost island Manuae, and a right-skew distribution (higher density of smaller colonies or recruits) in the southernmost islands Atiu, Mitiaro, and Takutea. It will be of interest to examine Mauke's reefs (the furthest island southeast in this chain not surveyed during this expedition) that should show higher densities of smaller colonies as this reef would have been the last in this chain to have gone through the previous cycle of reef disturbance.

Although COTS outbreaks have been reported in Aitutaki, without any prior information, it is difficult to determine whether outbreaks are indeed an important disturbance on the other islands. Outbreaks of COTS are often associated with runoff nutrients from human activities (e.g., Birkeland, 1982; Brodie et al., 2005). However, natural upwelling zones can also be a source of nutrients for COTS outbreaks to occur, particularly on remote islands (Houk et al., 2007). A plethora of literature support COTS outbreaks caused by anthropogenic inputs, however outbreaks on uninhabited islands (e.g., Manuae) nowhere near upwelling areas may be difficult to explain.

Manuae is less than 87 km southeast of Aitutaki, and a northwestward current observed in 2005 between the two islands has drawn suggestion that Manuae could potentially be a source population for Aitutaki (Rongo et al., 2005). On the contrary, hydrodynamic studies around Aitutaki (e.g., Damlamian and Kruger, 2010) showed that while a northwestward current predominates from April to November, the dominant current flow during spawning months (December to March) in this region is southeastward. In support, a larval distribution model has suggested a southeastward pattern of distribution (e.g., Treml et al., 2008), which strongly supports the results of this survey that showed a similar pattern regarding coral stress and recovery. With Aitutaki currently experiencing a COTS outbreak, it is likely that such a southeastward flow could supply COTS larvae to Manuae or even to islands south of this chain. Therefore the COTS outbreak observed on Manuae may be a result of this supply, and could potentially cascade down the rest of the island chain. Aitutaki is the most populated island in this island chain (Cook Islands Census, 2011) that has been experiencing increased development over the years, largely to meet the demand of the tourism industry. Consequently, lagoon water quality over the years has degraded, particularly in terms of nutrient levels and Total Suspended Solids (e.g., Anderson et al., 2004; Turua et al., 2006). Perhaps a bottom-up control of nutrients and a better management of dredging activities on Aitutaki may be critical not only during this reef recovery period for the island, but for the health of coral reefs on islands southeast of Aitutaki.

Coral disease noted on Manuae may also be a result of the island's close proximity to Aitutaki. Coral disease such as the yellow-band disease (a likely candidate for the disease recorded in Manuae) has been linked to anthropogenic nutrient inputs (Bruno et al., 2003). Again, with no anthropogenic nutrient inputs on uninhabited Manuae, both nutrients and the disease may be sourcing from Aitutaki. However, the effect of elevated temperatures on coral disease cannot be ruled out (e.g., Ward and Lafferty 2004). Considering the potential impact of climate change to marine organisms, it is possible that this impact is already taking effect. A more detailed study of this disease would be critical at this stage to elucidate the causes and the extent of the damage and distribution in this group of islands. Indeed, connectivity studies and information from regular monitoring of these reefs will certainly help us understand how these islands influence each other, which would feed into an effective management plan for these delicate ecosystems within the Cook Islands Marine Park.

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The CIMP research team also acknowledges the people of Aitutaki, Mitiaro, and Atiu, and the landowners of Manuae and Takutea for their permission to conduct our research activities. We are also very grateful for the hospitality shown to us when we were hosted on the various islands.

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The CIMP research team consisted of:

- Dr. Teina Rongo (Head Researcher; Office of the Prime Minister) – benthic communities & fish
- Jacqueline Evans (Te Ipukarea Society) – benthic communities
- Kelvin Passfield (Te Ipukarea Society) – benthic communities
- Jessica Cramp (Oceans 5) – fish
- Dr. Mareike Sudek (Pacific Islands Conservation Initiative) – benthic communities
- Ben Tautu (National Environment Service) – macro-invertebrates
- Graham McDonald (volunteer) – fish
- Teariki Charles Rongo (volunteer) – macro-invertebrates
- Barbara Hanchard (volunteer) – benthic communities

The Cook Islands Marine Park research team aboard Pacific Diver's boat. *From left to right*: Mareike Sudek, Ben Tautu, Jessica Cramp, Graham McDonald, Jacqueline Evans, Teina Rongo, Kelvin Passfield, and Teariki Charles Rongo. *Insert:* Barbara Hanchard; photo provided by Jessica Cramp.

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APPENDICES

Appendix A. Global Positioning System coordinates for fore reef sites surveyed on each island in the southern Cook Islands visited on this expedition from 28 July to 9 August 2013.

