Ministry of Marine Resources

Southern Group Baseline Coral Health Snapshot 2021

Dr Lara Ainley

Cover image: Acropora spp. in Rarotonga. Image copyright by Lara Ainley, MMR.

Introduction

The health and condition of nearshore coral reefs is of critical ecological importance due to their proximity to land, both in terms of supporting coastal communities and the risks of anthropogenic (human-derived) impacts. Outbreaks of disease and pests which impact coral health are increasing in both frequency and severity. These impacts are recognised as major causes of coral mortality and reef degradation on a global scale. Such degradation of coral reef ecosystems and biodiversity may have important implications for maintaining coastal ecosystem services.

Coral reefs are recognised under the National Sustainable Development Plan (NSDP, Goal 12, Indicator 12.1) as a key priority goal for sustainable development under the principle of "*the sustainable management of oceans, lagoons and marine resources*". Under this objective, the annual average percent cover of live coral is reported. Further to this, there is a focus on reporting the cover of hard coral since these are the calcium carbonate structure contributing to building up reef ecosystems and because the cover is soft coral is typically low.

Over the past 4 years, the Ministry of Marine Resources (MMR) have increased effort and improved methodologies to collect data relating to the cover of live coral on the forereef slopes of all nine of the Southern Group islands. This is the largest scale and most recent effort to collect coral health data in the Cook Islands and represents, in many cases, the first comprehensive dataset available covering many islands within a small timeframe. In this report, the data was used to generate baseline snapshots of coral cover and reef health on these islands. Recognising that some data already existed for some islands, here the recent data collection by MMR represents a timely, consistent and robust methodology, and a baseline for future comparisons.

The objective of this report is to provide an updated snapshot of coral health for the nine Southern Group islands and a baseline reference to which future assessments can be compared. This snapshot includes an individual reef health assessment for each island. Where new data has become available, comparisons have been made to assess any changes in coral cover or reef health over time.

Methodology

Coral and other substrate cover on forereef slopes were recorded during biodiversity and resource assessments between 2017 and 2021. Using SCUBA, photos of substrate were taken and later analysed to determine the percent cover of major substrate groups. Over the past 5 years, this kind of data has been collected for all nine of the Southern Group islands.

At 10 m depth on the forereef slope, using SCUBA, divers placed a total of 10 replicate 1 m^2 quadrats along a single 50 m transect at each site (at approximately 5 m spacing). This was repeated at multiple sites per island. The number of sites selected per island depended on assessment and management objectives and spatial representation around each island. A photo of each quadrat was taken using an underwater camera to capture substrate cover. Divers ensured that the whole quadrat was captured in each image. Photos were then visually assessed to record the percent cover across a range of substrate categories for each replicate, using 16 random points within each quadrat (ie, 1 point = 6.25% of total cover within the quadrat). Substrate at each of the 16 points was recorded and summarised into one of eight major substrate groups:

- Hard coral
- Soft coral
- Unhealthy coral – includes dead coral and bleached coral
- Total substrate – includes rock, rubble, pavement and sand
- Unknown – anything unable to be assigned
- Other live – any other live organism including sponges, gorgonians and animals
- Total macroalgae includes red, brown, green algae and cyanobacteria
- CCA (crustose coralline algae)

On initial inspection of the data, some outliers were present. Due to the nature of the data collection methodology, high variability and outliers may be expected since for one replicate the quadrat may land on a densely covered coral bommie and, along the same transect, the next quadrat may land on sand. Outliers were left in the dataset because it was determined that they still represent the natural variability in substrate cover.

Average cover for each category (± 1 S.E.) was calculated per site per island. At the island scale, an average for each category was also calculated using individual photoquadrats as individual replicates (number of replicates vary depending on the number of sites selected per island). At the island scale, an overall indicator for total live coral cover (total live coral cover is the sum of both hard coral and soft coral cover) was also calculated. This indicator is used to report against the NSDP goals. Chou *et al.* (1994)[1] was used to classify total live coral cover as poor (< 25%), fair (25-50%) and good (50-75%) and excellent (> 75%).

