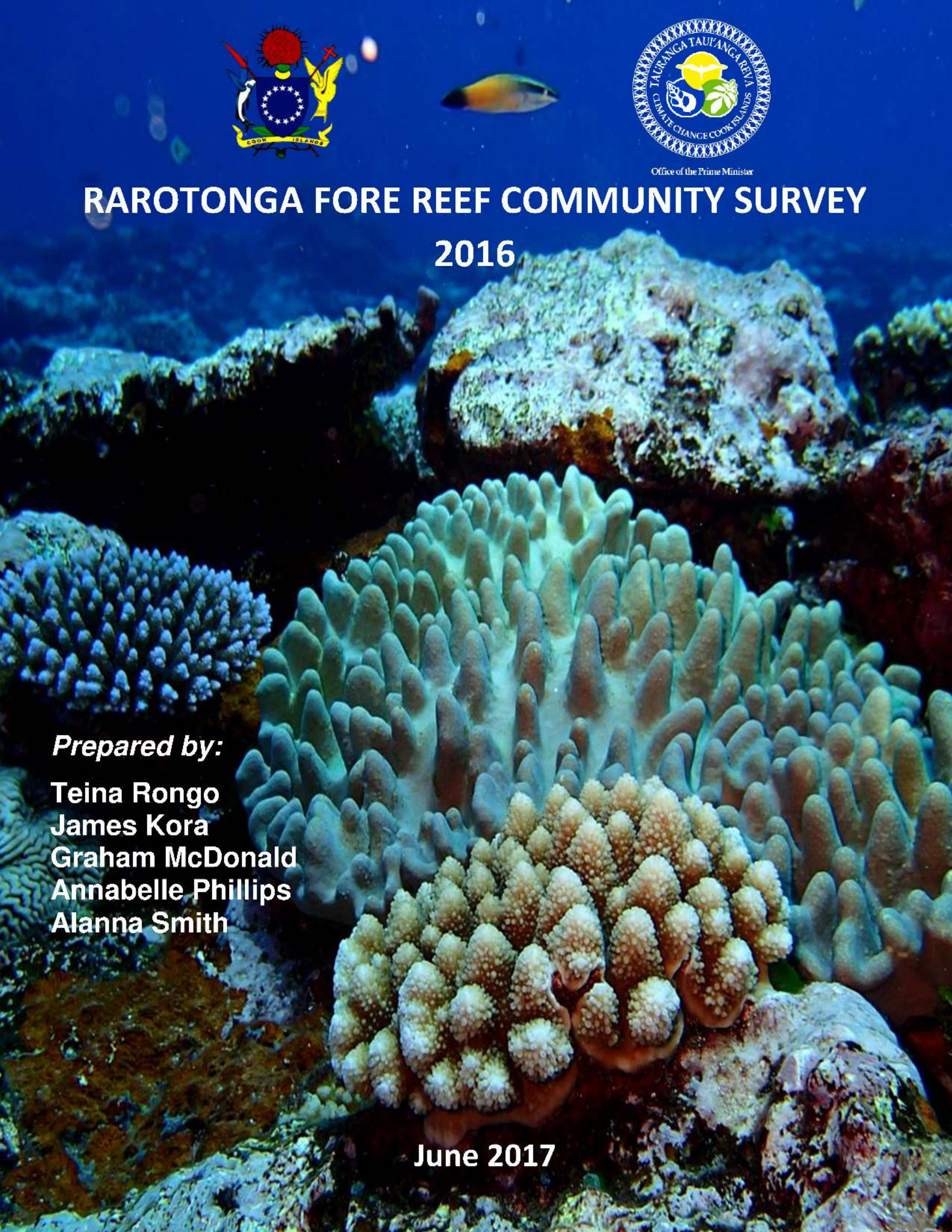

Office of the Prime Minister

RAROTONGA FORE REEF COMMUNITY SURVEY
2016

Prepared by:

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This work was done in collaboration between the Office of the Prime Minister of the Cook Islands (Climate Change Division), United Nations Environment Programme, Marae Moana and Te Ipukarea Society.

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Cover photo: *Acropora* colony and *Sinularia* soft coral on the fore reef of Vaimaanga. Photo taken by Annabelle Phillips in 2016.

Back cover photo: *Turbinaria reniformis* on the fore reef of Kavera. Photo taken by Annabelle Phillips in 2016.

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EXECUTIVE SUMMARY

Following the last crown-of-thorn starfish (COTS) outbreak around Rarotonga from 1995 – 2001, reefs for the last 16 years have been steadily recovering despite the various disturbance regimes during this period. Examining 10 years of data, mean coral cover has increased from ~1% in 2006 to ~5% in 2009, 8% in 2011, 16% in 2014, and 26% in 2016. In support, coral size class data also showed a significant increase of larger colonies in 2016 when compared with 2006. Coral-associated pomacentrids (e.g., *Chromis vanderbilti*) showed increased abundance, consistent with the improving hard coral cover noted during this recovery period. Important grazers (i.e., *Ctenochaetus striatus*) showed a sudden increase in 2006, but in 2009 their abundance showed a decline and has remained relatively stable. Coral cover is estimated to reach the pre-COTS conditions of the 1990s (at >30%) by 2020 — a period of 19 years since the end of the COTS outbreak around 2001. This is in stark contrast to anecdotal reports that suggested recovery following the 1970s COTS outbreak took less than 10 years. Certainly factors such as cyclones, coral bleaching, eutrophification, and climate change (i.e., ocean warming and acidification) that have all increased in the last few decades are likely contributors to the slow recovery since 2001. It is unlikely that overfishing is a contributing factor given the fear of ciguatera poisoning is still ingrained into residents from the high incidence experienced in the last 20 years or so. A recent concern was the report of juvenile COTS observed by divers at deeper sites. Considering the improved state of Rarotonga's reefs, the likelihood of COTS returning in the near future is high. Also, the mass die-off of *vana* (*Echinothrix diadema*) on Rarotonga — where a 99% loss was noted compared with data collected in 2014 — is of concern, with similar die-offs reported from Mauke and Mitiaro. *Echinothrix diadema* is an important grazer and its loss would likely increase algal cover in habitats where this species are found (i.e., fore-reef slopes and reef crest habitats). Reducing nutrient loading into the marine environment is essential through compliance with the Ministry of Health sanitation program. Future developments need to ensure that the resilience of our marine communities are not compromised considering the ever increasing threat of climate change. Continuation of this survey in the future is also critical to elucidate the causes of these changes and what measures need to be taken to adapt and mitigate. Unfortunately, during the preparation of this report, extensive coral bleaching was experienced on Rarotonga and throughout the southern Cook Islands due to a regional warming from October 2016 to April 2017. The next survey planned for 2018 may see a significant decline in coral cover if reefs on Rarotonga were unable to recover from this recent bleaching event.

1. INTRODUCTION

Coral reefs make up only 0.2 % of marine areas, yet they host approximately one-third of all described marine biodiversity (Reaka-Kudla, 1997, 2005). While coral reefs alone provide around USD$125 trillion in services globally per year, losses in their services due to poor land-use practices and ecosystem degradation amount up to $20.2 trillion per year (Costanza et al., 2014). The causes of reef degradation range from nutrient enrichment, increased sedimentation from terrestrial runoff, overfishing, and global climate change (Lapointe, 1997; Richmond et al., 2007; Jackson et al., 2001; Hoegh-Guldberg, 1999; Hoegh-Guldberg et al., 2007; Veron 2008; Veron et al., 2009).

On Rarotonga in the Cook Islands (Figure 1), reefs have experienced several natural disturbances over the last few decades (see Rongo and van Woesik, 2013). In the 1970s, Devaney & Randall (1973) documented the first reported crown-of-thorns starfish (COTS) outbreak on Rarotonga during a Pacific-wide outbreak (Sapp, 1999). According to their report, most of the damage occurred between Ngatangiia/Matavera (north-eastern side) counter-clockwise to Arorangi (western side). A second COTS outbreak in the mid-1990s to around 2001 that was limited to fore reef communities also reduced coral cover from more than 30% to less than 5% in 2006 (Rongo et al., 2006), but recovery seemed to be well on the way in subsequent years. For example in 2011, coral cover ranged from 10 – 15%. While reef recovery to pre-COTS conditions after the 1970s outbreak occurred over a period of less than 10 years, recovery from the 1990s outbreak has been slow even over a decade later. However, a notable increase in larger coral colony sizes of *Acropora* spp. indicate that a shift towards pre-COTS conditions of the 1990s has occurred on the fore reef.

Coral bleaching has also impacted these reefs particularly in 1991 and 1994 during a regional warming and associated calm periods and extreme low tides, causing high coral mortality within the lagoon and to a lesser extent the fore reef slopes (Goreau & Hayes, 1995). Bleaching events associated with extreme low tides were observed in subsequent years (e.g., 1998, 2006, 2009, 2014, and 2017; Table 1) where corals on the reef flats experienced aerial exposure for several hours (see Rongo & van Woesik, 2013). The 2015/2016 very strong El Nino event did not bring any major disturbance to Rarotonga compared with the extensive bleaching event that devastated all reefs in the northern islands (Rongo, 2016). The impact on hard coral populations following the passing of five cyclones in the region between 2003 and 2005, was difficult to determine as reefs were still recovering from the recent major COTS outbreak. Rarotonga did not experience any cyclones for 11 years (2005 – 2016), and this was a critical period allowing reefs to recover.

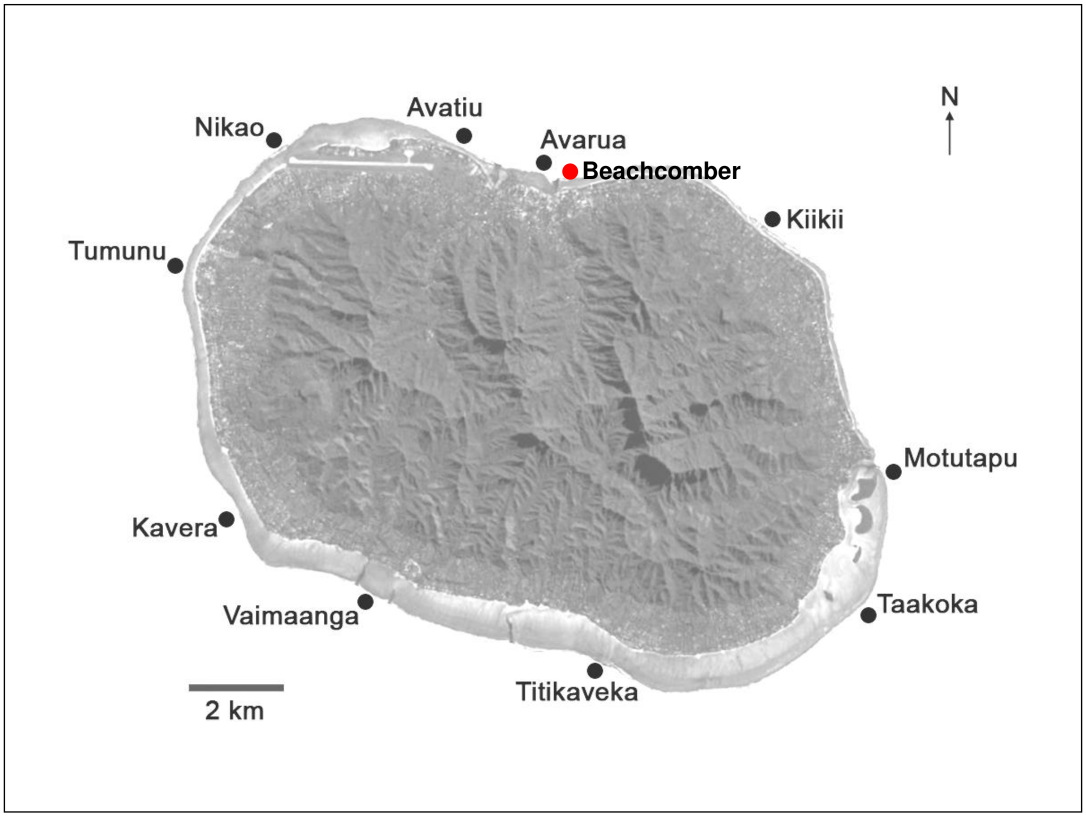

Figure 1. Map of Rarotonga with black dots indicating fore reef sites established since 1994 (photo taken from Google Earth); these sites have been consistently surveyed from 2000 to 2016. Red dot indicates Beachcomber site surveyed in 2011 and the current survey.

Given that Rarotonga's reefs have remained degraded for much of the 1990s and 2000s, it was suggested that such reef state accompanied by high frequency of disturbance events (e.g., cyclone, coral bleaching, etc.) may have facilitated the establishment of the ciguatoxic dinoflagellates that causes fish poisoning as reef disturbance provides reef space for opportunistic ciguatoxic dinoflagellates to colonize; this ultimately led to increased incidence of ciguatera poisoning in previous years (Rongo et al., 2009). Because ciguatera poisoning rendered reef fish unusable in the last few decades, Rongo & van Woesik (2013) suggested that ciguatera may have also led to the increase of fish abundance — especially herbivorous species reported in the 2006 survey — which are particularly important during this recovery period.

