Marine survey analysis for the proposed cruise ship landing jetty site in Arorangi

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EXECUTIVE SUMMARY

The Cook Islands Ports Authority is proposing to construct an alternative landing site for cruise ships during unfavorable sea conditions at the Avatiu Harbour. The Arorangi passage was considered an ideal site because it is located on the leeward exposure of Rarotonga where sea conditions are calm over 75% of the year, and a natural passage exists. As part of an Environmental Impact Assessment report, a marine survey was conducted to examine the potential impacts of the proposed jetty to the marine ecosystem and to stakeholders in the area. While data from previous studies and the present study showed that reef recovery around Rarotonga is well underway, it is critical that any activity that may jeopardize recovery is properly examined to ensure that impacts to the marine ecosystem are minimal. The jetty site was typical of reefs on the western exposure of Rarotonga, and no unique or endemic species were recorded on the reef flat or fore reef slopes. The high structural complexity of live and dead corals in the reef flat area at the site not only provide refuge for juvenile species but also buffer the effect of currents flushing out the Arorangi passage during tidal changes. The widening of the Arorangi passage to accommodate the design is perhaps the main concern. It is anticipated that the widening may increase, to some degree, flushing through the passage during tidal changes, which may cause erosion of coastal areas at least in the vicinity of the passage; this may also impact reef communities in the area from increased sediment load.

INTRODUCTION

Coral reefs play an essential role in protecting low-lying coastal areas from strong wave action and erosion. This delicate ecosystem provides many benefits, especially to island inhabitants whose lifestyle and culture have been reliant on ocean resources for centuries. Such benefits include food, recreational opportunities, medicinal products, and recently a major attraction for tourism industries, which is the foundation for the Cook Islands economy. With the increase of human activities over the years, coral reefs and coastal ecosystems around the world have been degraded (Wilkinson, 2004).

In the last few decades, reefs around Rarotonga (Figure 1) have experienced several natural disturbances. Devaney & Randall (1973) reported the first known crown-of-thorns starfish (COTS) outbreak in Rarotonga in the 1970s, which coincided with a COTS outbreak that extended across the Pacific Ocean (Sapp, 1999). The second COTS outbreak occurred from 1995 to 2001, which caused a decline in hard coral cover from more than 40% at most sites to less than 2% in 2006 (Rongo *et al.*, 2006). Coral bleaching has also contributed to the degradation of these reefs, particularly the events noted in 1991 and 1994 during elevated sea surface temperatures associated with El Niño episodes (Goreau and Hayes, 1995). These bleaching events were largely the result of extreme low tides such as those observed in 2001 and 2009 (Rongo *et al.*, 2009). Under such conditions, the reef edge is frequently exposed and lagoonal exchange with the adjacent ocean is reduced, increasing coral loss from increased irradiance and elevated temperatures. Such conditions have also been suggested to cause ciguatera fish poisoning in Rarotonga (Rongo and van Woesik, 2011).

Cyclones also impact the recovery of reefs (Wilson *et al.*, 2006), and frequency increases during El Niño events in the southern Cook Islands (Baldi *et al.*, 2009). For example, between 1970 and 2006, 56% of cyclones occurred during El Niño events while 9% occur during La Niña events (de Scally, 2008). Following the COTS outbreak in the 1990s, the five cyclones that swept through this region in 2005 may have impacted the recovery of the reefs around Rarotonga. Regardless, a follow-up of the 2006 survey in 2009 (Rongo *et al.*, 2009) indicated that reef recovery was well underway. Therefore, it is important that any activity that can potentially jeopardize this recovery is properly examined and its impact on the marine environment is minimal.

The Cook Islands Ports Authority is proposing to construct an alternative landing site for cruise ships in the village of Arorangi (see Figure 1) during unfavorable sea conditions at the Avatiu Harbour. The selection of this site was based on several factors, and from a marine perspective these include: 1) there is an existing passage, suggesting that changes to the reef area will be minimal, and 2) the site is located on the leeward exposure of the island. In support, several studies in the past (e.g., Thompson, 1984; Drumm, 2004) have shown that the general wind direction at the Arorangi site is predominantly offshore with only approximately three months of the year where moderate to rough sea conditions are experienced (see Figure 1). The goal of this survey was to examine and quantify the reef fauna and flora in close proximity to the proposed site (Appendix A). Comparison to other locations around Rarotonga were also made for a more extensive understanding of the relevance of this site to the ecology of Rarotonga's reefs.

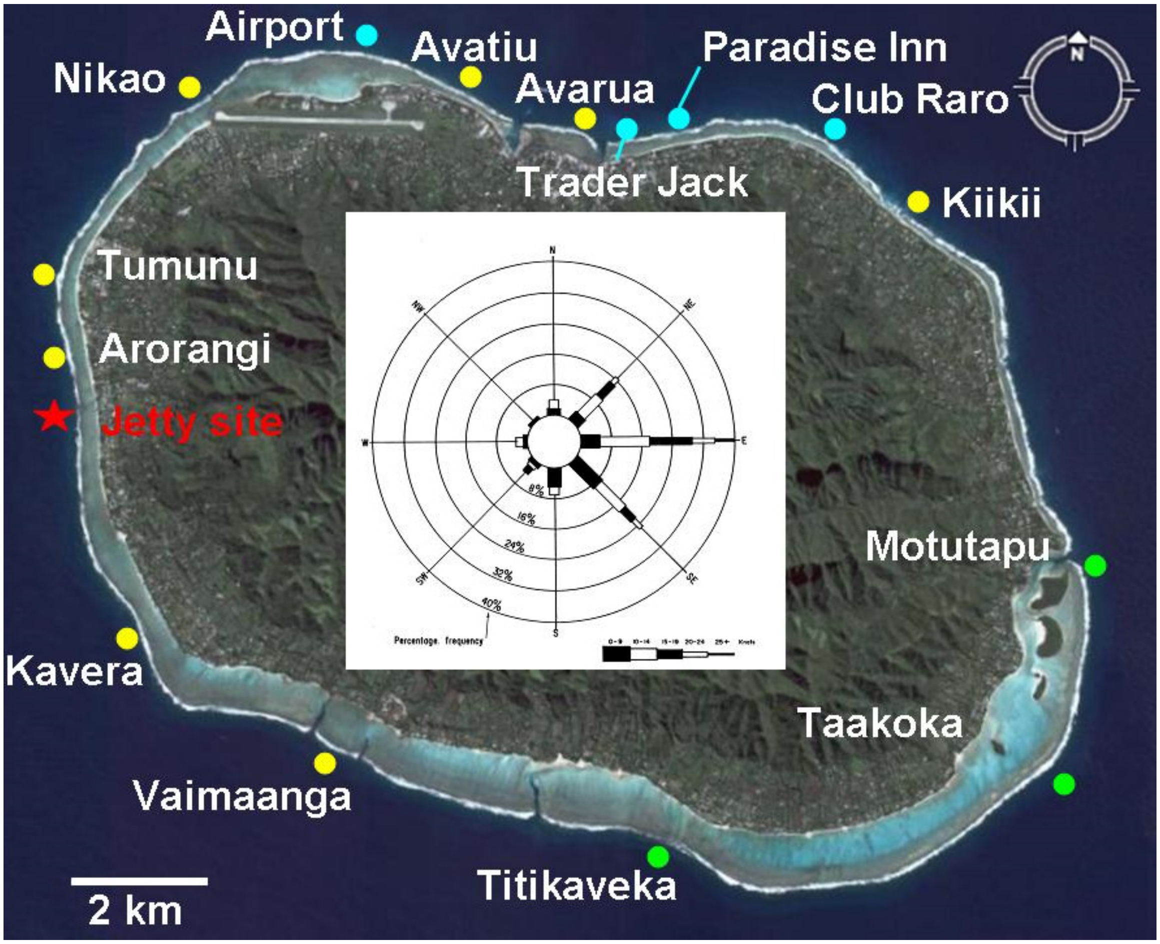

Figure 1. Map of Rarotonga (21° 12’ S, 159° 43’ W) with fore reef sites surveyed in the present survey (yellow and blue dots) as well as in previous surveys by the Ministry of Marine Resources and the National Environment Service (yellow and green dots). Red star indicates the site of the proposed cruise ship landing jetty. Picture taken from Google Earth. *Center*: Wind rose for the southern Cook Islands using open ocean surface wind estimates (percent frequency noted), generated by the New Zealand Meteorological Service. Taken from Holden (1992a).

MATERIALS AND METHODS

Site selection and survey methods

Fore reef sites within the proposed development area were examined and compared with sites previously surveyed around Rarotonga by the Ministry of Marine Resources (MMR) in 1994 and 1999 (Miller *et al.*, 1994; Ponia *et al.*, 1999), and the National Environment Service (NES) in 2000 (Lyon, 2000), 2003 (Lyon, 2003), 2006 (Rongo *et al.*, 2006), and 2009 (Rongo *et al.*, 2009). For the purposes of this proposal, a fore reef survey was conducted in June 2011 at selected sites, which examined: 1) the percent cover of corals and other benthos, and 2) the density and diversity of corals. Macro-invertebrate and fish communities were only examined at Tumunu, Jetty Site, Avatiu, and Avarua. Four 50-m transects (replicates) were deployed following the reef contour at a depth of 7 m parallel to shore, and laid consecutively at intervals of 10 m (Figure 2). Methods were kept consistent with previous surveys so comparisons could be made (see Rongo *et al.*, 2006, for a detailed description of survey methods). Coral (Veron,1986; 2000) and fish references (Myers, 1989; 1999; Randall, 2005) were used to verify identifications.