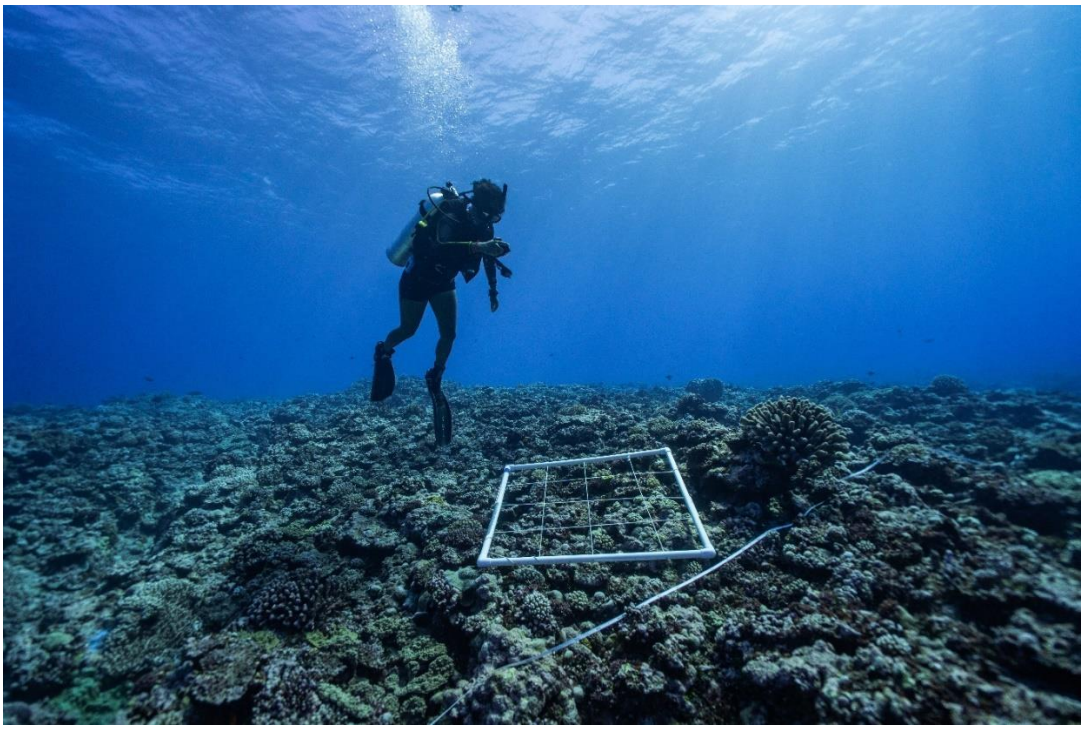


Image: MMR Fisheries Officer, Stella Marsters conducting photoquadrat surveys in Aitutaki. Image copyright by Lara Ainley, MMR.

[1] Chou, L. M., Wilkinson, C. R., Licuanan, W. R. Y., Alino, P., Cheshire, A. C., Loo, M. G. K., Soekarno (1994). Status of coral reefs in the ASEAN region. In: Proceedings, Third ASEAN-Australia Symposium on Living Coastal Resources, Chulalongkorn University, Bangkok, Thailand, 16-20 May 1994. Volume 1. Status Reviews (pp. 1-10). Australian Institute of Marine Science (AIMS).

Results – Baseline Snapshots

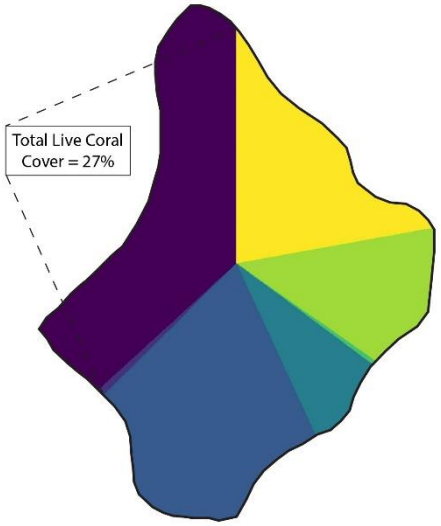
Presented below are baseline snapshots of forereef slope coral and substrate assessments, conducted across the Southern Group islands. These snapshots represent a baseline reference point for future assessments. Each snapshot briefly describes the baseline status of coral health in terms of live coral cover and other substrate on the forereef slope and provides an overall indicator of coral health per island and average total live coral cover. Substrate cover (averaged across sites per island) are further presented in the associated graphic, using the below key to identify substrate categories. Full tables of values for substrate cover per site, per island are presented in the Appendix.