Table 1. Summary of bleaching and other disturbances on Rarotonga and other islands

YEAR	ISLAND	ENSO PHASE	IMPACTS NOTED
1982/83	Rarotonga, Penrhyn, possibly other southern and northern group islands	Very strong El Niño	Bleaching from extreme low tide; other southern and northern islands may have been affected as well, but not recorded. In Penrhyn, micro-atolls (*kava*) were exposed for weeks and massive die-off of corals, clams and oysters were noted (Manata Akatapuria, pers. comm.).
1991/92	Aitutaki, Rarotonga	Moderate El Niño	Bleaching noted on the fore reef of Aitutaki and Rarotonga (T. Rongo, pers. obs.) from extreme low tides.
1994/95	Aitutaki, Rarotonga, Manihiki	Weak El Niño	Maximum temperature was 30.1°C in Manihiki; extensive bleaching on Aitutaki and Rarotonga fore reef habitats (Goreau & Hayes, 1995). Also the beginning of the COTS outbreak in 1995.
1997/98	Rarotonga, Penrhyn, Manikihi, Rakahanga	Very strong El Niño	Coral bleaching noted in the lagoon and reef flat habitats of Rarotonga and Penrhyn; bleaching on Rarotonga was due to extreme low tides. Although bleaching likely occurred on Manihiki and Rakahanga, this was not noted due to the overwhelming impact of cyclone Martin. COTS continue to degrade the fore reefs of Rarotonga.
2001	Rarotonga		End of the COTS outbreak
2002/03	Rarotonga	Moderate El Niño	Coral bleaching in the lagoon from warm and stagnant conditions from extreme low tide. The "Titikaveka Irritant Syndrome" also occurred in 2003 (Rongo & van Woesik, 2013).
2006/07	Rarotonga	Weak El Niño	Coral bleaching noted in lagoon and reef flat habitats in Ngatangiia from extreme low tides (Rongo et al., 2006).
2009/10	Rarotonga	Moderate El Niño	Coral bleaching noted in the lagoon and reef flat habitats (Rongo et al., 2009).
2014	Aitutaki, Rarotonga, possibly other southern group islands	Neutral ENSO	Extensive bleaching noted in the lagoon and reef flat habitats from extreme low tides (Rongo et al., 2015).
2016/17	Rarotonga and the southern group	Weak La Niña	Mass die-off of *Echinothrix diadema* in Rarotonga, Mitiaro, and Mauke. It is possible that other islands in southern group also had the problem. Extensive bleaching observed in the lagoons and fore reef of Rarotonga during the months of January to February. Bleaching was observed on Atiu in the same months, where *tai tu`a* (extreme low tide during mid-day) was reported. It is likely that bleaching also occurred on the other southern islands.

Although coral reef monitoring on Rarotonga has been inconsistent in terms of methodology, intervals, and also the Government ministry involved, reef monitoring has been ongoing for more than 20 years (Table 2). The first monitoring effort was carried out in 1994 (Miller et al., 1994), and subsequent monitoring was conducted in 1999 (Ponia et al., 1999), 2000 (Lyon, 2000), 2003 (Lyon 2003), 2006 (Rongo et al., 2006), 2009 (Rongo et al., 2009), 2011 (Rongo and van Woesik, 2013), and 2014 (Rongo et al., 2015). The present survey in 2016 is a continuation of this coral reef monitoring, which was a collaborative effort between Climate Change Cook Islands and Te Ipukarea Society. The purpose of the survey was to quantify spatial and temporal changes in the benthic and fish communities on the fore reefs of Rarotonga.

Table 2. Coral reef monitoring efforts in Rarotonga from 1994 to 2014 and the responsible entities.

Year	Entity	Reference
1994	Australian Institute of Marine Sciences	Miller et al., 1994
1999	Cook Islands Ministry of Marine Resources	Ponia et al., 1999
2000, 2003, 2006, 2009	Cook Islands National Environment Service	Lyon 2000, 2003; Rongo et al., 2006, 2009
2011	Teina Rongo (Ph.D. dissertation)	Rongo and van Woesik, 2013
2014	Climate Change Cook Islands (OPM)	Rongo et al., 2015

1.1. Primary objectives

The objective of this work was to resurvey sites established around Rarotonga as part of a long-term monitoring program designed to understand temporal changes of communities on the fore reefs. The survey revisited sites at Avatiu, Avarua, Kiikii, Motutapu, Taakoka, Titikaveka, Vaimaanga, Kavera, Tumunu, and Nikao (see Figure 1 and also Rongo et al., 2006, 2009) with a site added at Beachcomber in 2011 also revisited.

The survey was carried out from 17 November to 2 December 2016. The monitoring focused on collecting information on benthic communities (i.e., fish, corals, algae, and other macro-invertebrates). 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 Rarotonga's resources based on scientifically valid, quantitative data. This survey was a joint effort between Climate Change Cook Islands of the Office of the Prime Minister and Te Ipukarea Society.

2. MATERIALS AND METHODS

2.1. Transect deployment

Four 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 5 m intervals.

2.2. 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). A brief description of each general biota or coral survey is described below.

2.2.1. 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]).

2.2.2. Coral colony size

At every 20 m interval, a quadrat was tossed haphazardly to record coral communities for a total of eight 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* 2.3.2 below); class A colonies were considered new recruits for this survey.

2.2.3. 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.

2.2.4. Biological diversity

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. Species identification were verified using Randall and Myers (1983), Myers (1989, 1999), Veron (2000), Randall (2005), and some photographs provided by Gustav Paulay.

2.3. 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.

2.3.1. 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. 1).

$$\text{(1)} \quad \text{Percent cover} = \frac{\text{Category sum per transect}}{160} \times 100\%$$

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

2.3.2. Colony size calculation

The area of each colony was calculated using Eq. 2a, b and c:

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

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

(2c) $\text{Population density (colonies per m}^2\text{)} = n/8\ \text{m}^2$

where n is the total number of colonies of any given species and 8 m^2 is the total area surveyed using 8 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 < 32 cm), and E (≥ 32 cm).

2.3.3. Average density

Average density for macro-invertebrates and fish were calculated for each site using Eq. 3:

$$\text{Average density} = \frac{\text{Number of individuals per site / number of replicates}}{\text{Belt area (100 m}^2\text{ for invertebrates and 250 m}^2\text{ for fish)}} \tag{3}$$

PRIMER 6 software was used to generate these indexes.

2.3.4. 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), and ordination and vector plots. Bubbles on 2D plots were used for graphical representation of the respective categories. Mean error plots were generated using STATISTICA 12.

3. RESULTS

3.1 Benthic communities

Turf algae remain the most dominant substrate on the fore reef since 2006, despite showing some decline over the years (Figure 2a,b). At Titikaveka and Vaimaanga sites on the southern exposure, coralline algae was an important substrate; the highest soft coral cover was also found at these two sites. Patches of macro-algae (mainly *Asparagopsis*) were present at sites along the eastern exposure and the western exposure; extensive areas in close proximity to the Avana passage (Motutapu site) were dominated by *Asparagopsis*. Since 2006, hard coral cover has continued to increase for most sites. With the exception of Vaimaanga (10% average coral cover), average coral cover for all sites was above 20%; Avarua showed the highest coral cover at around 43%.

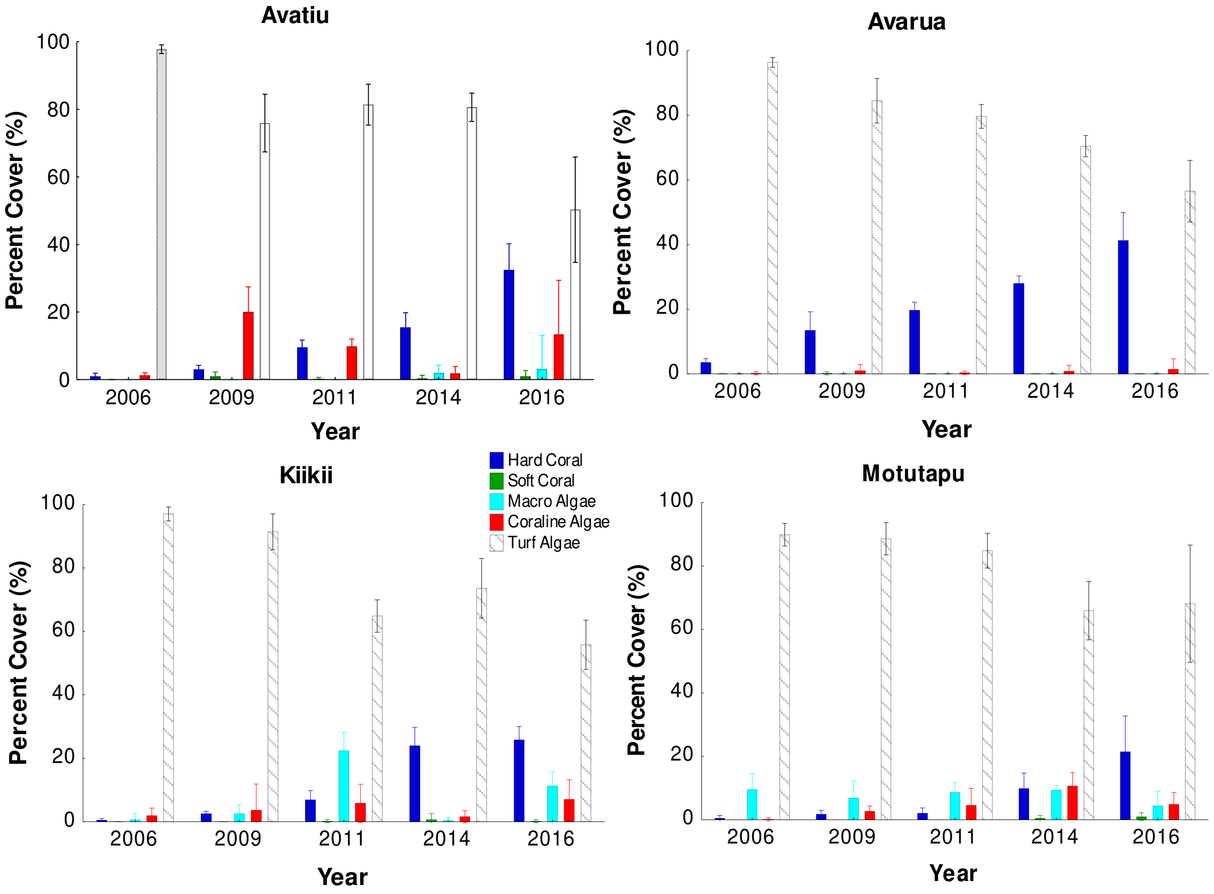

Figure 2a. Percent cover of benthic communities from Avatiu, Avarua, Kiikii, and Motutapu surveyed in 2006, 2009, 2011, 2014 and 2016. Plots indicate mean values with a ± 95% confidence interval.

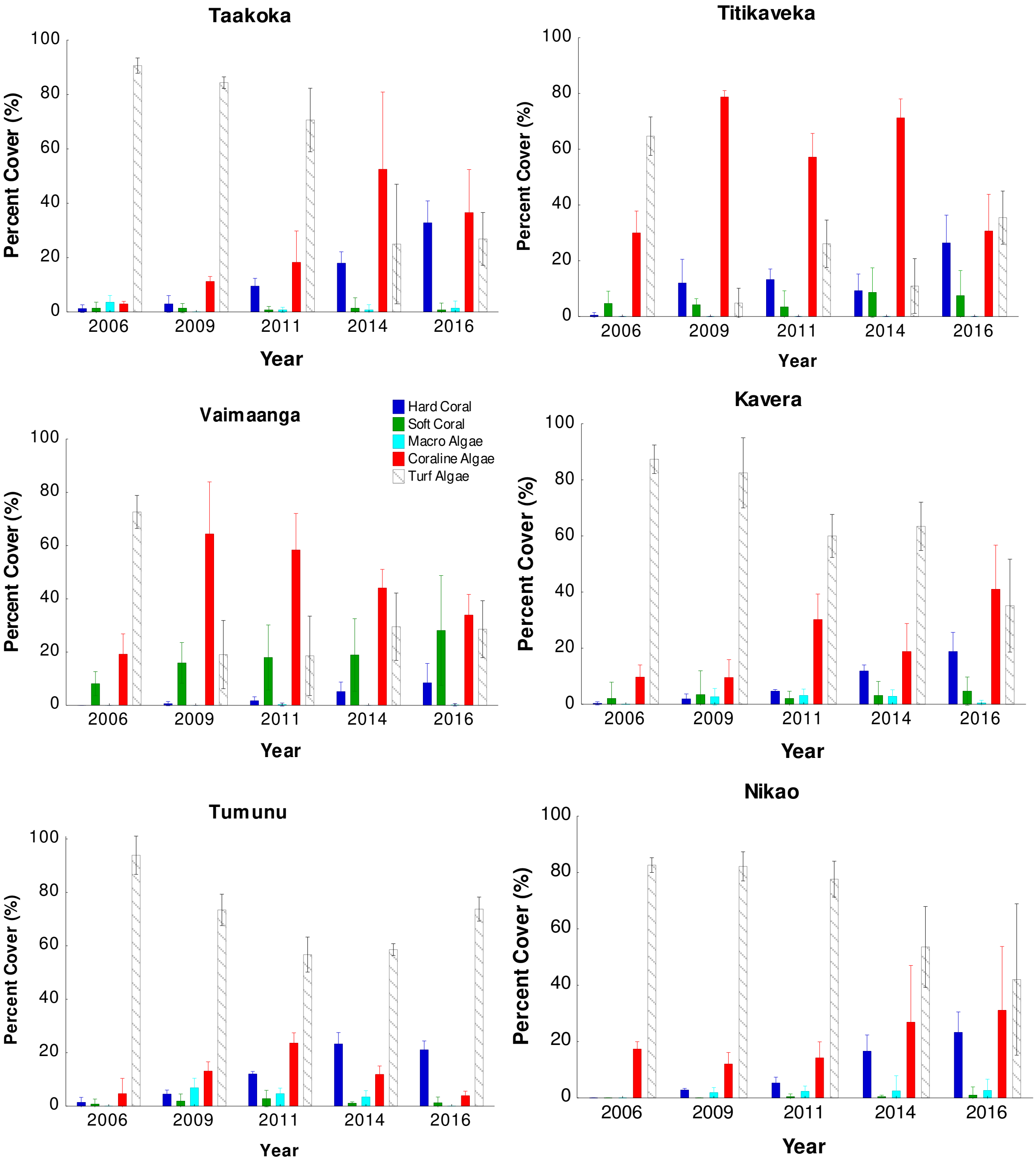

Figure 2b. Percent cover of benthic communities from Taakoka, Titikaveka, Vaimaanga, Kavera, Tumunu, and Nikao surveyed on Rarotonga in 2006, 2009, 2011, 2014 and 2016. Plots indicate mean values with a ± 95% confidence interval.