Reef flat sites within the proposed development area were examined by MMR in 2010 (Makikiriti *et al.*, 2010), with detailed information on macro-invertebrate and fish communities. However, more detailed information was needed on benthic communities, therefore the area on the northern side of the channel was re-examined on 24 June 2011. Preliminary analysis indicated that coral and fish diversity were similar with 2006 data (see Rongo *et al*., 2006) from a reef flat site located 700 m north of the Arorangi passage. Therefore no control site was examined for the present reef flat survey. Four 50-m transects were deployed parallel to shore at 10 m apart (see Figure 2). Percent cover of benthos and coral density and diversity were recorded, and a species checklist for hard corals and fishes generated.

Figure 2. Transects deployed on the fore reef (red lines) and reef flat (yellow lines) within the proposed jetty development area in the village of Arorangi.

Site description

Reef flat width from shore to the surf zone is approximately 200 m, with depths varying between 0.6 – 0.9 m at high tide (see Makikiriti *et al.*, 2010). The reef flat is dominated by large carbonate structures of dead corals (i.e., micro-atolls), typical of reefs on the western exposure. These structures provide refuge for juvenile species and are important for reducing flushing of the reef flat through major channels such as the Arorangi passage.

The fore reef slope outside the passage is typical of most reefs around Rarotonga, with live coral colonies of mainly *Acropora* species in the surf zone at depths less than 3 m that escaped COTS predation in the last outbreak. Beyond this zone, benthic substrate is primarily composed of turf algae and crustose coralline algae with the reef having less rugosity. Reef rugosity increases at depths greater than 7 m, largely the result of dead tabular and branching forms of mainly *Acropora* colonies from the last COTS outbreak.

Data analysis

Microsoft Excel, PivotTable, and PivotChart were used for basic computations. PRIMER 6 and STATISTICA 6 were used for graphical and comparative analysis. Data from previous surveys were re-analyzed and compared with the present survey to determine the current state of the reefs in Rarotonga.

Consultation with stakeholders

Interviews with local fishermen were conducted to understand the type of fishing carried out in both the reef flat and ocean area in close proximity to the proposed jetty site. In addition, interviews targeted information on the general current patterns around Rarotonga to understand the contribution of the area to the general health of Rarotonga's reefs.

RESULTS

Fore reef

<u>Benthic communities</u>

In 2011, turf algae dominated sites surveyed (ranging from 53.4% at Arorangi to 81.4% at Avatiu) with the exception of Vaimaanga (18.6%), which was dominated by crustose coralline algae and soft corals at 58.3% and 18.0% respectively (Figure 3). Mean hard coral cover was the lowest at Vaimaanga at 1.7%, 4.7% at Kavera, 5.3% at Nikao, 5.9% at Arorangi, 6.9% at Kiikii, 8.4% at Jetty Site, 9.5% at Avatiu, 12.0% at Tumunu, 13.1% at Club Raro, 13.8% at Airport, 18.4% at Paradise Inn, and the highest at Avarua and Trader Jack at 19.7% (see Figure 3). Macro-algae (predominantly *Asparagopsis taxiformis*) ranged from 0.3% at Vaimaanga to 22.3% at Kiikii (see Figure 3). The general trend for Rarotonga's fore reef is that mean hard coral cover has been slowly increasing over time (Table 1; Figure 4), at an average of 1.4% per year since 2006.

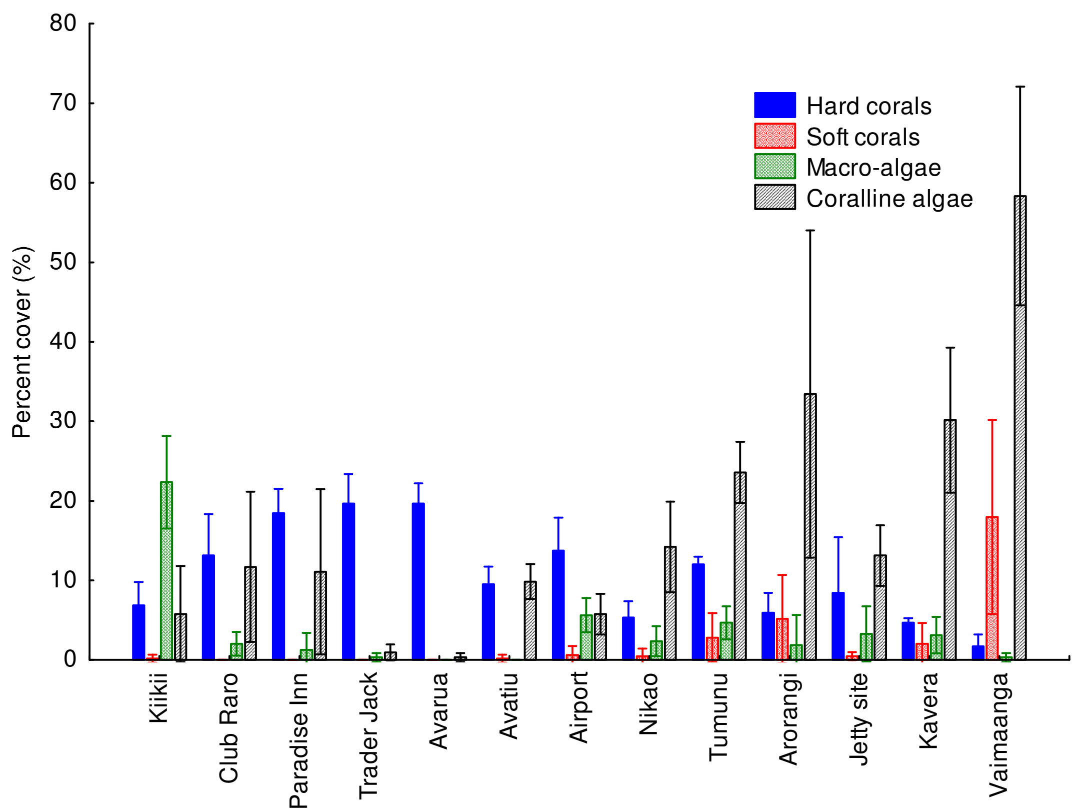

Figure 3. Mean percent cover of benthic communities for 2011 fore reef sites.

Table 1. Mean hard coral cover and standard error (SE) for selected fore reef sites surveyed from 1994 to 2011.

	Avarua	Avatiu	Airport	Nikao	Tumunu	Arorangi	Jetty site	Kavera	Vaimaanga	Titikaveka	Taakoka	Motutapu	Kiikii	Club Raro	Paradise Inn	Trader Jack
1994		11.1 ± 2.3								51.4 ± 3.8		19.9 ± 2.2				
1999	4.4 ± 1.3	6.2 ± 2.1		45.0 ± 10.1		31.0 ± 9.1				22.0 ± 3.9		20.0 ± 2.8				
2000	10.2 ± 1.4			19.2 ± 1.4		14.8 ± 1.5		46.0 ± 2.4		29.3 ± 2.1		53.5 ± 4.1				
2003	4.3 ± 0.6			0.8 ± 0.3		4.1 ± 1.3		4.8 ± 0.7		1.3 ± 0.6		1.7 ± 0.2				
2006	3.4 ± 0.4	0.9 ± 0.3		0	1.4 ± 0.6	0.2 ± 0.2		2.2 ± 1.8	0	0.5 ± 0.3	1.3 ± 0.4	0.5 ± 0.3	0.5 ± 0.2			
2009	13.4 ± 1.8	3.0 ± 0.4		2.8 ± 0.2	4.5 ± 0.5			1.9 ± 0.6	0.6 ± 0.3	12.0 ± 2.7	2.0 ± 1.0	1.7 ± 0.4	2.5 ± 0.3			
2011	19.7 ± 0.8	9.5 ± 0.7	13.8 ± 1.3	5.3 ± 0.7	12.0 ± 0.3	5.9 ± 0.8	8.4 ± 2.2	4.7 ± 0.2	1.7 ± 0.5				6.9 ± 0.9	13.1 ± 1.6	18.4 ± 1.0	19.7 ± 1.2