Island	Site name	Date surveyed	GPS Coordinates
Aitutaki	Ait 1	28/07/2013	18°50'32.10" S; 159°48' 03.23" W
	Ait 2	29/07/2013	18°52'48.19" S; 159°49' 12.93" W
Manuae	Man 1	30/07/2013	19°15'36.46" S; 158°58' 02.69" W
	Man 2	30/07/2013	19°15'44.83" S; 158°58' 10.33" W
	Man 3	30/07/2013	19°17'17.05" S; 158°57' 36.49" W
	Man 4	31/07/2013	19°14'52.59" S; 158° 56' 21.95" W
	Man 5	31/07/2013	19°15'03.50" S; 158° 56' 52.43" W
Mitiaro	Mit 1	1/08/2013	19°50'53.37" S; 157° 43' 19.38" W
	Mit 2	1/08/2013	19°52'58.17" S; 157° 43' 21.53" W
	Mit 3	2/08/2013	19°50'16.10" S; 157° 42' 33.63" W
	Mit 4	2/08/2013	19°53'48.93" S; 157° 42' 11.18" W
	Mit 5	3/08/2013	19°51'42.77" S; 157° 43' 21.47" W
	Mit 6	3/08/2013	19°51'39.00" S; 157° 43' 20.07" W
Takutea	Tak 1	5/08/2013	19°48'31.81" S; 158° 17' 55.85" W
	Tak 2	5/08/2013	19°48'52.53" S; 158° 16' 32.83" W
	Tak 3	5/08/2013	19°49'07.75" S; 158° 17' 24.14" W
	Tak 4	6/08/2013	19°48'22.73" S; 158° 17' 32.93" W
Atiu	Ati 1	7/08/2013	19°58'19.06" S; 158° 06' 17.82" W
	Ati 2	7/08/2013	19°59'53.01" S; 158° 04' 57.71" W
	Ati 3	7/08/2013	20°01'08.47" S; 158° 06' 04.91" W
	Ati 4	8/08/2013	20°00'53.83" S; 158° 07' 04.39" W
	Ati 5	9/08/2013	19°59'12.42" S; 158° 08' 34.41" W
	Ati 6	9/08/2013	19°58'32.62" S; 158° 08' 21.81" W

Appendix B. Checklist of hard coral species recorded at sites surveyed for each island visited on this 2013 expedition.

	Manuae	Mitiaro	Takutea	Atiu
ACROPORIDAE				
Acropora digitifera		1		1
Acropora gemmifera	1	1	1	1
Acropora sp				1
Acropora humilis	1	1	1	1
Acropora lutkeni	1			1
Acropora hyacinthus				1
Acropora nasuta			1	1
Acropora palmerae	1			
Acropopa schmitti	1	1	1	1
Acropora tenuis		1	1	
Acropora veweyi				1
Astreopora expansa	1	1	1	1
Astreopora gracillis			1	1
Montipora (pink)	1			
Montipora digitata		1		
Montipora floweri	1	1	1	1
Montipora foveolata			1	
Montipora meandrina	1			
FAVIIDAE				
Cyphastrea chalcidicum	1	1	1	1
Favites flexuosa				1
Favia rotumana	1	1		1
Favia stelligera	1	1	1	1
Leptoria phrygia		1		1
Leptastrea purpurea			1	1
Goniastrea pectinata				1
Montastrea curta	1	1	1	1
Platigyra pini		1		
AGARICIIDAE				
Pavona duerdeni	1			1
Pavona meldavensis	1	1		
Leptoseris sp	1			
MERULINIDAE				
Hydnophora exesa	1			
Hydnophora microcornis				1
MUSSIDAE				
Lobophylia hemprichii				1
Acanthastrea brevis		1	1	
Acanthastrea echinata	1	1	1	1
MILLEPORIDAE				
Millepora platyphyla		1	1	1
POCILLOPORIDAE				
Pocillopora eyedouxi		1		1
Pocillopora meandrina	1	1	1	1
Pocillopora verrucosa	1	1	1	1
Pocillopora woodjonesi				1
PORITIDAE				
Porites lichen			1	1
Porites lobata		1	1	
Porites lutea	1	1	1	1
SIDERASTREIDAE				
Psammocora niestraszi	1	1		1
Psammocora profundacella	1	1		1
Psammocora stellata	1			
Coscinaraea columna	1			
ALCYONIDS (soft corals)				
Sinularia spp				1
Cladiella spp				1
TOTAL NO. OF SPECIES	**25**	**25**	**21**	**35**
TOTAL NO. OF FAMILIES	**8**	**8**	**6**	**10**

Appendix C. Checklist of macro-invertebrate species recorded at sites surveyed for each island visited on this 2013 expedition.