3.1.1 *Coral diversity*

A total of 39 coral species were recorded during the survey representing 13 families (Appendix A). Number of species (S) and the number of individuals (N) was the highest at northern exposure sites (Avatiu, Avarua, and Beachcomber) (Table 3). Similarly, species diversity (H') was the highest at these sites as well.

Table 3. Biodiversity measure for coral species at all sites except for Tumunu. S = number of species, N = number of individuals, d = species richness, J' =evenness and H' = diversity. Highest values are highlighted in red.

Sample	S	N	d	J'	H'(loge)
Avatiu	27	229	4.785	0.8003	2.637
Avarua	27	229	4.785	0.8003	2.637
Beachcomber	27	182	4.996	0.8372	2.759
Kiikii	22	187	4.014	0.8056	2.49
Motutapu	19	167	3.517	0.7572	2.23
Taakoka	26	190	4.765	0.7342	2.392
Titikaveka	20	101	4.117	0.7994	2.395
Vaimaanga	27	139	5.269	0.7682	2.532
Kavera	26	149	4.996	0.7546	2.458
Nikao	24	170	4.478	0.8141	2.587

Coral colony size clearly showed a shift towards larger size classes when comparing data recorded in 2006 to 2014, with little difference between 2014 and 2016 (Figure 3a,b). While class A (<4 cm) was dominant in 2006, class B (4 to <8 cm) and C (8 to <16 cm) has continued to be the most dominant sizes class in 2016 for all sites examined. When compared with previous years, we note that class E (≥ 32 cm) has increased.

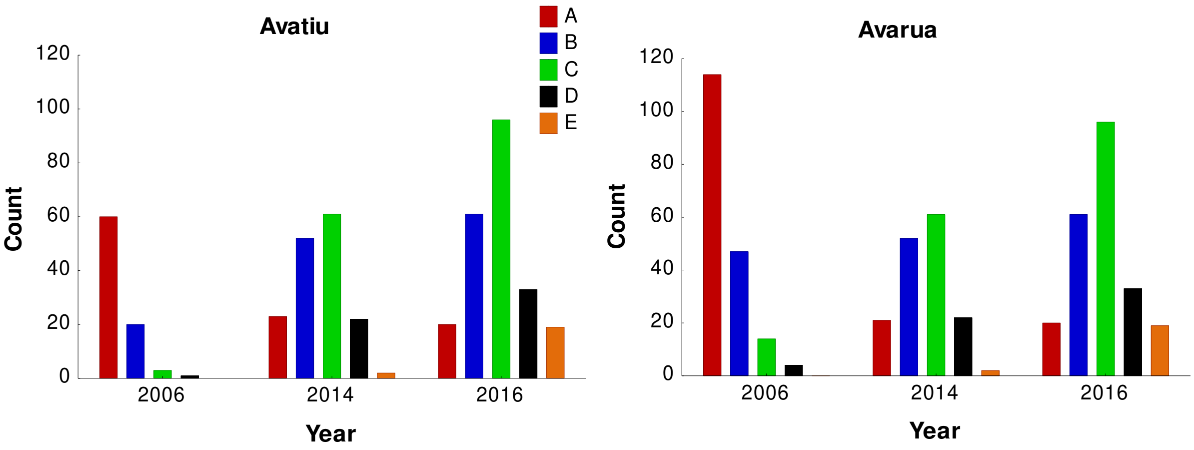

Figure 3a. Colony size counts for sites Avatiu and Avarua, surveyed on Rarotonga in 2006, 2014, and 2016.

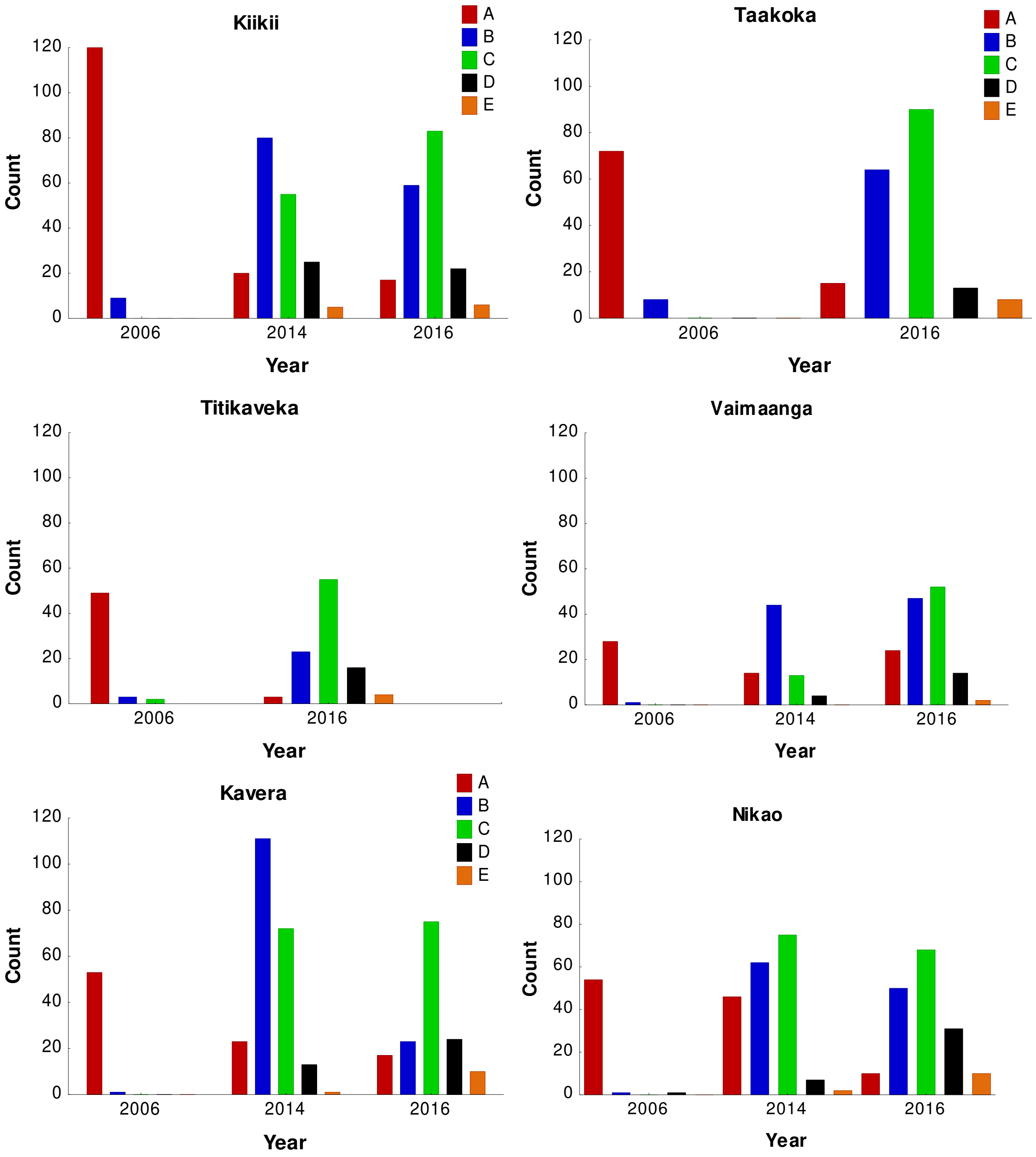

Figure 3b. Colony size counts for sites Kiikii, Taakoka, Titikaveka, Vaimaanga, Kavera, Vaimaanga, Kiikii, Nikao, Taakoka, and Titikaveka surveyed on Rarotonga in 2006, 2014, and 2016. Taakoka and Titikaveka did not have data for 2014.

A power trendline was fitted to the average coral cover for all sites lumped for each year from 2006 to 2016; extrapolation to 2018 and 2020 was also included. The power trendline showed a good fit with R-squared value of 0.9867 (Figure 4). With the assumption that coral cover will continue to improve, the expected cover is ~35% for 2018, and ~47% for 2020 (Table 4). However, there was recent coral bleaching observed from

December 2016 to April 2017 on Rarotonga where 80% of corals showed bleaching (this includes entire and partial bleaching; T. Rongo, pers. comm.). Not considering the recovery of bleached corals, 80% mortality would suggest a 5% average coral cover by the next survey in 2018.

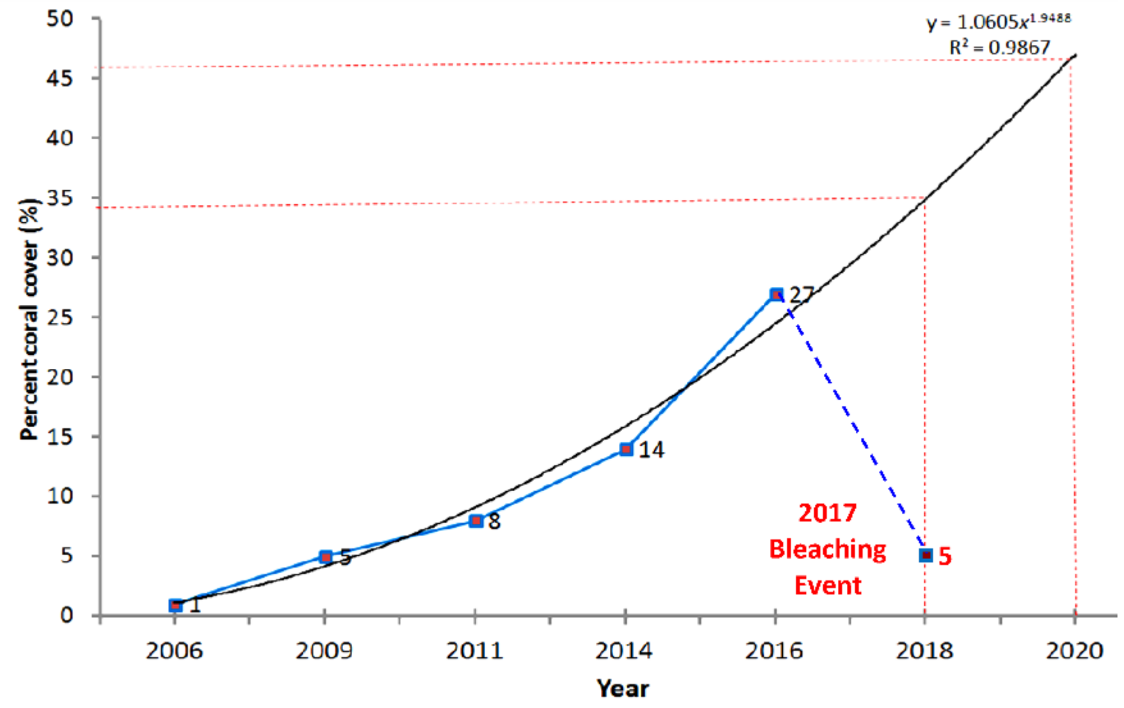

Figure 4. The average percent coral cover for all sites on Rarotonga lumped (blue line noting percentage), with a power trendline (black solid line) fitted to actual data. Red dotted-line suggests the expected average coral cover for 2018 and 2020. Blue dotted line from 2016 to 2018 suggests the expected average cover of 5% for 2018, considering 80% of corals were lost to the bleaching event of 2017.

Table 4. The actual average percent coral cover taken from surveys around Rarotonga from 2006 to 2016, and model predictions from 2006 to 2020.

Year	Survey number	Actual percent coral cover (%)	Model percent coral cover (%)
2006	1	1	1
2009	2	5	4
2011	3	8	9
2014	4	14	16
2016	5	27	24
2018	6	-	35
2020	7	-	47

Leptoria phrygia and *Montastrea curta* remained the two most important hard corals in the smaller size classes (A – C) in 2014 and 2016 (Figure 5). For both years, eigenvalues show that over 90% of the variations are explained in the first two axes (Table 5), which are largely attributed to *Leptoria phrygia* and *Montastrea curta*. In 2016, *Acropora* spp. showed an increase when compared with 2014.