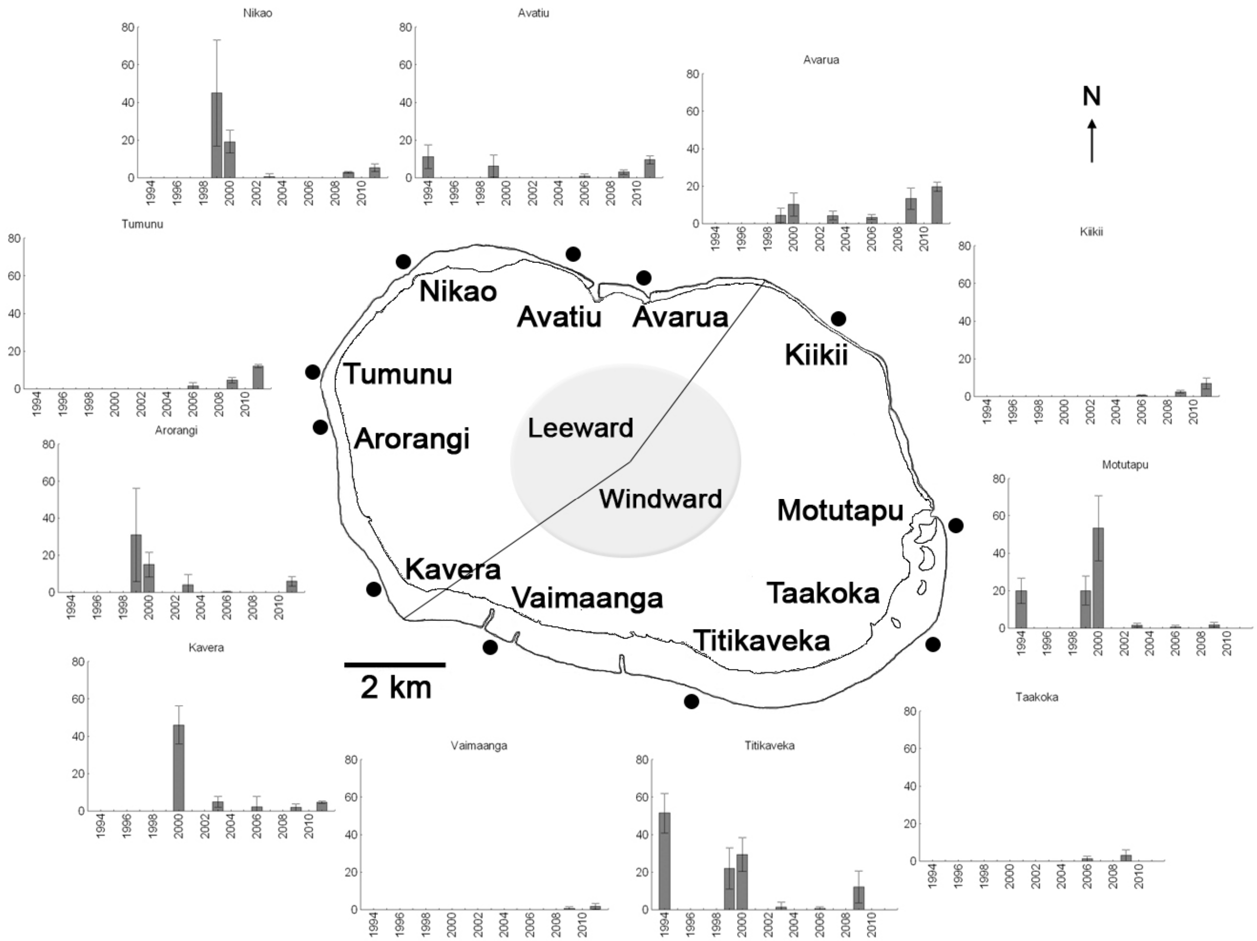

Figure 4. Mean hard coral cover of selected fore reef sites surveyed around Rarotonga in 1994 (Miller *et al.*, 1994), 1999 (Ponia *et al.*, 1999), 2000 (Lyon, 2000), 2003 (Lyon, 2003), 2006 (Rongo *et al.*, 2006), 2009 (Rongo *et al.*, 2009), and 2011 (present survey). Windward and leeward sites indicated.

Ordination of sites with respect to benthic communities clearly separated Avarua and Trader Jack, Avatiu, Kiikii, and Vaimaanga from the rest (Figure 5). In support, cluster analysis superimposed on the ordination indicated that sites excluding Avarua, Trader Jack, and Vaimaanga showed 60% similarity (see Figure 5). While turf algae dominated most sites, Avarua, Trader Jack, Paradise Inn, Airport, Club Raro, and Avatiu were closely associated with hard coral cover; Kiikii was closely associated with macroalgae, while Vaimaanga was closely associated with coralline algae and soft corals. Eigen analysis of the PCA for all major benthic categories showed that 97.2% of the variations were explained in the first three axes (Appendix B). Coralline algae and soft corals had the most weight on the first axis (0.809 and 0.471 respectively), macro-algae and hard corals on the second axis (0.981 and -0.166 respectively), and soft corals and coralline algae on the third axis (-0.705 and -0.585 respectively). The proposed jetty site showed a high degree of similarity with regards to benthic communities to most of the sites examined in this survey.

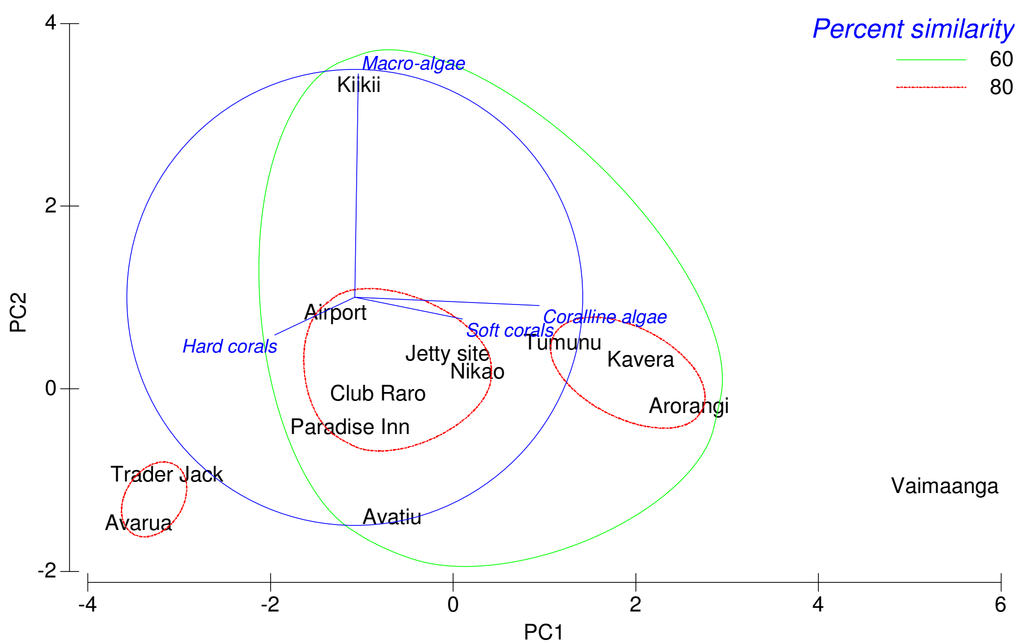

Figure 5. Principal Component Analysis (3 axes) in all major benthic categories except turf algae for 2011 fore reef sites. Data were square-root transformed.

Coral diversity

A total of 40 coral species (including at least three species of soft corals) were recorded within the quadrats representing 22 genera. However, there were 49 coral species recorded at all sites with the highest at Avarua (32) and lowest at Vaimaanga (12) (Appendix C). The most common corals recorded at most sites were *Leptoria, Montastrea, Leptastrea, Acanthastrea, Porites, Hydnophora, Pocillopora, Favia, Acropora,* and *Montipora* (in that order). At the Jetty site, there were 19 coral species identified within the quadrats representing 15 genera (Table 2), however 24 species were recorded at this site (see Appendix C and Plates A – F).

The Paradise Inn site had the highest number of species (S) and species richness (d). The Club Raro site had the highest species diversity (H`) and species evenness (J`). Colony density (n) was the highest at Avarua. Vaimaanga was the lowest in all categories. The Jetty site was similar to most of the sites examined, with colony density estimated at 16.9 ± 1.7 SE colonies per m^2. The biodiversity measures were also graphically represented in the PCA ordination (Figure 6). Ordination clearly showed that sites on the northern exposure (i.e., Avarua, Trader Jack, Paradise Inn, Club Raro) clustered to the right, indicating areas of high biodiversity.. Eigen-values indicated that all of the variations were explained in the first two axes with colony density (n = 0.783) having the most weight in the first axis and number of species (*S* = -0.689) contributing to much of the second axis (Appendix D).

Table 2. Coral biodiversity measures for 2011 fore reef sites. S = number of species, d = species richness, J` = evenness, H` = species diversity, and n = colony density (colonies per square meter). Highest values for each category indicated in blue.

	S	**d**	**J'**	**H' (loge)**	**n**
Kiikii	20	4.98	0.94	2.83	17.8 ± 2.6
Club Raro	25	5.96	0.96	3.08	20.5 ± 1.7
Paradise Inn	26	6.13	0.94	3.07	24.0 ± 2.1
Trader Jacks	25	5.87	0.94	3.03	24.9 ± 1.2
Avarua	19	4.45	0.95	2.79	27.6 ± 2.1
Avatiu	18	4.51	0.95	2.75	17.0 ± 1.5
Tumunu	15	3.86	0.95	2.57	15.3 ± 0.8
Arorangi	19	4.81	0.95	2.78	16.4 ± 2.7
Jetty site	20	4.99	0.95	2.85	16.9 ± 1.7
Kavera	22	5.67	0.94	2.89	14.3 ± 2.2
Vaimaanga	12	3.42	0.93	2.30	9.1 ± 1.4

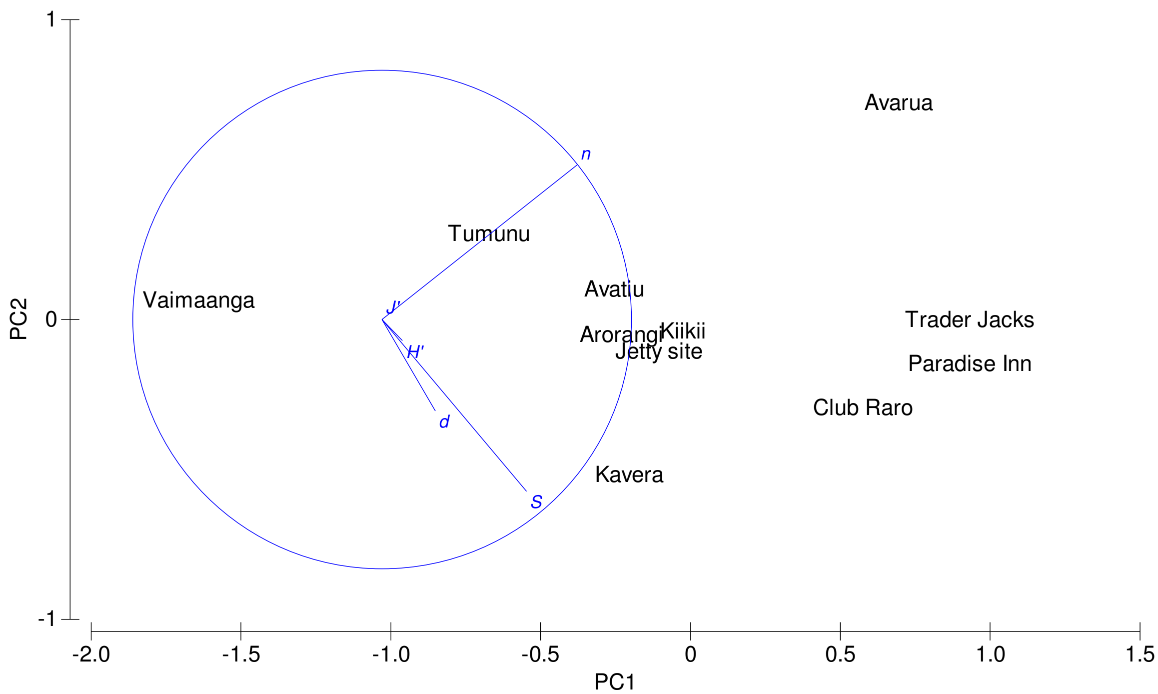

Figure 6. Principal Component Analysis (3 axes) for coral biodiversity measures at 2011 fore reef sites. Data were square-root transformed.