Coral and Substrate Categories - Key

Hard Coral	Unhealthy Coral	Unknown	Total Macroalgae
Soft Coral	Total Substrate	Other Live	Crustose Coralline Algae (CCA)

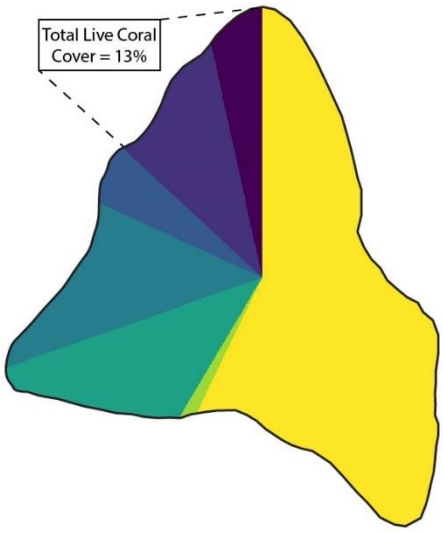
Palmerston 2018

Live coral cover in Palmerston in 2018 was dominated by hard coral. At most sites, there was no soft coral cover recorded. Hard coral cover was greatest (> 34%) at sites 5 and site 6, on the north-western forereef slopes of Palmerston. Hard coral cover was ranged from 9-29% at all other sites. The cover of unhealthy coral was reasonably low at all sites, except site 1 on the north-eastern forereef slope where a considerable amount of unhealthy coral was recorded (37%). The cover of CCA ranged from 9-26%. This is a moderate level of CCA coverage and correlates with qualitative observations, off-transect, on the reef flats around Palmerston. Total macroalgae cover was low at most sites, except site 5 where total macroalgae cover was higher (18%).



At the island scale, total live coral cover (including both hard and soft coral cover) was approximately 27% (27.07 ± 2.56%, n = 47) and classified as fair following Chou *et al.* (1994). On average, Palmerston substrates were dominated by the cover of hard coral and unhealthy coral.

Aitutaki 2017

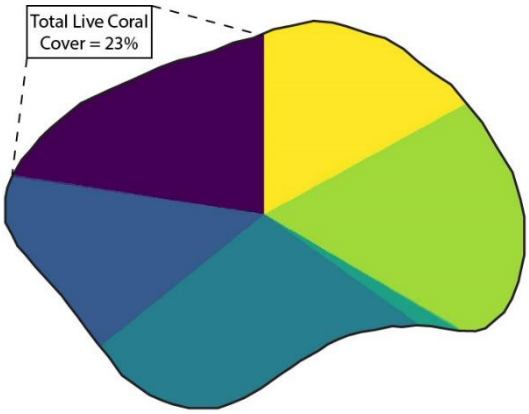


Overall in 2017, hard coral cover in Aitutaki was very low, ranging from 0-9%. The greatest hard cover was recorded at one of the Runway sites on the northern most forereef slopes. At most sites, there was considerably more soft coral cover recorded compared to hard coral cover, particularly along the eastern forereefs. Minimal records of unhealthy coral were recorded, except for all Long Reef sites along the southern forereef slopes where unhealthy coral accounted for 16-22% of the substrate cover. Total macroalgae cover was relatively low across all sites. At every site, the substrate composition was dominated by CCA, representing the highest proportion for any substrate category measured. The cover of CCA was greatest at both Akaiami sites on the eastern forereef slopes.

For Aitutaki, the average total live coral cover was 13% (12.70 ± 1.20%, n = 221) which is classified as poor, and substrate cover was dominated by CCA.

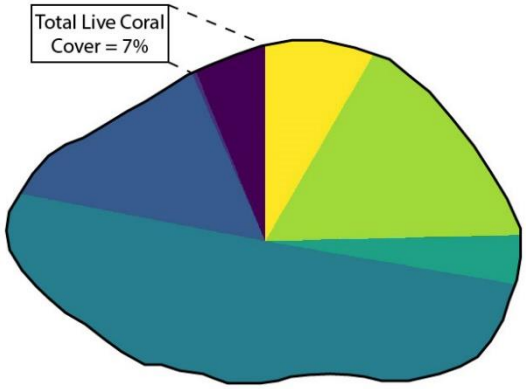
Manuae 2017

In 2017, live coral cover in Manuae was dominated by hard coral with negligible records of soft coral. Hard coral cover was moderately good across all sites, except site 3 on the south-eastern forereef slopes. Site 4 on the western forereef slope had the greatest hard coral cover (38%) with the remaining cover dominated by other substrate (rather than macroalgae or CCA for example). Moderate cover of unhealthy coral was also observed at sites 2 and 3 on the south-west and southern forereef slopes. In addition to the lowest hard coral cover and one of the highest records of unhealthy coral, site 3 also had the greatest cover of CCA. The cover of macroalgae was greatest on the northern and western forereef slopes at sites 5, 1 and 2.