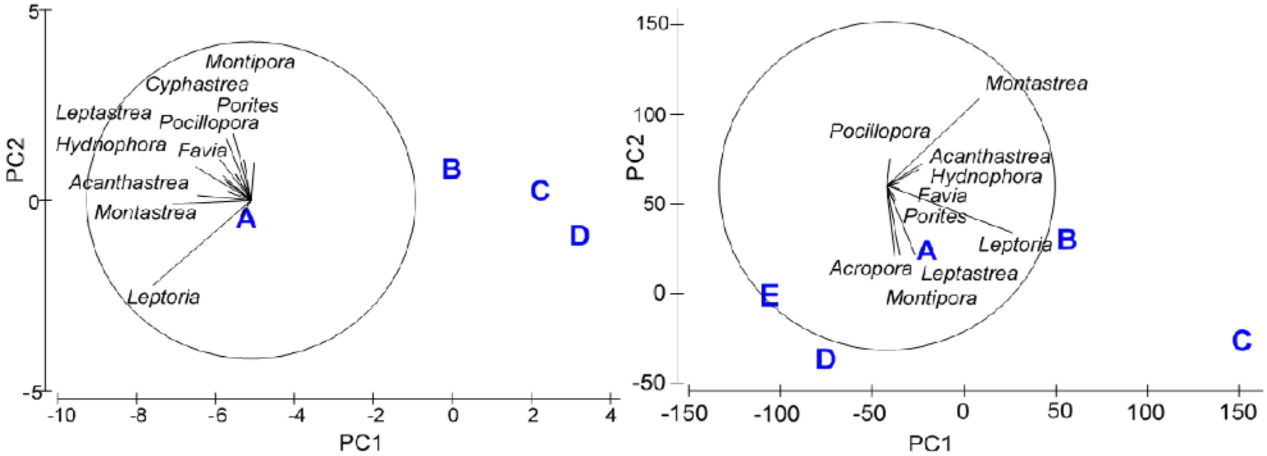

Figure 5. Principal Component Analysis (3 axes) for all coral genera and size classes recorded for 2014 (left) and 2016 (right); all sites were lumped for this analysis. Colony count for size class and the contribution of each genus to the class were used for this analysis.

Table 5. Eigen analysis of coral genera from 2006 and 2016 for all sites combined. Eigenvector values in red indicate the family with the most weight on the respective axis.

Eigenvalues		**2006**				**2016**		
PC	Eigenvalues	%Variation	Cum.% Variation	PC	Eigenvalues	%Variation	Cum.% Variation	
1	14.2	95.3	95.3	1	1.09E+04	89.4	89.4	
2	0.589	4	99.3	2	875	7.2	96.6	
3	0.105	0.7	100	3	365	3	99.6	
Eigenvectors								
Variable	PC1	PC2	PC3	Variable	PC1	PC2	PC3	PC4
Leptoria	-0.597	0.538	0.062	*Leptoria*	0.749	-0.287	0.517	-0.022
Montastrea	-0.478	0.023	-0.178	*Montastrea*	0.553	0.535	-0.417	0.039
Montipora	-0.108	-0.426	0.24	*Hydnophora*	0.192	0.102	-0.02	-0.024
Pocillopora	-0.163	-0.134	-0.516	*Montipora*	0.044	-0.431	-0.212	0.456
Favia	-0.151	-0.117	-0.466	*Acropora*	0.076	-0.424	-0.423	-0.402
Hydnophora	-0.17	-0.153	-0.017	*Porites*	0.055	-0.09	-0.113	0.651
Acanthastrea	-0.323	-0.03	0.371	*Favia*	0.072	-0.019	-0.361	0.115
Porites	-0.187	-0.255	0.061	*Cyphastrea*	0.07	0.019	-0.252	0.004
Cyphastrea	-0.149	-0.388	-0.031	*Acanthastrea*	0.207	0.133	-0.012	-0.011
Acropora	-0.139	-0.052	-0.323	*Cladiella*	0.045	0.041	-0.142	0.221
Leptastrea	-0.338	-0.211	0.237	*Goniastrea*	0.045	-0.111	-0.021	0.042
Coscinaraea	-0.094	-0.164	0.084	*Leptastrea*	0.167	-0.423	-0.287	-0.24
Goniastrea	-0.094	-0.164	0.084	*Psammocora*	0.027	0.001	-0.042	-0.032
Lobophyllia	-0.059	0.104	0.102	*Pocillopora*	0.018	0.165	-0.136	-0.198

3.2. Fish communities

Principal Component Analysis of fish families indicated that 72.3% of the variation was explained by the first two axes (Figure 6 & Table 6). The Eigenvectors (graphically illustrated on the vector plot) indicated that acanthurids had the most weight in the first axis (0.84), pomacentrids on the second axis (0.78), and scarids on the third axis (0.65). Bubble plots showed the direction of change with a general increase in pomacentrids (Figure 7) and chaetodontids (Figure 8) between 2006 and 2014 to 2016. However, a decline in acanthurids (Figure 9) has continued since 2006.

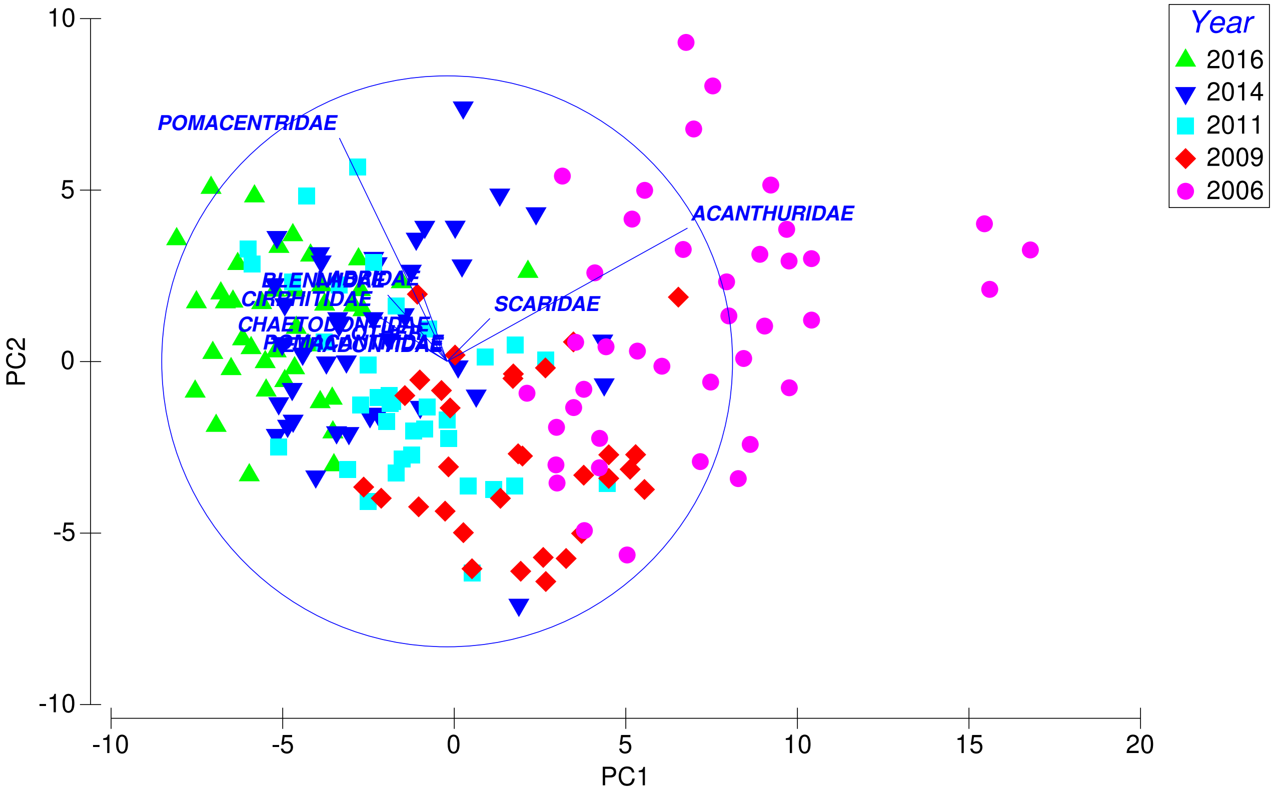

Figure 6. Principle Component Analysis (PCA) using all replicates of each fish families for all sites from 2006, 2009, 2011, 2014, and 2016. Ordination of replicates were superimposed on the vector plot. Square-root transformation was carried out on the data prior to PCA.

Table 6. Eigen analysis of fish families in 2016 for all sites. Eigenvector values in red indicate the family with the most weight on the respective axis.

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	24.6	52.6	52.6
2	9.18	19.7	72.3
3	4.28	9.2	81.5
4	3.29	7.0	88.5
5	1.86	4.0	92.5

Eigenvectors

Variable	PC1	PC2	PC3	PC4	PC5
ACANTHURIDAE	0.842	0.467	0.223	-0.057	0.078
POMACENTRIDAE	-0.377	0.782	-0.305	-0.377	-0.005
SCARIDAE	0.150	0.150	-0.645	0.717	-0.067
LABRIDAE	-0.087	0.238	0.335	0.219	-0.594
CIRRHITIDAE	-0.256	0.168	0.321	0.339	-0.040
BLENNIIDAE	-0.208	0.233	0.423	0.393	0.457
OTHER	-0.080	0.048	0.160	0.109	0.170
CHAETODONTIDAE	-0.054	0.078	-0.124	0.089	0.255
POMACANTHIDAE	-0.006	0.017	0.072	0.050	-0.573
TETRADONTIDAE	-0.005	0.005	0.029	0.027	0.062

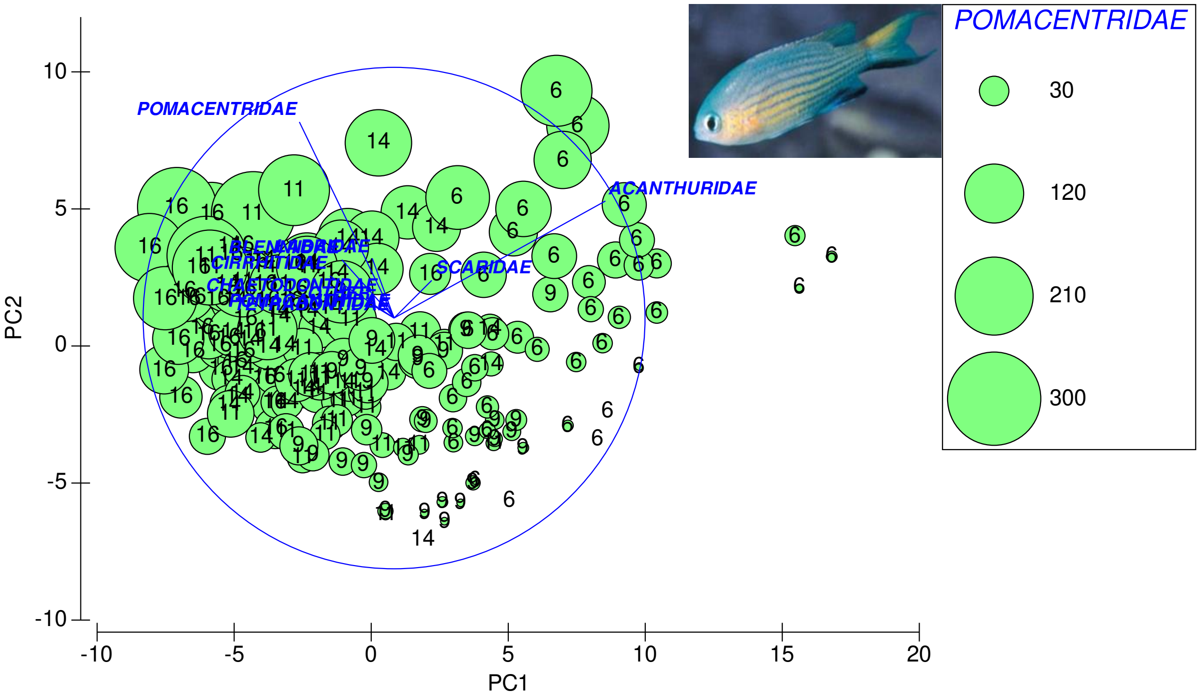

Figure 7. Principle Component Analysis (PCA) for Pomacentridae using all replicates for all sites from 2006 (6), 2009 (9), 2011 (11), 2014 (14) and 2016 (16). Ordination of replicates were superimposed on the vector plot. Square-root transformation was carried out on the data prior to PCA. Bubble values indicate the abundance (individuals per 100 m^2) of Pomacentridae for each replicate. *Chromis vanderbilti* photo taken from Randall (2005).