<u>Macro-invertebrate communities</u>

The urchin *kina* (*Echinometra* spp.) was the most common invertebrate on the fore reef with densities ranging from 1.72 ± 0.16 ind./m^2 at Avatiu to 7.40 ± 0.87 ind./m^2 at the Jetty site (Figure 7 & Table 3). The larger urchin (*Echinothrix* spp.) was the second most abundant with densities ranging from 0.50 ± 0.12 ind./m^2 at Avarua to 1.60 ± 0.26 ind./m^2 at the Jetty site. The most common Holothurid found on the fore reef was *rori matie* (*Stichopus chloronotus*), with the highest density (0.30 ± 0.06 ind./m^2) reported at the Jetty site. Though *Holothuria atra* and *Thelenota ananas* have been reported in the vicinity in previous surveys, they were not reported during the present survey. *Ungakoa* (*Dendropoma* spp.) was reported at all sites with the highest density at Avarua (1.90 ± 0.58 ind./m^2). *Paua* (*Tridacna maxima*) was the least common macro-invertebrate reported.

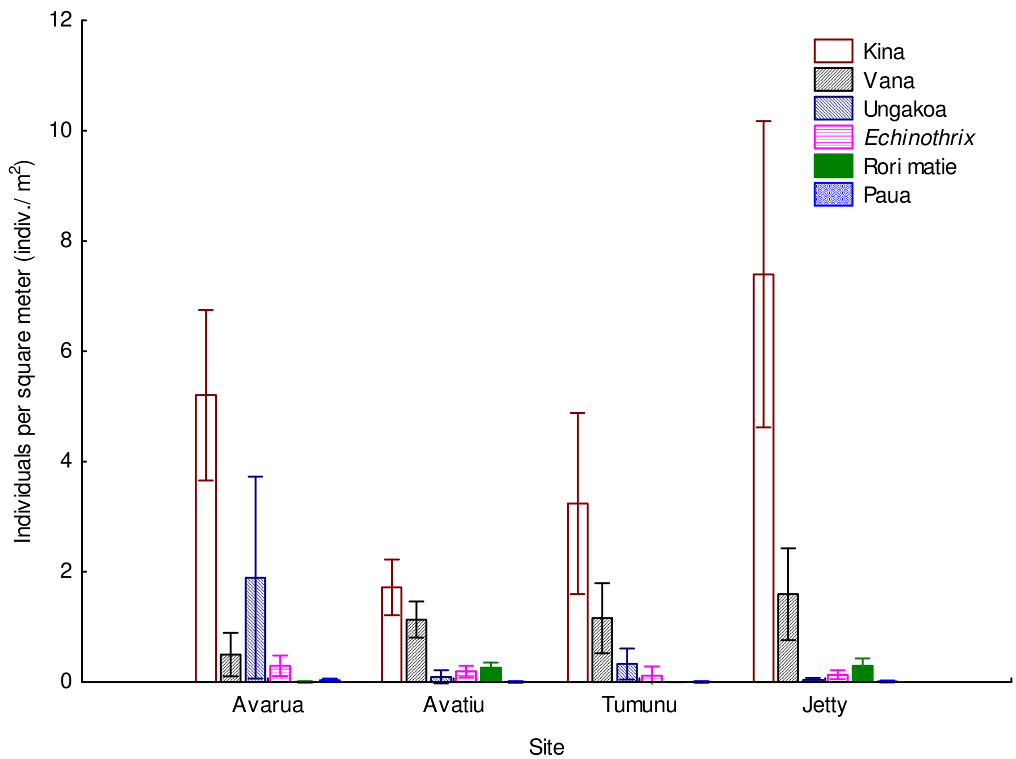

Figure 7. Mean macro-invertebrate density in 2011 for Avarua, Avatiu, Tumunu, and Jetty fore reef sites.

Table 3. Mean macro-invertebrate density and standard error (SE) in 2011 for Avarua, Avatiu, Tumunu, and Jetty fore reef sites.

	Kina	**Vana**	**Ungakoa**	***Echinothrix***	**Rori matie**	**Paua**	**Urchin**
Avarua	5.21 ± 0.49	0.5 ± 0.12	1.90 ± 0.58	0.30 ± 0.06	0.01 ± 0.01	0.04 ± 0.01	6.00 ± 0.55
Avatiu	1.72 ± 0.16	1.12 ± 0.10	0.10 ± 0.04	0.20 ± 0.03	0.26 ± 0.03	0.01 ± 0.01	3.05 ± 0.24
Tumunu	3.24 ± 0.52	1.16 ± 0.20	0.33 ± 0.09	0.12 ± 0.05	0	0.01 ± 0.01	4.52 ± 0.71
Jetty site	7.40 ± 0.87	1.60 ± 0.26	0.04 ± 0.01	0.14 ± 0.03	0.30 ± 0.06	0.02 ± 0.01	9.13 ± 1.10

Fish communities

Based on the species checklist for fore reef sites surveyed (Appendix E), a total of 77 fish species were recorded representing 17 families, with the highest number recorded (54 species) at the Jetty site. However, transect data indicated that Avarua and Avatiu had the highest number of species at 50 (Table 4). In addition, species richness (d), evenness (J\`), and diversity (H\`) were highest at Avarua (see Table 4). The number of individuals recorded was the highest at the Jetty site (1053 ind./800 m^2). Eigenvalues indicated that most of the variations were explained in the first axis (99.9 %) with the number of individuals (N = 1.000) having the most weight (Appendix F). The biodiversity measures were graphically represented in Figure 8.

Table 4. Biodiversity measures for fishes at 2011 fore reef sites. S = number of species, N = number of individuals, d = species richness, J` = evenness, and H` = diversity. Highest values for each category indicated in blue.

	S	N	D	J`	H` (log *e*)
Avarua	50	625	7.611	0.758	2.966
Avatiu	50	888	7.218	0.700	2.740
Jetty site	49	1053	6.897	0.695	2.704
Tumunu	37	672	5.530	0.757	2.734

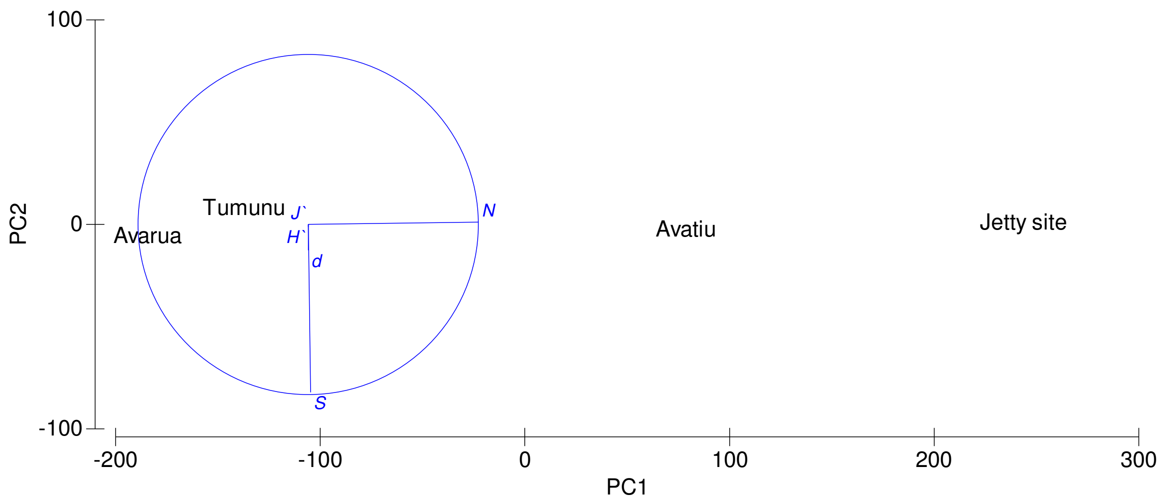

Figure 8. Principal Component Analysis (3 axes) for fish biodiversity measures at 2011 fore reef sites.

Reef flat

<u>Benthic communities</u>

According to the 2010 MMR report (Makikiriti *et al.*, 2010), benthic reef flat communities within the proposed jetty site were dominated by eroded dead coral rock (60%), followed by sand (21.2%), large boulders (18.7%), live hard coral cover (5%), and all other habitats having average cover below 10%. Examining benthic communities in the area directly north of the channel (Plate G) indicated that average percent cover were as follows: turf algae (63.9%), sand (13.3%), macro-algae (11.4%), rubble (9.8%), coralline algae (2.0%), and hard corals (1.1%) (Figure 9). A total of 24 coral species representing 16 genera were recorded at the reef flat site (Appendix G; Plates H - O), with *Psammocora* and *Leptastrea* the most common corals recorded. Average coral density was reported at 7.38 ± 1.41 SE colonies per m^2, which was similar to the 6.9 ± 1.43 SE estimated at the 2006 reef flat site (data re-calculated from Rongo *et al.*, 2006).