INVERTEBRATE SPECIES	MANUAE	MITIARO	TAKUTEA	ATIU
Tridacna maxima	x	x	x	x
Tridacna squamosa				
Dendropoma maxima	x	x	x	x
Echinometra mathaei	x	x	x	x
Echinostrephus aciculatus	x	x	x	x
Echinothrix diadema		x	x	x
Holothuria whitmaei				x
Acanthaster planci	x		x	x
Tectus niloticus				x
Spirobranchus giganteus	x	x		
Lambis lambis	x	x		
Octopus cyanea	x	x	x	x
Ophiomastix janualis		x		
Pseudobbiceros spp.				
Tripneustes gratilla		x	x	
Thelenota ananas		x		x
Echinothrix calamaris			x	x
Diadema savignyi		x	x	x
Diadema setosum			x	
Drupella spp.			x	x

Appendix D. Checklist of fish species recorded at sites surveyed for each island visited on this 2013 expedition. x notes fish is present within the vicinity of the transect but not recorded during the count.

SPECIES	COMMON NAME	MANUAE	MITIARO	TAKUTEA	ATIU
ACANTHURIDAE					
Acanthurus nigrofuscus	Brown Surgeonfish	27	34	90	143
Acanthurus achilles	Achilles Tang	24	34	27	4
Acanthurus nigricans	Whitecheek Surgeonfish	8		2	97
Acanthurus nigroris	Blue-lined Surgeonfish	2	9	21	40
Acanthurus nigricaudus	Blackcheek Surgeonfish	1			
Acanthurus leucopareius	Whitebar Surgeonfish		7		
Acanthurus olivaceus	Orangeband Surgeonfish			1	
Acanthurus guttatus	Whitespotted Surgeonfish				2
Ctenochaetus striatus	Bristletooth Surgeonfish	44	86	14	247
Ctenochaetus flavicauda	Pale-tailed Bristletooth	35	27	9	10
Ctenochaetus cyanocheilus	Blue-lipped Bristletooth			2	2
Ctenochaetus hawaiensis	Hawaiian Surgeonfish	5			
Naso lituratus	Orangespine Unicorn	2	8	3	34
Naso unicornis	Bluespine Unicorn	2			19
Zebrasoma scopas	Brushtail Tang				3
ANTHIINAE					
Pseudanthias pascalus	Purple Queen Anthias	95			
Pseudanthias olivaceus	Olive Anthias	191	195	20	
BALISTIDAE					
Melichthys vidua	Pinktail Triggerfish		4	2	7
Melichthys niger	Black Triggerfish	1	3	30	21
Sufflamen bursa	Scythe Triggerfish	1	2	4	16
Sufflamen chrysopterum	Flagtail Triggerfish	1			1
CIRRHITIDAE					
Cirrhitops hubbardi	Hubbard's Hawkfish		11	3	3
Paracirrhitus arcatus	Arc-eye Hawkfish	79	247	93	206
Paracirrhitus forsteri	Freckled Hawkfish	3	3		
Paracirrhtes hemistictus	Spotted Hawkfish	5	6	3	7
Neocirrhtes armatus	Flame Hawkfish	1	128	77	168
CAESIONIDAE					
Pterocaesio tile	Bluestreak Fusilier				12
CARACANTHIDAE					
Caracanthus maculatus	Spotted Coral Croucher	3	21	7	36
CARANGIDAE					
Caranx lugubris	Black Trevally	x			
Caranx melampygus	Bluefin Trevally	x	x	x	x
Caranx sexfasciatus	Bigeye Trevally	x			
Carangoides orthogrammus	Yellow-spotted Trevally	2		x	
CHAETODONTIDAE					
Chaetodon auriga	Threadfin Butterfly				1
Chaetodon ephippium	Saddled Butterfly		1		
Chaetodon lunula	Raccoon Butterfly				2
Chaetodon quadrimaculatus	Four-spot Butterfly	5	47	23	28
Chaetodon reticulatus	Reticulated Butterfly	9	26	7	25
Chaetodon unimaculatus	Teardrop Butterfly	3			1
Chaetodon pelewensis	Dot-and-Dash Butterfly	8	37	20	10
Chaetodon ornatissimus	Ornate Butterfly		3		
Heniochus chrysostomus	Pennant Bannerfish	2			
Forcipiger flavissimus	Longnose Butterfly			2	4
BLENNIIDAE					
Aspidontus taeniatus	Mimic Cleaner	1	7	2	5
Cirripectes variolosus	Red-speckled Blenny	43	13	21	228
Exallias brevis	Leopard Blenny				1
Plagiotremus tapeinosoma	Piano Blenny	14	28	20	11
Enneapterygius sp	Striped Triplefin	10			3
FISTULARIDAE					
Fistularia commersonii	Cornetfish	2			
GOBIIDAE					
Eviota sp	Pygmy Goby			1	17
HOLOCENTRIDAE					
Myripristis kuntee	Epaulette Soldierfish			3	
Sargocentron spiniferum	Sabre Squirrelfish	1			3
LABRIDAE					
Anampses caeruleopunctatus	Blue spotted Wrasse				7
Anampses twisti	Yellow-breasted Wrasse	5			
Coris aygula	Clown Coris		1		2
Cirrhilabrus scottorum	Scott's Wrasse	53	20	25	10
Gomphosus varius	Bird Wrasse	8	9	2	8
Halichoeres margaritaceus	Weedy Surge Wrasse	1			