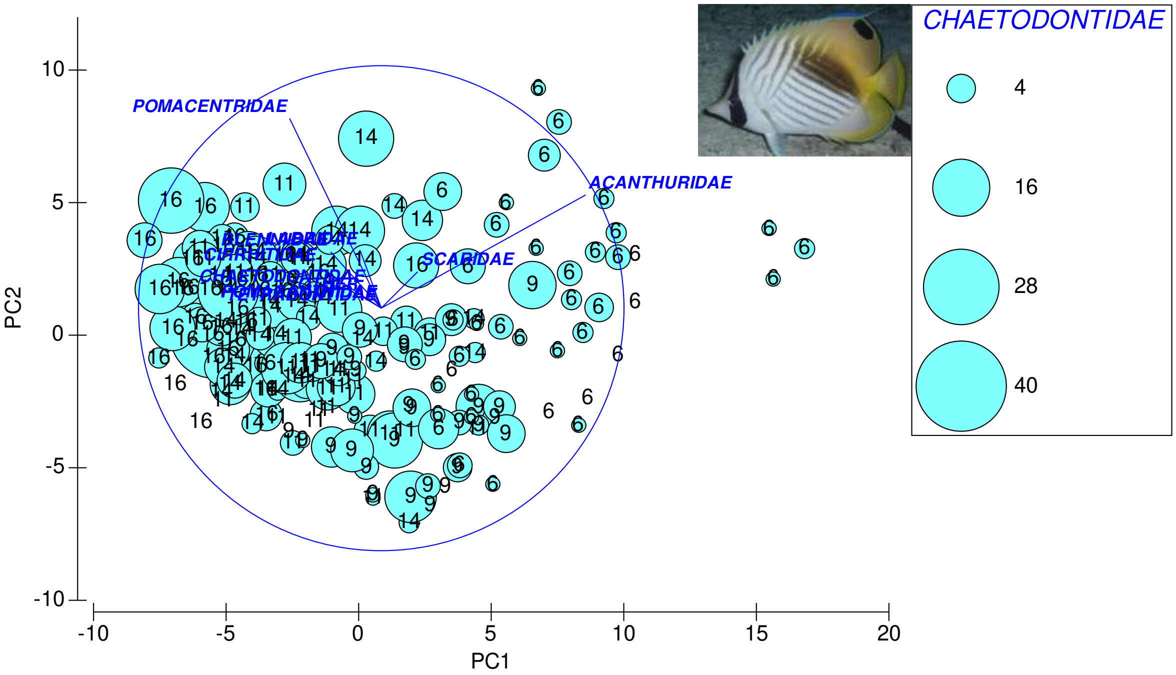

Figure 8. Principle Component Analysis (PCA) for Chaetodontidae using all replicates for all sites from 2006 (6), 2009 (9), 2011 (11), 2014 (14) and 2016 (16). Ordination of replicates were superimposed on the vector plot. Square root transformation was carried out on the data prior to PCA. Bubble values indicate the abundance (individuals per 100 m^2) of Chaetodontidae for each replicate. *Chaetodon auriga* photo taken by Teina Rongo.

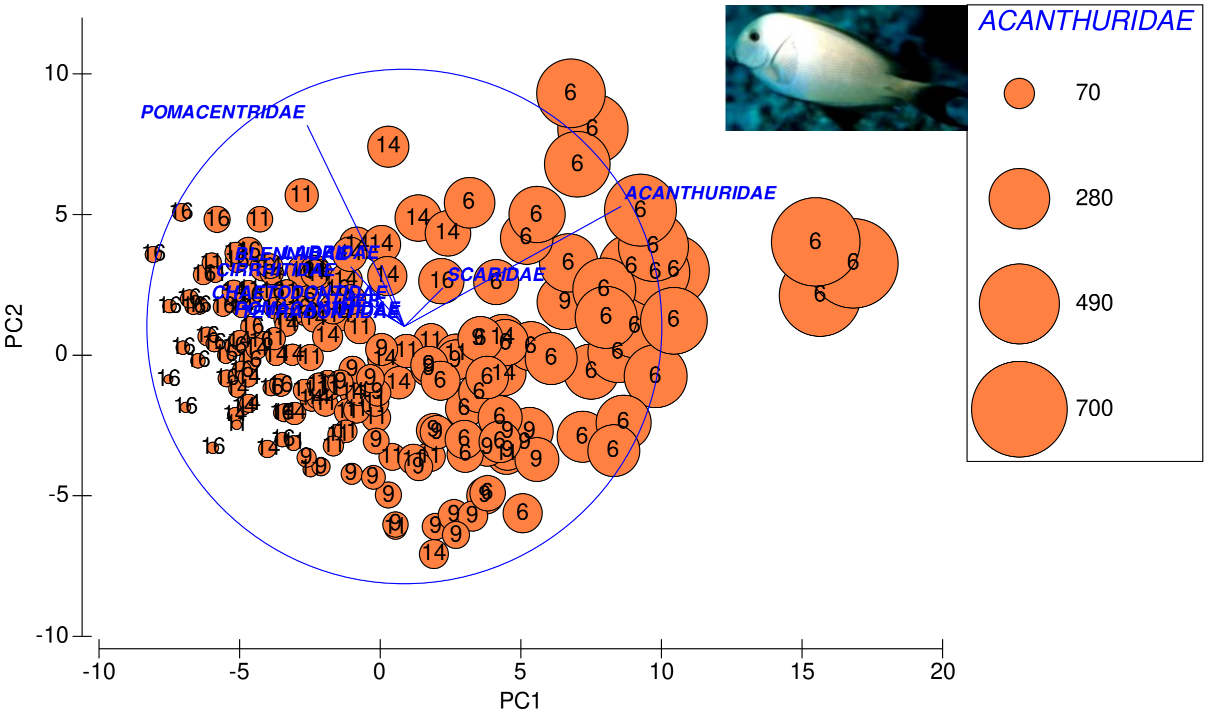

Figure 9. Principle Component Analysis (PCA) for Acanthuridae using all replicates for all sites from 2006 (6), 2009 (9), 2011 (11), 2014 (14) and 2016 (16). Ordination of replicates were superimposed on the vector plot. Square root transformation was carried out on the data prior to PCA. Bubble values indicate the abundance (individuals per 100 m^2) of Acanthuridae for each replicate. *Ctenochaetus striatus* photo taken from Randall (2005).

3.3. Macro-invertebrate communities

Echinometra spp. and *Dendropoma maxima* were the most common invertebrates on the fore reefs of Rarotonga in 2016. *Echinometra* spp. numbers ranged from around 50 ind./ 100 m^2 at Avarua to 480 ind./100 m^2 at Titikaveka (Figure 10). In addition, *Dendropoma maxima* ranged from < 10 ind./ 100 m^2 at Vaimaanga to around 200 ind./ 100 m^2 at Beachcomber. Data for Kavera and Tumunu were not collected during this survey.

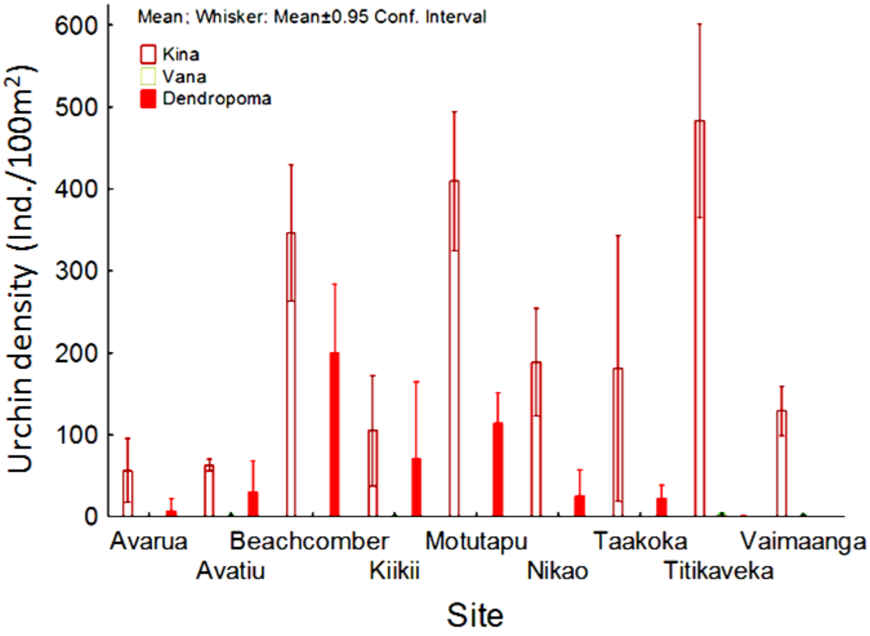

Figure 10. *Echinothrix diadema* (*vana*), *Dendropoma maxima* and *Echinometra* spp. (*kina*) density (ind./100 m^2) for 2016. All counts were lumped for each site.

Since 2009, the abundance of *Echinometra* spp. showed no significant difference among years. On the other hand, *Echinothrix diadema* showed an increase from 2006 to 2011, but declined after 2014. However, *Echinothrix diadema* population showed a significant decline in 2016, with density decreasing from around 40 ind./100m^2 in 2014 to less than 1 ind./100m^2 in 2016 (Figure 11). Only a few *E. diadema* were recorded from four sites (Avatiu, Kiikii, Titikaveka, and Vaimaanga) in 2016.

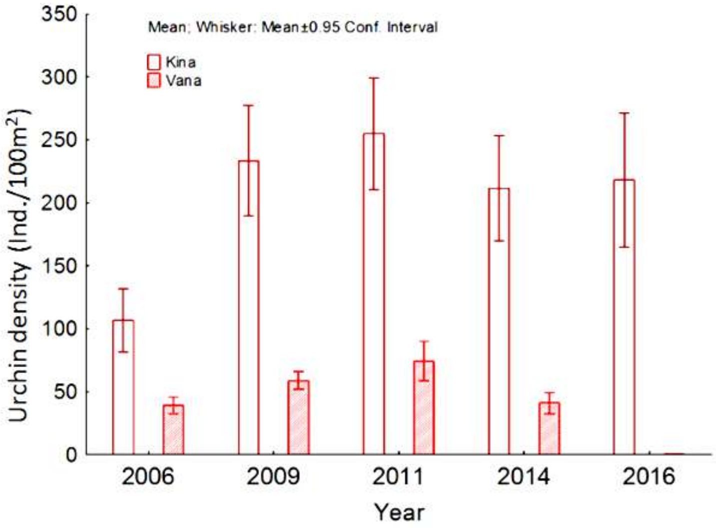

Figure 11. *Echinometra* spp (*kina*) and *Echinothrix diadema* (*vana*) density (ind./100 m^2) from 2006 to 2016. All sites were lumped for each year.

Principal Component Analysis of macro-invertebrates indicated that 90% of the variation was explained by the first three axes (Table 7). The eigenvectors (graphically superimposed on the ordination; Figure 12) indicated that *kina* (*Echinometra* spp.) had the most weight in the first axis (-0.946), *Dendropoma maxima* on the second axis (0.820), and *Echinothrix diadema* (*vana*) (0.806) on the third axis. Bubble plots showed a general increase in the *Echinometra* spp. (*kina;* Figure 13) from 2006 to 2011, then a decline to 2016. *Dendropoma* spp. (*ungakoa;* Figure 14) populations in 2006 to 2011 have always been low, and the increase only occurred in 2014 and 2016. On the contrary, *Echinothrix* spp. (*vana;* Figure 15) showed an increase from 2006 to 2011, but drastically declined in 2016 (Figure 12).

Table 7. Eigen analysis of macro - invertebrates in 2016 for all sites.

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	25.6	42.5	42.5
2	20.2	33.6	76.1
3	8.34	13.9	90.0
4	3.14	5.2	95.2
5	2.31	3.8	99.0

Eigenvectors

Variable	PC1	PC2	PC3	PC4	PC5
Echinometra (*kina*)	-0.946	-0.185	-0.231	0.054	0.120
Dendropoma	-0.282	0.820	0.456	-0.198	0.007
Echinothrix (*vana*)	-0.139	-0.477	0.806	0.073	-0.312
Echinostrephus	-0.018	0.244	-0.059	0.913	-0.294
Holothurian	0.074	-0.065	0.291	0.326	0.894
Trochus	-0.017	-0.025	-0.023	-0.088	0.015
Tridacna (*pa`ua*)	-0.014	0.040	0.019	0.067	-0.049

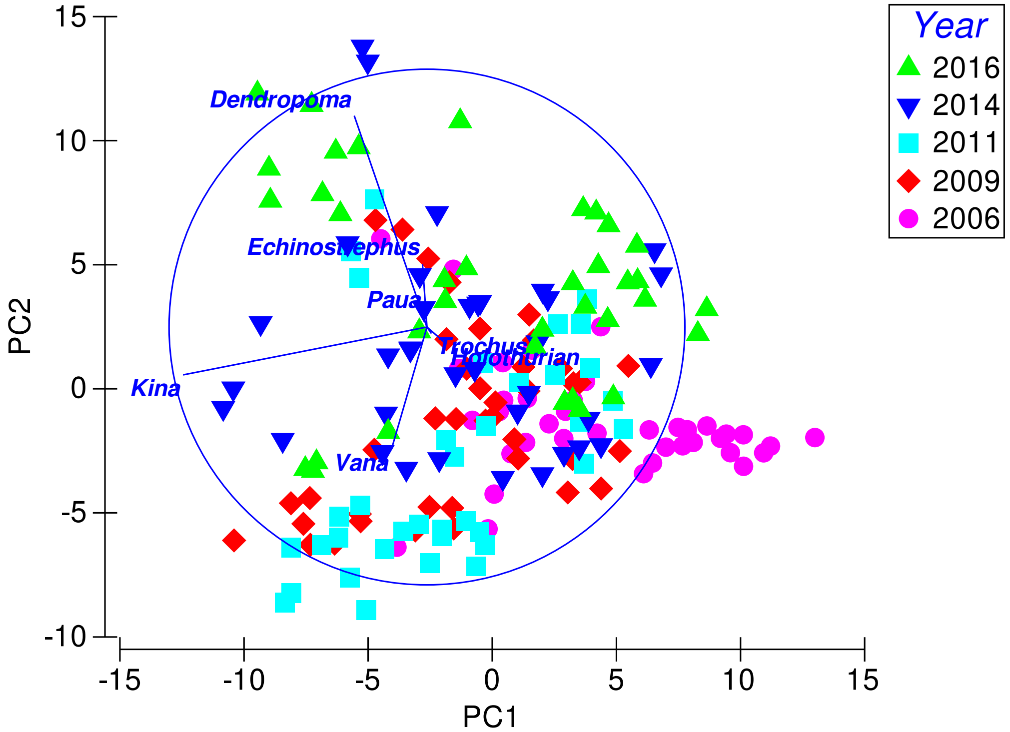

Figure 12. Principle Component Analysis (PCA) using all replicates for each invertebrate category for all sites from 2006, 2009, 2011, 2014, and 2016. Ordination of replicates were superimposed on the vector plot. Square root transformation was carried out on the data prior to PCA.