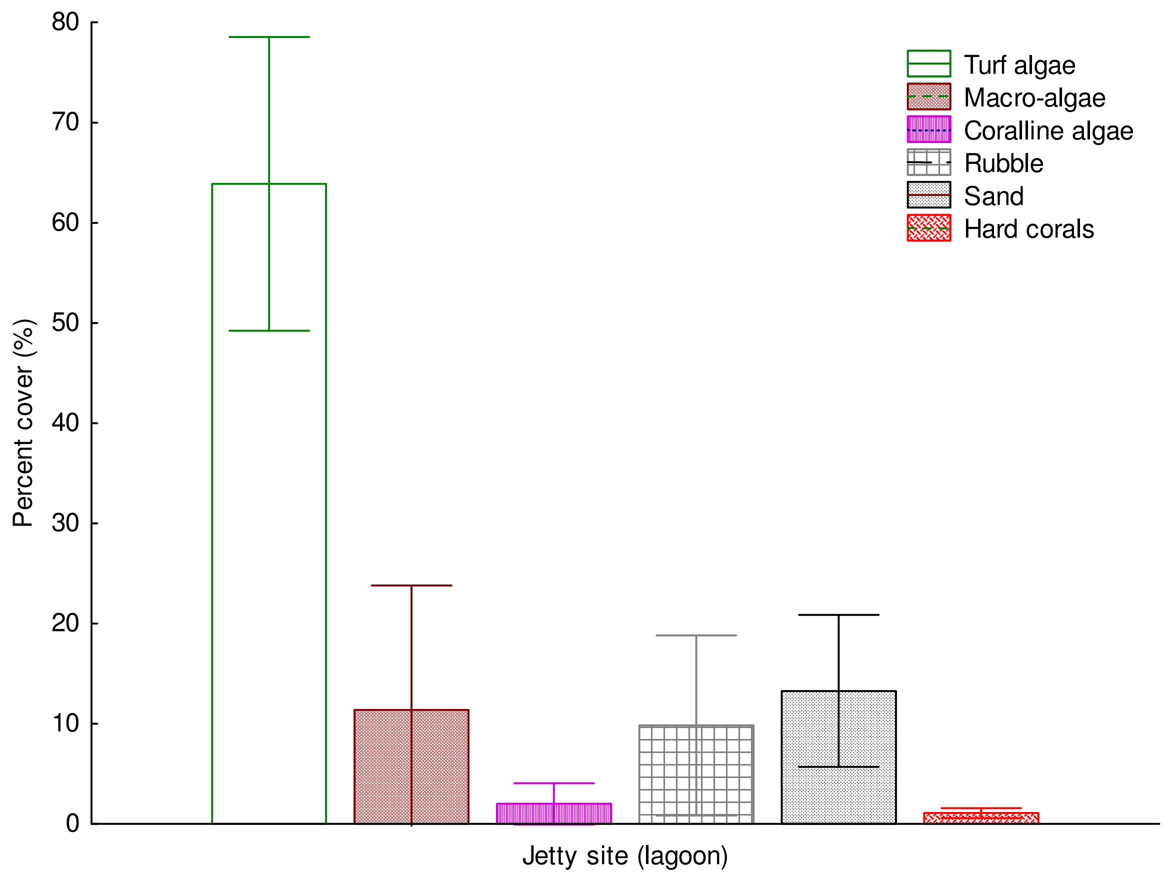

Figure 9. Mean percent cover of benthic communities at the reef flat jetty site.

<u>Macro-invertebrate and fish communities</u>

The MMR 2010 report examined macro-invertebrates on the reef flat within the proposed jetty site, and fish communities on the fore reef outside the mouth of the Arorangi passage. A species checklist of fishes on the reef flat (Appendix H) recorded in the present survey, indicated a total of 45 fish species representing 17 families.

Consultation with stakeholders

It was indicated that among regular reef fishing carried out around Rarotonga (e.g., *takiri patuki* and invertebrate collecting; Plate P & Q), a smaller reef passage slightly south of the main Arorangi passage has been used by residents for catching *pipi* (*Kyphosus* spp.). These species tend to inhabit particular passages that are also useful for spawning aggregations. From the Tumunu to Kavera, there are approximately four locations where these aggregation sites are found (F. Robati, pers. comm.). In addition, the fore reef area some 200 or more meters from the surf zone have been traditionally an important area for *manga* (*Promethichthys* spp.) fishing, especially in the last two decades, because areas in Arorangi are considered low-risk for ciguatera fish poisoning by residents (see Rongo and van Woesik, 2011). In addition, the calmness of the area for most of the year is ideal for *manga* fishing.

Current patterns around Rarotonga

Based on several interviews with fishermen as well as current direction recorded around Rarotonga on 7 July 2010 (T. Rongo, unpublished data), it was indicated that there are two main current directions around Rarotonga (Figure 10). One current flows predominantly northeastward, splitting around the southwestern exposure of Rarotonga and converging in the northeastern exposure. The other current is reversed, splitting on the northeastern exposure and converging on the southwestern exposure.

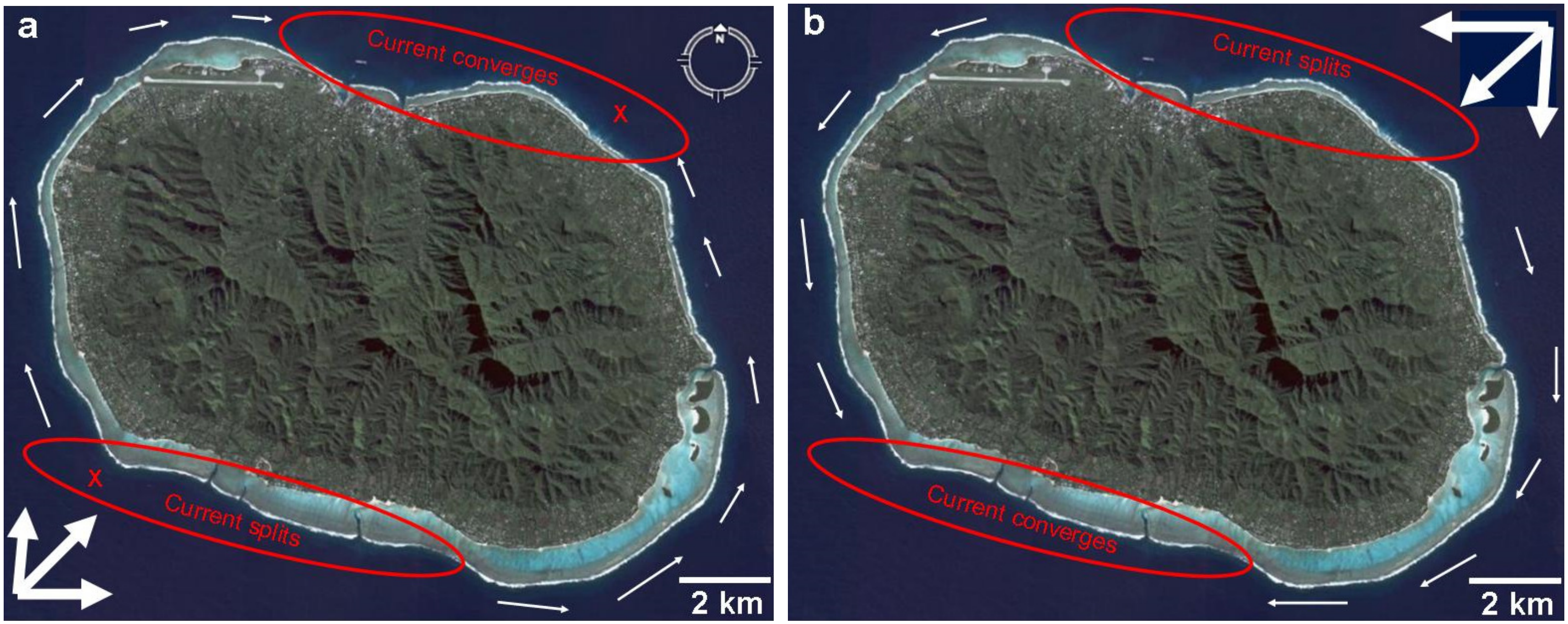

Figure 10. a) Current flow around Rarotonga on 7 July 2010, based on data collected by Teina Rongo, and b) reversed current flow as noted by interviews with fishermen. Arrows indicate the general direction of flow. Red circles indicate areas where the current splits and converges, with the particular day observed in *a* marked by red *x* symbols. Map taken from Google Earth.

DISCUSSION

The present survey of fore reef locations around Rarotonga indicated that hard coral cover remains well below pre-COTS conditions, even over a decade. However, when comparing the present survey with previous surveys (Rongo *et al.*, 2006; 2009), there is a general increase in hard coral cover indicating that recovery is well underway.

Fish abundance on the fore reef was the highest at the Jetty site due largely to two zooplankton species (i.e., *Chromis vanderbilti* and *Pomachromis fuscidorsalis*) common on fore reef slopes with high structural reef complexity or rugosity. Among all fore reef sites examined, the Jetty site was observed to have the highest reef rugosity, a feature that was also common on reef flat areas on the western exposure (Plate R). High rugosity not only offers refuge for juveniles and zooplankton species, but also offers ideal framework and substrate for coral recruits to settle and establish. The Jetty site was typical of reefs around Rarotonga, particularly those on the western exposure, and no unique species were noted on the reef flat or fore reef.