Halichoeres marginatus	Dusky Wrasse		1		1
Halichoeres ornatissimus	Ornate Wrasse	37	121	43	158
Hemigymnus fasciatus	Barred Thicklip Wrasse	2			
Stethojulis bandanensis	Redshoulder Wrasse		3		1
Thalassoma lutescens	Sunset Wrasse	19	46	8	24
Thalassoma quinquevittatum	Fivestripe Wrassse	21	52	93	60
Laabroides bicolor	Bicolor Cleaner Wrasse	2	2		2
Labroides dimidiatus	Bluestreak Cleaner Wrasse	2	6	2	8
Labroides rubrolabiatus	Redlip Cleaner Wrasse	31	8	4	12
Macropharyngodon meleagris	Leopard Wrasse		9	1	2
Cheilinus oxycephalus	Snooty Wrasse				1
Pseudocheilinus octotaenia	Eightline Pygmy Wrasse	53	13		2
Pseudocheilinus tetrataenia	Fourline Pygmy Wrasse	103	203	98	290
Pseudojuloides atavai	Tahitian Wrasse			1	9
Oxycheilinus unifasciatus	Ringtail Wrasse	12	1		
LUTJANIDAE					
Lutjanus bohar	Red Snapper			3	3
MULLIDAE					
Parupeneus bifasciatus	Two-barred Goatfish				9
Parupeneus multifasciatus	Multibar Goatfish		4	12	7
POMACANTHIDAE					
Centropyge flavissimus	Lemonpeel Angelfish	5	79	24	63
Centropyge loriculus	Flame Angelfish	12	76	21	6
Pomacanthus imperator	Emperor Angelfish	7	1	15	1
POMACENTRIDAE					
Chromis acares	Midget Chromis	2378	917	388	261
Chromis agile	Reef Chromis	38	97		18
Chromis vanderbilti	Vanderbilt's Chromis	204	632	421	1055
Chromis xanthura	Black Chromis		2		
Plectroglyphidodon imparipennis	Brighteye Damselfish			21	3
Plectroglyphidodon johntonianus	Johnston Damselfish	119	234	180	330
Dascyllus flavicaudus	Yellowtail Dascyllus				5
Dascyllus trimaculatus	Three-spot Dascyllus		5		1
Pomachromis fuscidorsalis	Tahitian Damselfish	3	120	91	362
Stegastes fasciolatus	Pacific Gregory	36	328	2	660
PTERELEOTRIDAE					
Nemateleotris magnifica	Fire Dartfish	64	19	26	9
Ptereleotris evides	Two-tone Dartfish	1		3	
SCARIDAE					
Calotomus carolinus	Stareye Parrotfish	1			
Cetoscarus bicolor	Bicolor Parrotfish	2			
Chlorurus sordidus	Bullethead Parrotfish	5			
Hipposcarus Longiceps	Pacific Longnose Parrotfish			1	
Scarus altipinnis	Filament Fin Parrotfish				2
Scarus frenatus	Bridled Parrotfish	2			
Scarus ghobban	Bluebarred Parrotfish	1			
Scarus forsteni	Rainbow Parrotfish				13
SCORPAENIDAE					
Dendrochirus biocellatus	Two-spot Lionfish		1		
Sebastapistes cyanostigma	Yellow-spotted Scorpionfish				2
SERRANIDAE					
Cephalopholis urodeta	Flagtail Grouper	27	24	7	24
Cephalopholis argus	Peacock Grouper	18	6	2	3
Cephalopholis spiloparaea	Strawberry Grouper				1
Epinephalus hexogonatus	Hexagon Grouper	1	1	1	4
Epinephalus fasciatus	Blacktip Grouper		1	8	
TETRADONTIDAE					
Canthigaster solandri	Blue-spotted Toby		3		
Arothron nigropunctatus	Blackspotted Puffer		1		
Arothron stellatus	Star Puffer		1		
ZANCLIDAE					
Zanclus cornutus	Moorish idol	2	2		2
TOTAL NO. OF SPECIES		**66**	**62**	**55**	**76**
TOTAL NO. OF FAMILIES		**17**	**16**	**17**	**19**

This research was a collaboration between:

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