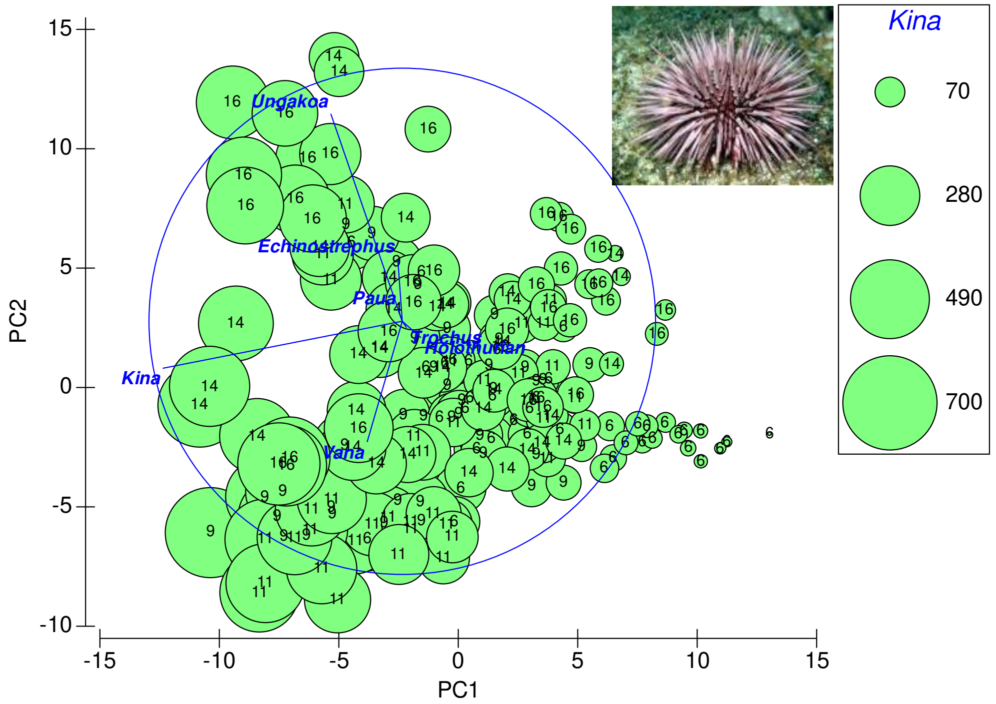

Figure 13. Principle Component Analysis (PCA) for *Echinometra* spp. (*kina*) using all replicates for all sites from 2006 (6), 2009 (9), 2011 (11), 2014 (14) and 2016 (16). Ordination of replicates were superimposed on the vector plot. Square root transformation was carried out on the data prior to PCA. Bubble values indicate the abundance (individuals per 100 m^2) of invertebrates for each replicate.

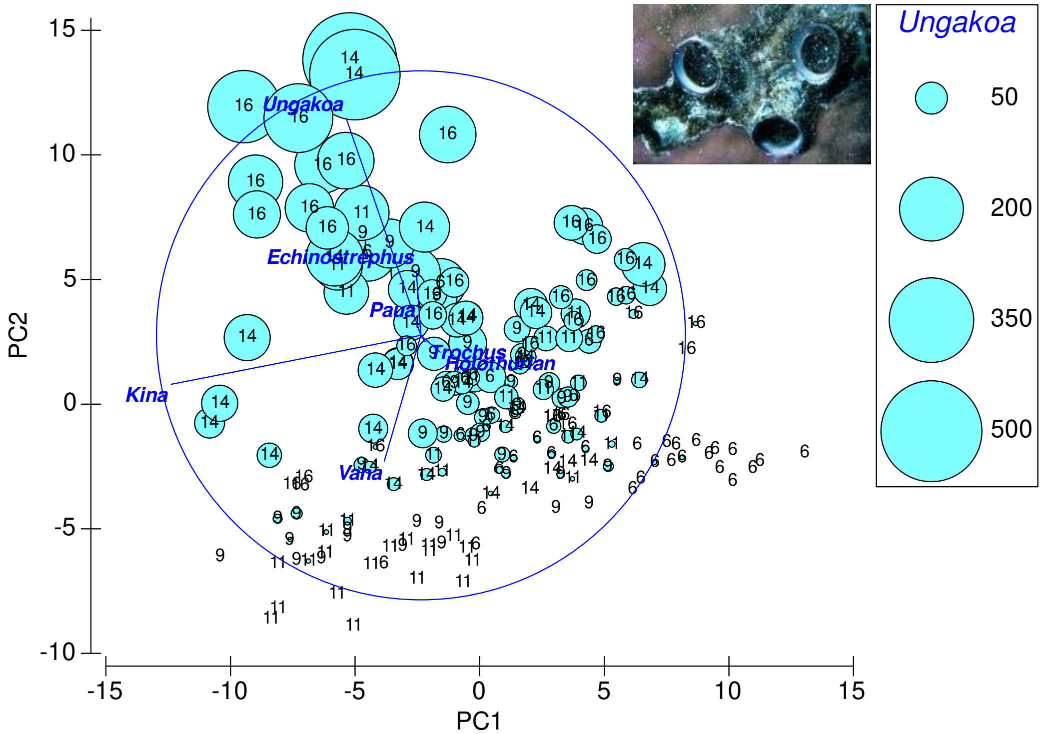

Figure 14. Principle Component Analysis (PCA) for *Dendropoma* spp. (*ungakoa*) using all replicates for all sites from 2006 (6), 2009 (9), 2011 (11), 2014 (14) and 2016 (16). Ordination of replicates were superimposed on the vector plot. Square root transformation was carried out on the data prior to PCA. Bubble values indicate the abundance (individuals per 100 m²) of invertebrates for each replicate.

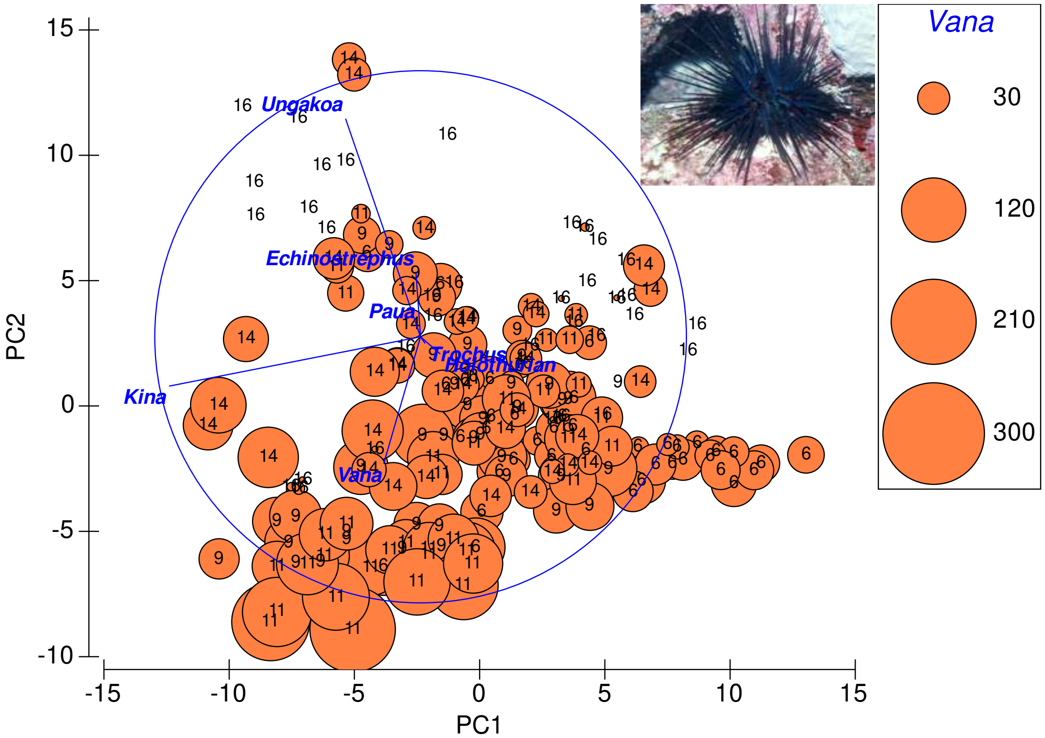

Figure 15. Principle Component Analysis (PCA) for *Echinothrix* spp. (*vana*) using all replicates for all sites from 2006 (6), 2009 (9), 2011 (11), 2014 (14) and 2016 (16). Ordination of replicates were superimposed on the vector plot. Square root transformation was carried out on the data prior to PCA. Bubble values indicate the abundance (individuals per 100m²) of invertebrates for each replicate.

4. DISCUSSION

The 2016 survey showed that the average coral cover around Rarotonga is now similar to cover noted in the 2000 survey (Lyons, 2000). For the last 13 years, following the crown-of-thorn starfish (COTS) outbreak between 1995 and 2001 and the passing of six cyclones in 2004 and 2005, hard coral cover has seen an increase from 1% in 2006 to 5% in 2009, 8% in 2011, 16% in 2014, and 27% in 2016 (Figure 16). When compared with average coral cover of 22.1% estimated from 2,667 Indo-Pacific reefs in 2003 (Bruno & Selig, 2007), the average estimate for Rarotonga is clearly above this in 2016 (see Figure 16). Considering the increase in average coral cover since 2006, we expect cover to reach the pre-COTS conditions of the 1990s (at >30%) by 2018 — a period of 17 years since the end of the COTS outbreak in 2001. In contrast, the recovery period estimated from the 1970s COTS outbreak took less than 10 years. Factors such as increased cyclone frequency (de Scally, 2008), coral bleaching (Rongo and van Woesik, 2013), nutrient overloading (e.g., Anderson et al., 2004), and perhaps ocean acidification (e.g., Kleypas et al., 1999) may all play an important role in determining the current state of Rarotonga's reefs.

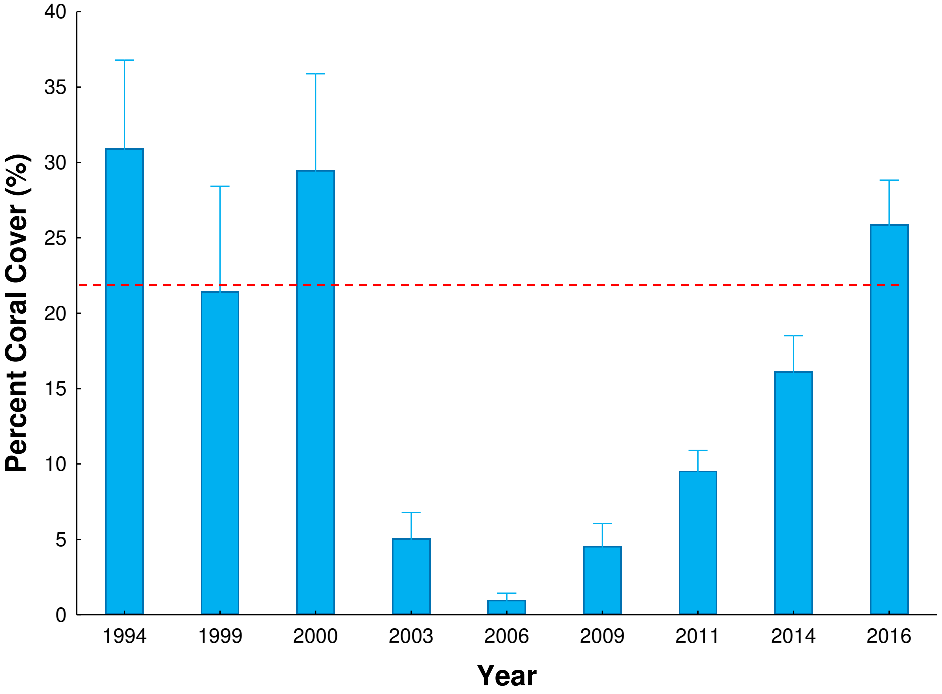

Figure 16. Mean percent coral cover for all sites lumped for each year. Data taken from 1994 (Miller, 1994), 1999 (Ponia et al., 1999), 2000 (Lyon, 2000), 2003 (Lyon, 2003), 2006 (Rongo et al., 2006), 2009 (Rongo et al., 2009), 2011 (Rongo & van Woesik, 2013), 2014 (Rongo et al., 2015) and 2016 from the present survey. Dotted red line represents the Indo-Pacific average of 22.1% estimated in 2003 (Bruno & Selig, 2007).