Based on reports from the 1990s (e.g., Holden, 1992*a,b*), interviews with fishermen, and current direction recorded around Rarotonga on 7 July 2010 (T. Rongo, unpublished data), it seems that there are two main areas on Rarotonga critical for biodiversity: the Avarua and Titikaveka areas (see Figure 10). This is the result of large eddying effects occurring in these areas that are important for the retention of larval recruits. During a general northeastward current flow, currents split on the southwestern exposure and a large eddying effect occurs in the Avarua area. In such a scenario, the Avarua area become a potential ‘sink’ population while the Titikaveka area becomes a source; the opposite effect occurs when currents reverse. This may explain the high coral and fish diversity on the northern exposure (i.e., Avarua, Trader Jacks, Paradise Inn, and Club Raro) when compared with all sites around Rarotonga including the Jetty site. Recent studies examining larval dispersal of connectivity among populations using biophysical models (e.g., Cowen *et al.*, 2000; Cowen *et al.*, 2006), genetics (Baums *et al.*, 2005), and tagging experiments (Jones *et al.*, 1999; Swearer *et al.*, 1999; Planes *et al.*, 2009) show that reefs tend to self-seed (see also review by Jones *et al.*, 2009). These findings and perhaps the isolation of Rarotonga suggests that the recovery of reefs may depend on local communities. However, this needs confirmation through more detailed hydrodynamic studies to understand connectivity and hence source/sink populations.

Although smaller eddying may occur at other locations including the Jetty site, for the most part, locations along the western coast as well as the eastern coast of Rarotonga may act as ‘corridors’, where reproductive propagules of marine organisms transition through. While corridors are also important, ‘source’ and ‘sink’ reefs are a priority when considering long-term reef health. Provided that the construction phase of the jetty generates minimal sediment load to adjacent reefs, the location of the jetty should have minimal impact not only on adjacent reefs but to the overall reef health of Rarotonga.

While the fore reef area 200 m or more from the mouth of the Arorangi passage are frequently fished for *manga*, it is not known how sedimentation and anticipated increased boat traffic may affect this deepwater species. Although we lack information on this fishery, the *manga* is still caught in areas affected by sedimentation and heavy boat traffic (i.e., town area from Nikao to Avarua). If these activities have had an impact on *manga* fishing in the town area, then the anticipated small-scale use of the Arorangi jetty may have minimal impact on this fishery.

The widening of the Arorangi passage may be a concern as the removal of large carbonate structures (i.e., micro-atolls) at the passage mouth may increase outward flushing on the reef flat during tidal changes. Therefore it is anticipated that the construction may alter the hydrodynamics as well as sediment dynamics on the reef flat area. This can potentially erode nearby coastal areas and increase sediment deposition on nearby reef communities, which may continue until sediment dynamics stabilizes.

RECOMMENDATIONS

- Jetty construction, in particular dredging and blasting, should not be conducted during summer periods due to spawning activities of most marine organisms occurring around November to January.

- Removal of large carbonate structures (i.e., micro-atolls) that are common on the reef flat in close proximity to the proposed development area must be minimized as these structures may buffer the effects of increased flushing that may result from the widening of the Arorangi passage.

- The coastal area must be monitored during and after jetty construction to ensure that coastal erosion does not become a problem.

- The Jetty site on the fore reef and reef flat should be re-examined during and after jetty construction is completed to monitor changes in reef communities.

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APPENDICES

Appendix A. Nature and Scope of the Engagement

This engagement shall undertake and complete the following;

a) Review previous EIA and related reports completed for the Arorangi Cruise Ship jetty
b) Undertake the necessary site assessments / measurements
c) Complete an assessment of the immediate reef and lagoon surroundings of the reef passage, planned activities pre construction, during construction and post construction and how the project intends to mitigate any negative impacts that may arise to the Jetty and surrounds.
d) Complete an assessment of the fauna and flora present or likely to be present in the area; to include: fish species, mammals, reptiles, amphibians, crustaceans and aquatic invertebrates occurring in the waterways within the affected area, and/or those in any associated freshwater and marine environment;· any rare or threatened marine species

e) Undertake consultations with stakeholders

Prepare a draft and final report.

2. Submit to and liaise with the NES the application per the final Marine Assessment report and is compliant with the relevant section of the EIA TOR in obtaining the necessary permit for the necessary works to be carried out in the completion of the Arorangi Cruise Ship Jetty

   a) Attend to both the NES and REA as required.

Appendix B. Eigen analysis for PCA of all major benthic categories for 2011 sites. Highest variation for each axes are indicated in blue.

PC	*Eigenvalues*	*%Variation*	*Cum.%Variation*
1	5.68	73.5	73.5
2	1.57	20.3	93.8
3	0.267	3.5	97.2

Eigenvector variables	*PC1*	*PC2*	*PC3*
Hard corals	-0.351	-0.166	-0.402
Soft corals	0.471	-0.095	0.705
Macro-algae	0.016	0.981	-0.020
Coralline algae	0.809	-0.036	-0.585

Appendix C. Checklist of coral species for 2011 fore reef sites.

FORE REEF SPECIES	Kiikii	Club Raro	Paradise Inn	Trader Jack	Avarua	Avatiu	Tumunu	Arorangi	Jetty site	Kavera	Vaimaanga
ACROPORIDAE											
Acropora digitifera	1			1	1			1	1		
Acropora gemmifera	1	1	1	1	1	1				1	
Acropora humilis		1	1	1	1				1		
Acropora hyacinthus	1	1	1	1	1		1			1	
Acropora lutkeni		1	1	1						1	
Acropora nasuta	1	1			1	1	1		1	1	1
Acropora palmerae	1	1	1	1				1			
Acropora polystoma		1	1	1	1		1		1		
Acropora selago					1						
Acropora spp.										1	1
Acropora verweyi		1	1		1				1		
Astreopora myriophthalma					1						
Montipora monasteriata	1	1	1	1	1	1	1	1	1	1	
Montipora faveolata			1								
AGARICIIDAE											
Pavona duerdeni	1		1								
Pavona varians					1		1				
Pavona venosa		1	1	1							
DENDROPHYLLIIDAE											
Turbinaria reniformis		1							1		
Turbinaria stellulata	1							1			
FAVIIDAE											
Cyphastrea chalcidicum	1				1	1		1	1	1	
Cyphastrea serailia		1	1	1	1						
Favia favus					1						
Favia mathaii	1	1	1	1	1	1	1		1		
Favia stelligera	1	1	1	1	1	1	1	1	1	1	1
Favites abdita		1	1	1		1					
Favites flexuosa			1	1	1	1		1		1	
Leptastrea purpurea	1	1	1	1	1	1	1	1	1	1	
Leptastrea transversa	1	1	1	1	1	1	1	1	1	1	1
Leptastrea prunosa				1							
Leptoria phrygia	1	1	1	1	1	1	1	1	1	1	1
Montastrea curta	1	1	1	1	1	1	1	1	1	1	1
Montastrea valenciennesi		1		1						1	
Platigyra pini				1							
Goniastrea aspera		1	1	1	1						
Goniastrea edwardsi										1	
Goniastrea pectinata	1	1									
MERULINIDAE											
Hydnophora exesa					1						
Hydnophora microconos	1	1	1	1	1	1	1	1	1	1	1
MILLEPORIDAE											

Millepora platyphyla	1	1	1	1	1	1	1			1	
Millepora dychotoma		1									
MUSSIDAE											
Acanthastrea echinata	1	1	1	1	1	1	1	1	1	1	
Lobophylia hemprichii	1	1	1	1	1						
OCCULINIDAE											
Galaxea fascicularis					1						
POCILLOPORIDAE											
Pocillopora dannae		1	1	1	1						
Pocillopora eydouxi	1	1	1	1	1	1	1	1	1	1	1
Pocillopora meandrina	1	1	1	1	1	1	1	1	1	1	1
Pocillopora verrucosa	1	1	1	1	1	1	1	1	1	1	1
Pocillopora woodjonesi		1				1					
PORITIDAE											
Porites australiensis			1	1	1	1					
Porites lobata	1	1	1	1	1				1		
Porites lutea	1	1	1	1	1	1	1	1	1	1	1
SIDERASTREIDAE											
Coscinaraea columna		1	1	1	1	1					
Psammocora contigua		1	1	1	1		1			1	1
ALCYONIDS (soft corals)											
Cladiella spp.	1	1	1				1	1	1	1	1
Lobophytum spp.	1		1				1		1		
Sinularia spp.	1	1	1			1		1	1	1	1
TOTAL # OF SPECIES OBSERVED:	28	38	37	35	37	23	21	19	24	25	14
TOTAL # OF FAMILIES OBSERVED:	10	10	10	9	9	9	10	8	8	9	7

Appendix D. Eigen analysis for PCA of coral biodiversity measures for 2011 sites. Highest variation for each axes are indicated in blue.

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	0.587	85.3	85.3
2	0.101	14.7	100.0
3	1.51E-4	0.0	100.0

Eigenvectors

Variable	PC1	PC2	PC3
S	0.579	-0.689	-0.094
d	0.214	-0.367	0.436
J'	0.003	0.001	-0.318
H'	0.082	-0.086	-0.835
n	0.783	0.619	0.039

Appendix E. Checklist of fish species for 2011 fore reef sites.