As noted in previous surveys, *Asparagopsis taxiformis* remained the most common macro algae observed on the reef slopes, which was particularly high at shallower sites (4 – 8 m). It must be noted that *A. taxiformis* is a chemically-defended algae and would therefore deter grazing by herbivorous species (e.g., Meyer et al., 1994). While *Echinothrix diadema* is an important grazer on the fore reefs and are non-selective with their algal food, their loss due to the recent die-off noted around Rarotonga may increase the cover of *A. taxiformis* in coming years. The high cover of macro algae noted at Avatiu, Kiikii, Motutapu, Taakoka, and Nikao may reflect the deteriorating conditions of these reefs due to poor land-use practices, and increased development along these coastlines. Of interest are the reefs in close proximity to the Tumunu site, which is directly offshore from the Blue Shop stream that drains the watershed where the Arorangi landfill is located. Although the Tumunu site was established to monitor the present landfill, located on a spur where current flow is sufficient, it is likely that this site is unable to detect the impact of the landfill. In support, reefs in the embayment just south of the Tumunu site, directly offshore from the Blue Shop stream mouth, was observed to have higher algal cover, less coral colonies in general, and poorer visibility. Indeed, future surveys may need to monitor this site as well to effectively determine the impact of the landfill and activities within this adjoining watershed.

Coral recovery on Rarotonga was also consistent with the increase of coral-associated fish species since 2006. In particular, pomacentrids (i.e., *Chromis vanderbilti and Pomachromis fuscidorsalis*) and chaetodontids (*Chaetodon* spp.) showed an increase from 2006 to 2016. Acanthurids, on the other hand, showed a decline since 2006. Rongo and van Woesik (2013) suggested that major reef disturbances (i.e., COTS outbreaks and cyclones) that occurred prior to 2006 on Rarotonga resulted in a shift towards an algal-dominated community. Consequently, more food was available to grazers that likely supported large recruitment of acanthurids (mainly *Ctenochaetus striatus*) as observed in 2006 (Rongo et al., 2015). Their increase also suggested that early algal successions consisted mainly of palatable types, but shifted towards unpalatable types over the years because no major disturbances have occurred since 2005 to remove them. This shift to unpalatable algal types likely contributed to the general decline in acanthurid populations since 2006 as less food was available. It is unlikely that overfishing is a contributing factor given the fear of ciguatera poisoning is still ingrained into residents from the high incidence experienced in the last 20 years or so (Rongo & van Woesik, 2011).

In 2006, a large number of small colonies of *Leptoria phrygia* that would be considered recruits were clearly remnants of what used to be larger colonies. Recruits belong to several species of *Acropora, Favia* and *Pocillopora,* which comprised only 12% of the colonies within class A. Interestingly, larger colonies (class D) recorded in 2006 were predominantly *Porites* in the Avarua area and colonies of *Pocillopora* (Rongo et al., 2006), which notably escaped predation by COTS. However, during this recovery stage, we note that in 2014 and 2016, *Acropora* were among the most common corals in the larger size class (16 to < 32 cm). Based on observation from the pre-COTS period in the 1990s, large plate-like colonies of *Acropora* were among the most dominant coral on the reef slope (T. Rongo, pers. comm.). The increase of acroporid species in the larger size classes clearly indicates a shift towards the pre-COTS conditions of the 1990s.

With coral recovery occurring on Rarotonga, establishing new *ra`ui* or enforcing the management of the current *ra`ui* around the island as well as implementing fishing quotas should be considered, especially as reef fishing activities are expected to increase following the decline in ciguatera poisoning in recent years. In addition, good land-use practices to reduce runoff sediment as well as continued efforts to reduce nutrient inputs will be critical at this stage not only to facilitate recovery, but also to build the resilience of these reefs to the impacts of climate change. Although conditions have been favorable over the years to trigger coral bleaching events, this was not monitored because coral cover has been too low to properly assess. Considering that coral cover has increased over the years, we expect coral bleaching to become more evident and assessments should be included in future surveys. Although monitoring every two to three years has been carried out, intermittent disturbances such as coral bleaching and reef diseases that may occur between survey intervals should also be examined.

Unfortunately, following the completion of this survey, a bleaching event occurred between December 2016 and April 2017, which could not be assessed because of lack of funding. Around 80% of corals were observed to have been bleached, and assuming all bleached corals died, we suggest that the average coral cover for all sites would have decreased to around 5%. However, some corals (especially partially bleached colonies) were observed to have fully recovered in June during the preparation of this report (T. Rongo, pers. comm.), and therefore we expect the average coral cover around Rarotonga in the next survey to be higher than the 5% suggested in this survey.

Observed oceanographic changes such as stronger currents and rougher sea conditions associated with the intensification of tradewinds in recent decades (e.g., England et al. 2014) throughout most of the Cook Islands (Rongo and Dyer, 2014) is a concern because such changes may decrease the recruitment of many marine organisms to natal reefs (see Kingsford et al., 2002 and references therein). For example, increased flow rate from 1.6 to 9.8 cm/sec decreased recruitment in a coral species from 20% to 2% respectively (Harii & Kayanne, 2002). In support, Rongo and Dyer (2014) indicated that recruitment of many seasonal reef fish species throughout the Cook Islands has declined. In Manihiki, a species of parrotfish (*tomore*; *Scarus* spp.) that normally recruit in the thousands within the lagoon are rarely seen today. In many of the southern islands, *Siganus spinus* and *S. argenteus,* two important food fish that have recruited in large numbers in the past, are rarely seen today. In addition, Rongo and Dyer (2014) suggested that the effect of stronger currents and increased frequency of storm surge in recent decades may be responsible for increased sediment transport within many lagoons throughout the Cook Islands. Sedimentation in the marine environment can be detrimental to coral growth and recruitment (e.g., Rogers, 1990); it is likely that sedimentation is contributing to the slow recovery of Rarotonga's reefs. Understanding recruitment patterns of reef fishes and the rates of marine sedimentation should be monitored in upcoming surveys to determine their contribution to the state and recovery of reefs on Rarotonga.

Urchin die-off

The die-off of *Echinothrix diadema* populations (Figure 17) on Rarotonga and two other islands in the southern group (Mitiaro and Mauke) between May and November 2016 is of interest. The die-off was first reported by dive operators on the fore reef in the Avarua area in August/September 2016, and by October almost all *E. diadema* on the reef flat were killed and only a few recorded on the fore reef during the survey (see Figure 11). Although the cause of the disease is yet to be determined, a die-off of a similar urchin *Diadema antillarum* was noted in the Caribbean in the 1980s (see Lessios, 2016, and references therein), which to this day the cause is still unknown. Although urchin die-off appeared to be species specific on Rarotonga with the highest mortality noted among *E. diadema* populations, tests of other species (i.e., *Echinometra mathaei*) were also found in small numbers along the coast. At the point of this assessment, the inclusion of other urchin species was difficult because none were found to be in a similar dying state to *E. diadema*. Of note is the analysis carried out by CAWTHRON Institute in New Zealand for marine toxins on urchin samples flown over for testing. Though many marine toxins were tested, a cyanobacteria-specific toxin was detected from the urchin viscera (S. Murray, pers. comm). Through cyanobacterial sequencing, it was identified that the toxin was produced by *Nostoc* spp., which is a bacteria normally found in freshwater to brackish water environments.

Figure 17. *Left:* diseased *Echinothrix diadema* found on the reef flat of Avarua; photo by Anabelle Phillips. *Right*: dead tests of *Echinothrix diadema* on the shores of Mauke in the southern Cook Islands; photo by Tai George.

Interviews with elders on Rarotonga suggested that a similar die-off may have occurred in the early 1950s. According to those interviewed, reef flat fishing in the southern Cook Islands during this period was often done barefoot, suggesting that urchins were uncommon on the reef flat. We ask, could the past and recent die-offs be related to a shift in rainfall patterns associated with the Pacific Decadal Oscillation (PDO)? In particular, a shift from a predominantly dry period to a predominantly wet period may have changed the composition of marine flora to a state unfavorable for *E. diadema*. The 1950s anecdotal reports of urchins being uncommon on the reef flat coincided with the late 1940s shift from a dry period to a wet period in the southern Cook Islands (positive PDO to negative PDO; Figure 18). In addition, the recent urchin die-off also coincided with the recent shift to a predominantly wet period experienced today. In support, we note that the cyanotoxin detected in the urchin samples were those produced by *Nostoc* spp., which is a fresh/brackish water bacteria. Further culturing studies and toxicity analysis is required by CAWTHRON to determine whether this toxin detected is responsible for the urchin die-off. In addition, we need to determine the extent of the die-off throughout the Cook Islands because if the problem is spread by currents, such information may also shed light on connectivity among islands, which is not only useful for managing marine diseases in the future, but also for the planning of Marine Protected Areas within the Cook Islands.

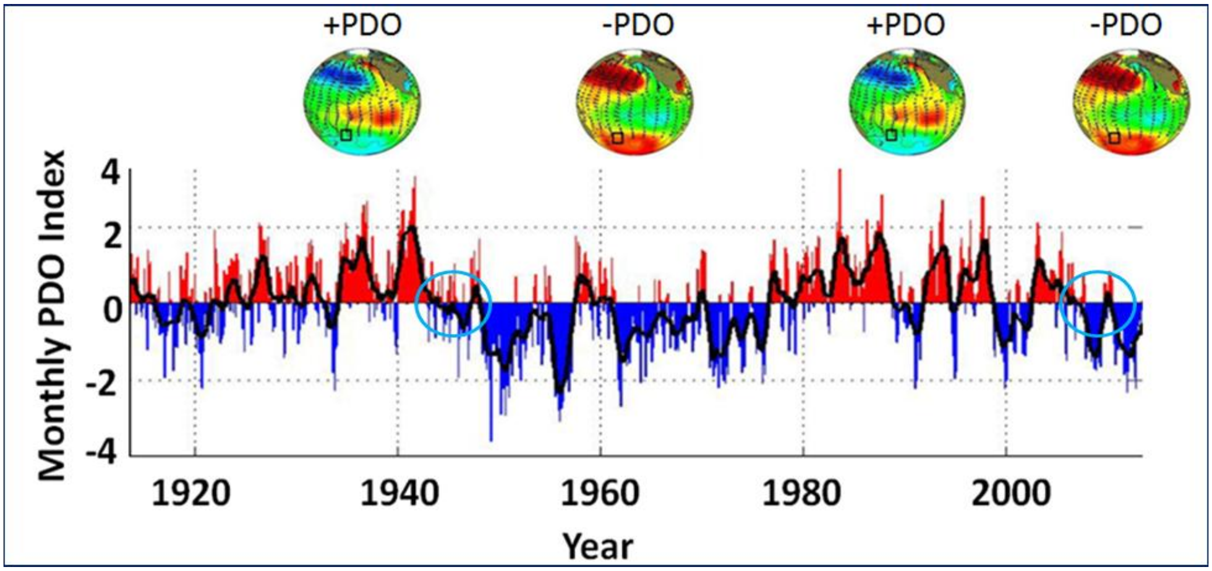

Figure 18. Monthly values for the Pacific Decadal Oscillation (PDO) from 1910 to 2013 (modified from http://jisao.washington.edu/pdo/). Blue circles indicate the period of transition from a dry to a wet period in the southern Cook Islands, which seems to coincide with the *Echinothrix diadema* die-off.

5. RECOMMENDATIONS

The following are recommendations derived from this study:

- Over the last two decades, the monitoring of Rarotonga's reefs has been at the mercy of funding and the availability of trained individuals. While it is critical that reef monitoring continues, there is need to determine who will carry this out in the long term. Though government ministries such as the Ministry of Marine Resources, National Environment Service, and Climate Change Cook Islands of the Office of the Prime Minister have all led past monitoring efforts, we highly recommend future monitoring efforts be conducted independently of government to avoid conflicts of interest.
- While funding in the past has been secured to monitor Rarotonga's reefs every two to three years in general, funds should also be available to investigate intermittent disturbances as they occur (e.g., coral bleaching events and various reef-associated diseases) to enable decision makers to understand the causes and take action accordingly.
- Considering that the recent coral bleaching event in 2016/2017 occurred after the data collection for this survey concluded, there is a need to properly assess this bleaching event in 2017 to determine the mortality and recovery rates among species and sites.
- Understanding the cause of the urchin die-off is critical to elucidate the impacts of climate change and variability as well as poor land-use practices on Rarotonga. Urchin samples collected during the disease outbreak in 2016 went through some testing at CAWTHRON in New Zealand, however more funding is needed to proceed with further investigation via culturing studies and toxicity tests.

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The research team consisted of:

- Teina Rongo (Head Researcher; Office of the Prime Minister) – benthic communities
- James Kora (volunteer) – macro-invertebrates
- Graham McDonald (volunteer) – fish
- Annabelle Phillips (volunteer) – benthic communities
- Alanna Smith (Te Ipukarea Society) – macro-invertebrates

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APPENDICES

APPENDIX A. Checklist of coral species recorded by site in the present survey around Rarotonga.