FORE REEF SPECIES	Avarua	Avatiu	Jetty site	Tumunu
ACANTHURIDAE				
Acanthurus leucopareius	x	x	x	
Acanthurus nigricans		x		
Acanthurus nigricauda	x			
Acanthurus nigrofuscus	x	x	x	x
Acanthurus olivaceus	x	x	x	x
Acanthurus triostegus	x	x	x	x
Ctenochaetus striatus	x	x		
Naso lituratus	x	x	x	x
Naso unicornis	x			
BALISTIDAE				
Melichthys vidua	x	x	x	x
Rhinecanthus aculeatus	x			
Rhinecanthus rectangulus	x	x	x	x
Sufflamen bursa	x	x	x	x
BLENNIIDAE				
Plagiotremus tapienosoma				x
CHAETODONTIDAE				
Chaetodon auriga	x			
Chaetodon citrinellus	x			x
Chaetodon ephippium	x			
Chaetodon lunula		x		
Chaetodon ornatissimus		x		x
Chaetodon quadrimaculatus	x	x	x	x
Chaetodon reticulates		x		
Chaetodon unimaculatus	x	x	x	x
Forcipiger flavissimus		x	x	x
Hemitaurichthys polylepis			x	x
CIRRHITIDAE				
Cirrhitops falco	x			
Cirrhitops hubbardi	x		x	
Neocirrhites armatus	x	x	x	x
Paracirrhitus arcatus	x	x	x	x
Paracirrhitus forsteri			x	x
GOBIIDAE				
Valenciennea strigata	x	x	x	
LABRIDAE				
Cheilinus chlorourus		x		
Cheilinus trilobatus		x	x	x
Coris aygula	x	x	x	
Coris gaimard			x	x
Gomphosus varius		x		x
Halichoeres hortulanus			x	
Halichoeres ornatissimus	x	x	x	x
Labroides dimidiatus		x	x	x
Macropharngodon meleagris		x	x	x
Stethojulis bandanensis	x	x	x	x
Thalassoma lutescens	x	x	x	
Thalassoma purpureum			x	
Thalassoma quinquevittatum	x	x	x	x
LUTJANIDAE				
Aphareus furca	x		x	

MICRODESMIDAE				
Nemateleotris magnifica		x	x	x
Ptereleotris evides		x		
Ptereleotris zebra			x	
MONACANTHIDAE				
Amanses scopas	x	x	x	x
MULLIDAE				
Parupeneus bifasciatus		x	x	x
Parupeneus cyclostomus	x			
Parupeneus multifasciatus	x	x	x	x
MURAENIDAE				
Gymnothorax javanicus			x	
PINGUIPEDIDAE				
Parapercis clathrata	x	x	x	x
POMACANTHIDAE				
Centropyge flavissima	x	x	x	x
Pomacanthus imperator	x	x	x	
POMACENTRIDAE				
Chromis vanderbilti	x	x	x	x
Chrysiptera brownriggii	x	x	x	x
Dascyllus trimaculatus			x	
Plectroglyphidodon imparipennis	x	x	x	x
Plectroglyphidodon johnstonianus	x	x	x	x
Pomacentrus imitator	x	x	x	x
Pomachromis fuscidorsalis	x	x	x	x
SCARIDAE				
Calotomus carolinus		x		
Chlorurus sordidus	x	x		
Scarus altipinnis	x		x	
Scarus forsteni	x	x	x	
Scarus frenatus			x	x
Scarus globiceps	x	x	x	
Scarus psittacus	x	x	x	x
Scarus schlegeli	x	x	x	
SCORPAENIDAE				
Scorpaenopsis possi	x			
SERRANIDAE				
Cephalopholis argus	x	x		
Cephalopholis urodeta	x			
SIGANIDAE				
Siganus argenteus	x		x	
TETRADONTIDAE				
Canthigaster amboinensis	x			
Canthigaster solandri	x	x	x	x
ZANCLIDAE				
Zanclus cornutus		x	x	
TOTAL # OF FAMILIES OBSERVED:	**17**	**15**	**17**	**14**
TOTAL # OF SPECIES OBSERVED:	**52**	**52**	**54**	**40**

Appendix F. Eigen analysis for PCA of fish biodiversity measures for 2011 sites. Highest variation for each axes are indicated in blue.

PC	*Eigenvalues*	*%Variation*	*Cum.%Variation*
1	3.95E4	99.9	99.9
2	34.4	0.1	100.0
3	1.77E-3	0.0	100.0

Eigenvector variables	*PC1*	*PC2*	*PC3*
S	0.013	-0.988	-0.093
N	1.000	0.013	0.001
d	0.001	-0.152	0.530
J`	0.000	0.001	0.208
H`	0.000	-0.014	0.817

Appendix G. Checklist of coral species for 2011 reef flat jetty site.

ACROPORIDAE	
Acropora digitifera	x
Acropora gemmifera	x
Acropora palmerae	x
Acropora selago	x
Astreopora myriophthalma	x
Montipora monasteriata	x
AGARICIIDAE	
Pavona varians	x
DENDROPHYLLIIDAE	
Turbinaria stellulata	x
FAVIIDAE	
Cyphastrea serailia	x
Cyphastrea spp.	x
Favia matthaii	x
Favia stelligera	x
Favites flexuosa	x
Leptastrea purpurea	x
Leptoria phrygia	x
Montastrea curta	x
Goniastrea edwardsi	x
MERULINIDAE	
Hydnophora microconis	x
POCILLOPORIDAE	
Pocillopora meandrina	x
Pocillopora verrucosa	x
PORITIDAE	
Porites australiensis	x
Porites lobata	x
Porites lutea	x
SIDERASTREIDAE	
Psammocora contigua	x
TOTAL # OF SPECIES OBSERVED:	24
TOTAL # OF FAMILIES OBSERVED:	8

Appendix H. Checklist of fish species for 2011 reef flat jetty site.

ACANTHURIDAE	
Acanthurus nigrofuscus	x
Acanthurus triostegus	x
Ctenochaetus striatus	x
Naso lituratus	x
Naso unicornis	x
AULOSTOMIDAE	
Aulostomus chinensis	x
BALISTIDAE	
Rhinecanthus aculeatus	x
Rhinecanthus rectangulus	x
CHAETODONTIDAE	
Chaetodon auriga	x
Chaetodon citrinellus	x
Chaetodon ephippium	x
Chaetodon lunula	x
Chaetodon ornatissimus	x
Heniochus chrysostomus	x
DIODONTIDAE	
Diodon hystrix	x
HOLOCENTRIDAE	
Sargocentron microstoma	x
LABRIDAE	
Cheilio inermis	x
Coris aygula	x
Gomphosus varius	x
Halichoeres hortulanus	x
Halichoeres trimaculatus	x
Labroides dimidiatus	x
Stethojulis bandanensis	x
Thalassoma hardwickii	x
Thalassoma lutescens	x
Thalassoma purpureum	x
LETHRINIDAE	
Lethrinus xanthochilus	x
MULLIDAE	
Mulloides flavolineatus	x
Parupeneus bifasciatus	x
Parupeneus ciliatus	x
Parupeneus multifasciatus	x
MURAENIDAE	
Gymnothorax undulatus	x
PINGUIPEDIDAE	
Parapercis clathrata	x
POMACANTHIDAE	
Centropyge flavissima	x
POMACENTRIDAE	
Abudefduf septemfasciatus	x

Chrysiptera brownriggii	x
Chrysiptera glauca	x
Dascyllus aruanus	x
Pomacentrus spilotoceps	x
Stegastes albifasciatus	x
Stegastes fasciolatus	x
SCARIDAE	
Chlorurus sordidus	x
SIGANIDAE	
Siganus argenteus	x
OSTRACIIDAE	
Ostracion cubicus	x
ZANCLIDAE	
Zanclus cornutus	x
TOTAL # OF SPECIES OBSERVED:	45
TOTAL # OF FAMILIES OBSERVED:	17

PLATES

FORE REEF – Jetty site

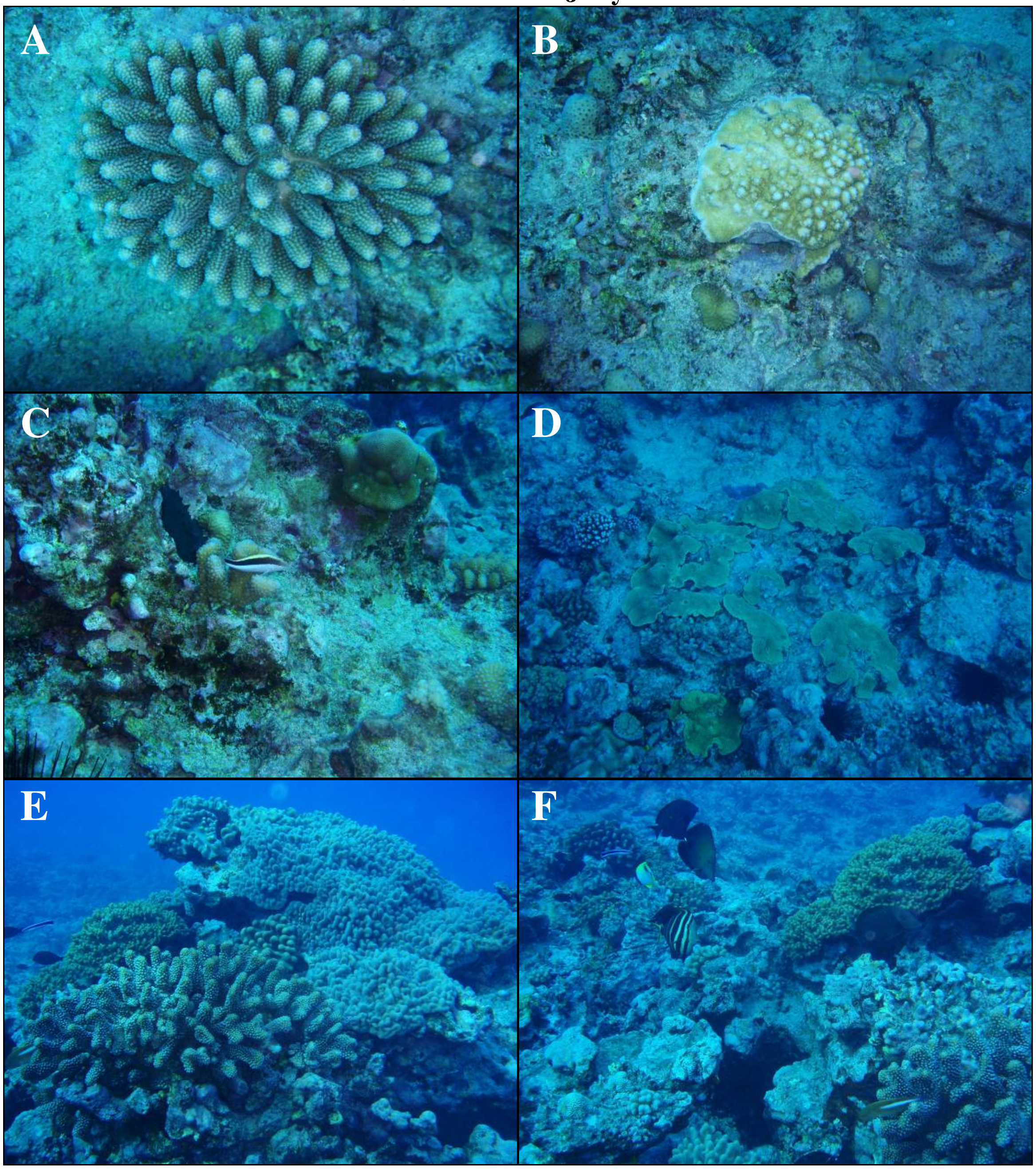

Plate A. *Acropora humilis*
Plate B. *Acropora palmarae*
Plate C. *Paracirrhites forsteri* on a *Pocillopora eydouxi*
Plate D. *Turbinaria* spp.
Plate E. *Pocillopora eydouxi* in foreground and *Sinularia* spp. in background
Plate F. Cleaning station by cleaner wrasse (*Labroides dimidiatus*) in background, and *Paracirrhites arcatus* on a *Pocillopora eydouxi* in foreground.