FORE REEF SPECIES	Avarua	Avatiu	Beachcomber	Kavera	Kiikii	Motutapu	Nikao	Taakoka	Titikaveka	Vaimaanga
ACROPORIDAE										
Acropora aspera			x							
Acropora carduus										x
Acropora danai				x				x	x	x
Acropora digitifera	x	x	x	x	x	x	x	x	x	x
Acropora humilis	x	x	x	x				x		x
Acropora hyacinthus	x	x	x	x	x	x	x	x	x	x
Acropora lutkeni			x	x	x		x	x	x	
Acropora monticulosa				x		x	x		x	x
Acropora palmerae					x					
Acropora samoensis	x	x	x	x		x	x	x	x	x
Acropora verweyi							x			x
Astreopora myriophthalma	x	x								x
Montipora (blue)			x		x		x			
Montipora (brown)	x	x	x		x	x	x	x	x	x
Montipora (purple)								x		
AGARICIIDAE										
Pavona clavus								x		
Pavona minuta					x				x	
Pavona varians	x	x								
DENDROPHYLLIIDAE										
Turbinaria reniformis				x						
FAVIIDAE										
Cyphastrea serailia	x	x	x	x	x	x	x	x		
Favia rotumana	x	x			x	x		x		x
Favia stelligera	x	x	x	x	x	x	x	x	x	x
Favites flexuosa	x	x		x	x		x	x		
Goniastrea pectinata	x	x	x	x	x		x		x	
Leptastrea pruinosa			x							
Leptastrea purpurea	x	x	x	x	x	x	x	x		x
Leptastrea transversa	x	x	x		x	x	x			
Leptoria phrygia	x	x	x	x	x	x	x	x	x	x
Montastrea curta	x	x	x	x	x	x	x	x	x	x
Montastrea valenciennesi							x			
MERULINIDAE										
Hydnophora microconos	x	x	x	x	x	x	x	x	x	x
MILLEPORIDAE										
Millepora platyphyla			x						x	
MUSSIDAE										
Acanthastrea echinata	x	x	x	x	x	x	x	x	x	x
Lobophylia hemprichii	x	x	x							
PECTINIIDAE										
Echinophyllia spp								x		
POCILLOPORIDAE										
Pocillopora damicornis			x	x		x		x	x	x
Pocillopora eydouxi	x	x	x					x		x
Pocillopora meandrina	x	x				x				
Pocillopora verrucosa			x	x	x	x	x	x	x	x
PORITIDAE										
Porites australiensis	x	x								
Porites lobata	x	x	x	x	x		x	x		x
Porites lutea	x	x	x	x	x	x	x	x		x
SIDERASTREIDAE										
Coscinaraea columna	x	x		x			x			
Psammocora obstusangula				x		x		x	x	x
Psammocora profundacella	x	x								
ZOANTHID										

Zoanthid sp				x						x
ALCYONIDS (soft corals)										
Cladiella krempfi							x			
Cladiella sp	x	x	x	x	x			x	x	x
Lobophytum			x							x
Sinularia spp								x	x	x
TOTAL SPECIES	**27**	**27**	**27**	**25**	**22**	**19**	**24**	**27**	**20**	**27**
TOTAL FAMILIES	**9**	**9**	**8**	**10**	**8**	**7**	**8**	**10**	**9**	**9**

APPENDIX B. Checklist of fish species recorded in the present survey around Rarotonga.

FAMILY	COMMON NAME	Tumunu	Nikao	Avarua	Avatiu	Motutapu	Kiikii	Titikaveka	Vaimaanga	Taakoka	Beachomber
ACANTHURIDAE	**Surgeons, Tangs, Unicorns**										
Acanthurus guttatus	Whitespotted Surgeonfish							x	x		
Acanthurus leucopareius	Whitebar Sugeonfish		x						x	x	
Acanthurus nigricaudus	Blackcheek Surgeonfish						x				
Acanthurus nigrofuscus	Brown Surgeonfish	x	x	x	x	x	x	x	x	x	x
Acanthurus olivaceus	Orangeband Surgeonfish		x		x	x				x	x
Acanthurus triostegus	Convict Tang				x		x	x			
Ctenochaetus hawaiensis	Hawaiian Surgeonfish		x	x	x			x	x		
Ctenochaetus striatus	Bristletooth Surgeonfish	x	x	x	x	x	x	x	x	x	x
Naso lituratus	Orangespine Unicorn		x	x	x	x	x	x	x	x	x
Zebrasoma scopas	Brushtail Tang		x			x			x	x	
BALISTIDAE	**Triggerfish**										
Melichthys niger	Black Triggerfish							x			
Melichthys vidua	Pinktail Triggerfish					x				x	x
Pseudobalistes fuscus	Blue Triggerfish						x				x
Rhinecanthus aculeatus	Lagoon Triggerfish			x							
Rhinecanthus rectangulus	Wedgetail Triggerfish				x	x	x	x	x		x
Sufflamen bursa	Scythe Triggerfish	x	x	x	x	x	x				x
BLENNIIDAE	**Blenny**										
Aspidontus taeniatus	Mimic Cleaner	x	x	x	x	x	x	x	x		x
Cirripectes variolosus	Red-speckled Blenny	x	x	x	x	x	x	x	x		x
Enneapterygius sp	Striped Triplefin	x			x		x	x	x		
Exallias brevis	Shortbodied Blenny		x	x		x	x	x			x
Plagiotremus tapeinosoma	Piano Blenny	x	x	x	x	x	x			x	x
Stanulus talboti sp	Talbot's Blenny					x	x	x	x		
CAESIONIDAE	**Fusiliers**										
Pterocaesio tile	Neon Fusilier							x			
CARACANTHIDAE	**Coral Crouchers**										
Caracanthus maculatus	Spotted Coral Croucher	x	x	x	x	x	x	x	x		x
CHAETODONTIDAE	**Butterflyfish**										
Chaetodon auriga	Threadfin Butterflyfish		x	x				x			
Chaetodon bennetti	Bennett's Butterflyfish		x								
Chaetodon citrinellus	Speckled Butterflyfish		x	x	x		x	x			x
Chaetodon ephippium	Saddled Butterflyfish								x		
Chaetodon lunula	Racoon Butterflyfish							x			
Chaetodon ornatissimus	Ornate Butterflyfish	x	x	x	x	x				x	x
Chaetodon pelewensis	Dot-and-Dash Butterflyfish		x	x		x	x				
Chaetodon punctatofasciatus	Spotband Butterflyfish										x
Chaetodon quadrimaculatus	Four-spot Butterflyfish		x	x	x	x	x	x	x	x	
Chaetodon reticulatus	Reticulated Butterflyfish		x	x	x		x	x	x	x	x
Chaetodon ulietensis	Pacific Double-saddled Butterflyfish									x	
Chaetodon unimaculatus	Teardrop Butterflyfish	x	x		x		x	x	x	x	
Chaetodon vagabundas	Vagabond Butterflyfish		x							x	x
Forcipiger flavissimus	Longnose Butterflyfish		x		x		x				
Heniochus monoceros	Masked Bannerfish				x						
CIRRHITIDAE	**Hawkfish**										
Cirrhitops hubbardi	Hubbard's Hawkfish	x	x	x	x	x	x	x	x		x
Neocirrhtes armatus	Flame Hawkfish	x	x	x	x	x	x	x	x		x
Paracirrhitus arcatus	Arc-eye Hawkfish	x	x	x	x	x	x	x	x		x
Paracirrhitus forsteri	Freckled Hawkfish			x			x	x	x		
Paracirrhtes hemistictus	Spotted Hawkfish							x	x		
GOBIIDAE	**Goby**										
Valenciennea strigata	Bluestreak Goby			x	x		x				
LABRIDAE	**Wrasses**										
Anampses caeruleopunctatus	Blue Spotted Wrasse		x		x	x	x	x	x		x
Cheilio inermis	Cigar Wrasse		x		x						x
Chelinus chlorourus	Floral Wrasse					x				x	
Chelinus trilobatus	Tripletail Wrasse		x	x		x					

Cirrhilabrus scottorum	Scott’s Wrasse	x	x								
Coris aygula	Clown Coris				x						
Coris centralis	Central Pacific Coris					x	x	x			
Coris gaimard	Yellow-tail Coris							x			
Coris roseoviridis	Vivid Rose Coris	x	x	x		x	x				
Gomphosus varius	Bird Wrasse	x	x	x	x	x	x	x	x	x	x
Halichoeres hortulanus	Checkerboard Wrasse						x		x		
Halichoeres margaritaceus	Weedy Surge Wrasse				x	x	x				x
Halichoeres marginatus	Dusky Wrasse		x				x	x	x		
Halichoeres ornatissimus	Ornate Wrasse	x	x	x	x	x	x	x	x		x
Hemigymnus fasciatus	Barred Thicklip Wrasse							x			
Hologymnosus annulatus	Ring Wrasse		x	x			x				
Laabroides bicolor	Bi-color Cleaner Wrasse							x	x	x	
Labroides dimidiatus	Blue-streak Cleaner Wrasse			x		x	x	x	x	x	
Labroides rubrolabiatus	Red-lipped Cleaner Wrasse								x		
Macropharyngodon meleagris	Leopard Wrasse	x		x	x		x			x	x
Oxycheilinus unifasciatus	Ringtail Wrasse	x			x		x				x
Pseudocheilinus tetrataenia	Fourline Pygmy Wrasse	x	x	x	x	x		x	x		x
Stethojulis bandanensis	Redshoulder Wrasse		x	x	x	x					x
Stethojulis strigiventer	Stripebelly Wrasse										
Thalassoma lutescens	Sunset Wrasse	x	x	x	x	x	x	x	x	x	x
Thalassoma quinquevittatum	Fivestripe Wrasse	x	x	x	x	x	x	x			x
LUTJANIDAE	**Snapper**										
Aphareus furca	Smalltooth Jobfish				x				x		
MONACANTHIDAE	**Filefish**										
Cantherhrines sanwichiensis	Squaretail Filefish	x									x
MULLIDAE	**Goatfish**										
Parupeneus bifasciatus	Island Goatfish						x			x	
Parupeneus cyclostomus	Goldsaddle Goatfish		x	x			x		x		
Parupeneus multifasciatus	Multibar Goatfish	x	x	x	x		x		x	x	x
PINGUIPEDIDAE	**Sandperch**										
Parapercis millipunctata	Spotted Sandperch	x	x		x	x	x				x
Parapercis clathrata	Latticed Sandperch									x	
POMACANTHIDAE	**Angelfish**										
Centropyge flavissimus	Lemonpeel Angelfish	x	x		x	x		x	x	x	x
Centropyge loriculus	Flame Angelfish	x						x			
Pomacanthus imperator	Emperor Angelfish		x		x				x		
POMACENTRIDAE	**Damselfish**										
Chromis acares	Midget Chromis			x							
Chromis vanderbilti	Vanderbilt’s Chromis	x	x	x	x	x		x	x	x	x
Chromis xanthura	Variable Chromis		x								
Chryseptera brownriggii	Surge Damselfish										x
Chrysiptera galba	Canary Damselfish			x							
Dascyllus flavicaudus	Yellowtail Dascyllus		x								x
Dascyllus trimaculatus	Three-spot Dascyllus		x				x				x
Plectroglyphidodon imparipennis	Brighteye Damselfish	x	x	x	x	x	x	x		x	x
Plectroglyphidodon johntonianus	Johnston Damselfish	x	x	x	x	x	x	x	x	x	x
Plectroglyphidodon phoenixensis	Pinkbarred Damselfish										x
Pomacentrus vaiuli	Princess Damselfish										x
Pomachromis fuscidorsalis	Tahitian Damselfish	x	x	x	x	x				x	x
Stegastes fasciolatus	Pacific Gregory	x	x	x	x	x	x	x	x	x	x
PTERELEOTRIDAE	**Dartfishes**										
Nemateleotris magnifica	Fire Dartfish	x		x	x		x				
Ptereleotris evides	Two-tone Dartfish		x								
SCARIDAE	**Parrotfish**										
Calotomus carolinus	Stareye Parrotfish					x				x	
Chlorurus sordidus	Bullethead Parrotfish		x	x	x		x	x	x	x	x
Scarus altipinnis	Filament Fin Parrotfish				x		x		x		x
Scarus forsteni	Bluepatch Parrotfish								x	x	
Scarus frenatus	Bridled Parrotfish						x		x		x
Scarus globiceps	Violet-lined Parrotfish				x		x		x		
Scarus psittacus	Pale-nose Parrotfish	x	x	x	x	x	x	x	x	x	x
Scarus schlegeli	Yellowbar Parrotfish		x	x	x		x				x
SCORPAENIDAE	**Scorpionfish**										
Sebastapistes cyanostigma	Yellowspotted Scorpionfish					x	x		x		x

SERRANIDAE	**Groupers and Allies**										
Cephalopholis argus	Peacock Grouper		x	x	x	x	x	x	x	x	
Cephalopholis urodeta	Flagtail Grouper		x	x		x	x			x	
Epinephalus fasciatus	Blacktip Grouper			x							
Epinephalus hexogonatus	Hexagon Grouper	x	x	x		x	x	x	x	x	x
Gammistes sexlineatus	Sixline Soapfish			x	x		x				x
SYNODONTIDAE	**Lizardfish**										
Synodus jaculum	Javelinfish				x						
TETRADONTIDAE	**Toby**										
Canthigaster amboinensis	Spider-eye Toby		x		x		x		x	x	x
Canthigaster solandri	Blue-spotted Toby	x	x	x	x		x		x	x	x
ZANCLIDAE	**Moorish Idol**										
Zanclus cornutus	Moorish Idol		x			x	x		x	x	x
	TOTAL FAMILIES	**22**									
	TOTAL SPECIES	**114**									

APPENDIX C. Checklist of macro-invertebrates recorded at each site in the present survey around Rarotonga.

Site	**Kina**	**Vana**	***Echinostrephus***	**Trochus**	**Pa`ua**	***Dendropoma***
Avatiu	x	x	x		x	x
Avarua	x		x	x	x	x
Beachcomber	x		x		x	x
Kiikii	x	x	x		x	x
Motutapu	x		x		x	x
Taakoka	x		x	x	x	x
Titikaveka	x	x	x	x		x
Vaimaanga	x	x	x		x	
Kavera	x		x	x	x	x
Nikao	x		x	x	x	x