REEF FLAT– Jetty site

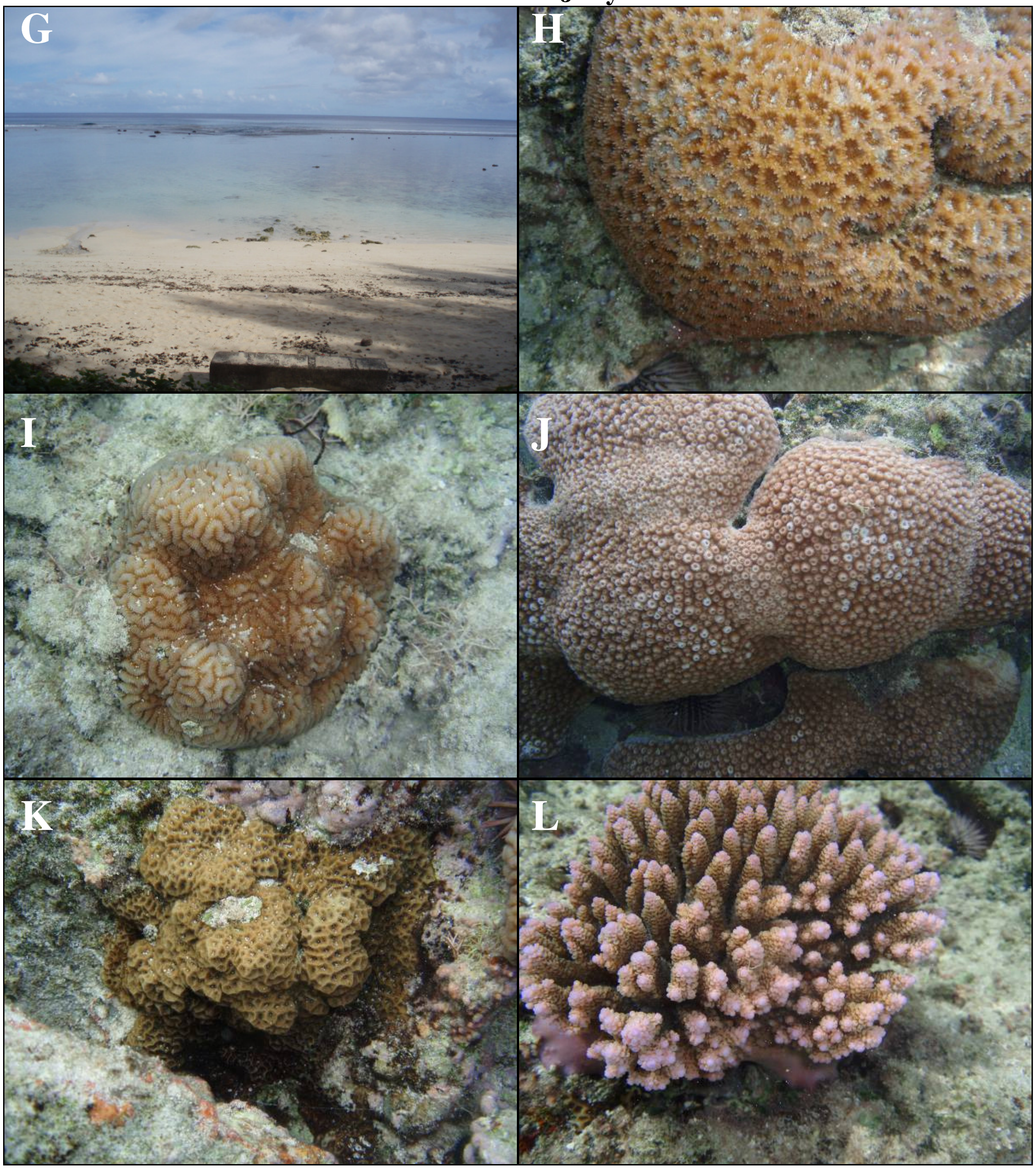

Plate G. Arorangi passage and location of reef flat site on northern side of the channel.
Plate H. *Favia matthaii*
Plate I. *Leptoria phrygia*
Plate J. *Astreopora myriophthalma*
Plate K. *Pavona venosa*
Plate L. *Acropora selago*

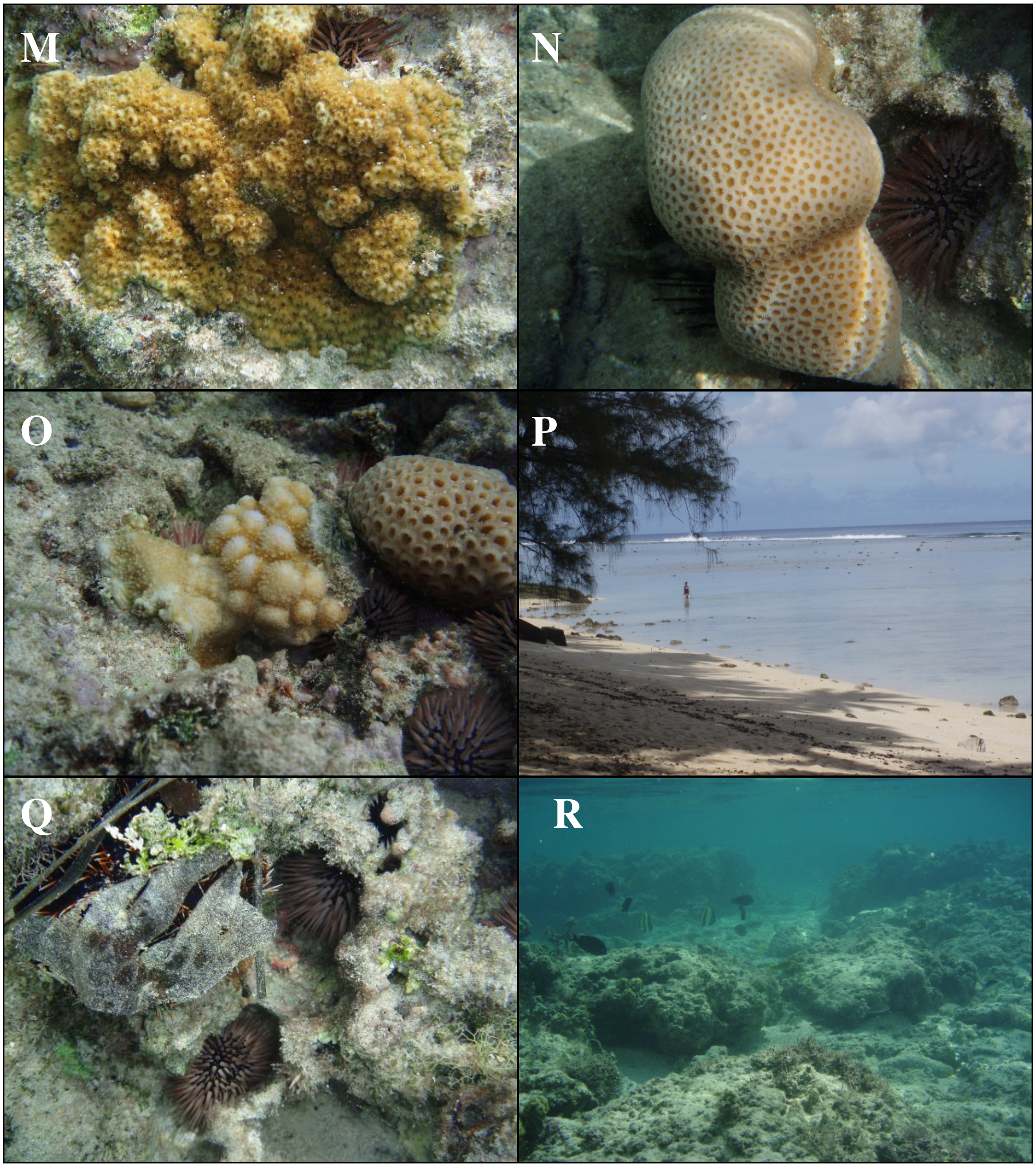

Plate M. *Cyphastrea serailia*
Plate N. *Favia stelligera*
Plate O. *Acropora digitifera* (left) and *Montastrea curta* (right)
Plate P. A woman collecting *vana* on the reef flat.
Plate Q. Collector urchin (*Tripneustes gratilla*) and rock-boring urchins (*Echinometra mathaei*)
Plate R. Large carbonate structures common on reef flats on the western exposure of Rarotonga.