Overall, total live coral cover in Manuae averaged 23% (22.7 ± 2.8%, n = 51), classified as poor, and was predominantly hard coral.

Takutea 2018



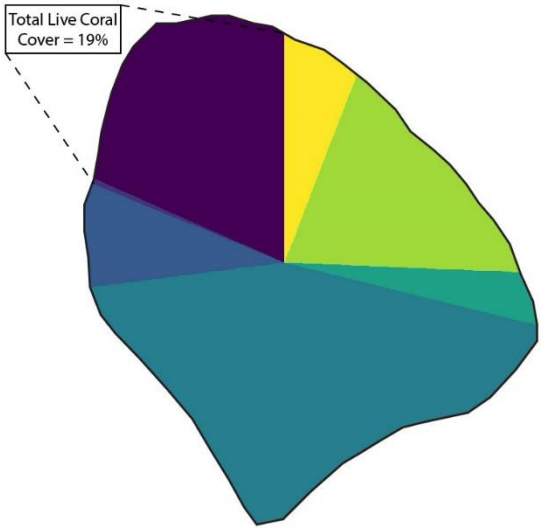
Across all sites, hard coral cover was low (< 10%) and soft coral cover was negligible. Hard coral cover was lowest at Taupoto (< 2%; on the western point of the island, close to where boats "land"). Forereef slopes in Takutea were dominated by other substrates (rock, sand, pavement, etc) where the percent cover of this category was the greatest (> 40%) across all sites. Cover of unhealthy coral and macroalgae were the second and third most dominant categories for substrate cover in Takutea.

The total live coral cover for Takutea, on average, was 7% and classified as poor (6.5 ± 1.2%, n = 35).

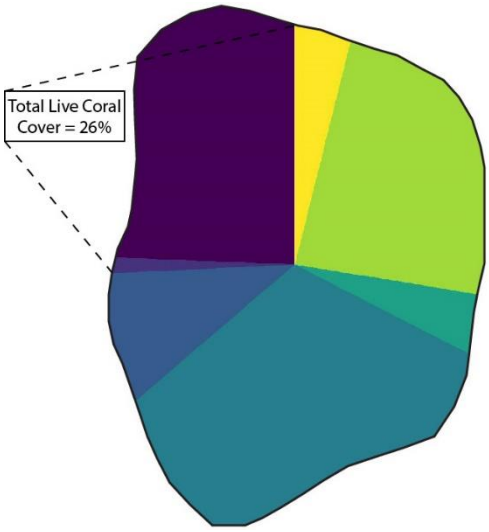
Atiu 2018

Overall, live coral cover was low, predominantly comprised of hard coral and ranged from 15-21% cover. Soft coral cover was minimal. The cover of total macroalgae was noticeable, particularly around Pia Tai (approximately 29%). The cover of unhealthy coral was greatest at Avatapu, Konakonako and Tepari Pupui on the north-western side of the island. Cover was otherwise categorised as general substrate.

In Atiu, the average total live coral cover was 19% and classified as poor (18.8 ± 1.1%, n = 98).



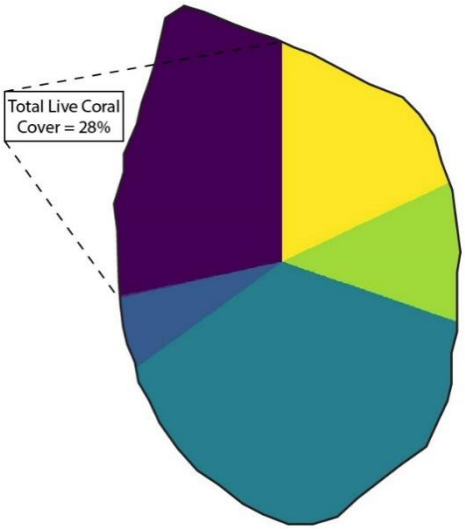
Mitiaro 2018



Similar to other *maketea* islands, live coral cover in Mitiaro was mostly hard coral with very little observed soft coral cover. Hard coral cover was reasonably good, ranging from 14-32% across all sites. Hard coral cover was greatest at Kovea (31.7 ± 6.1%, n = 9) on the western forereef slopes. A moderate cover of total macroalgae was recorded across all sites. Unhealthy coral cover was generally low, with the greatest observations being approximately 15% at Poavea, Tepari and Teuru on the eastern side of the island.

Overall, average total live coral cover was 26% and classified as fair (25.8 ± 1.6%, n = 100).

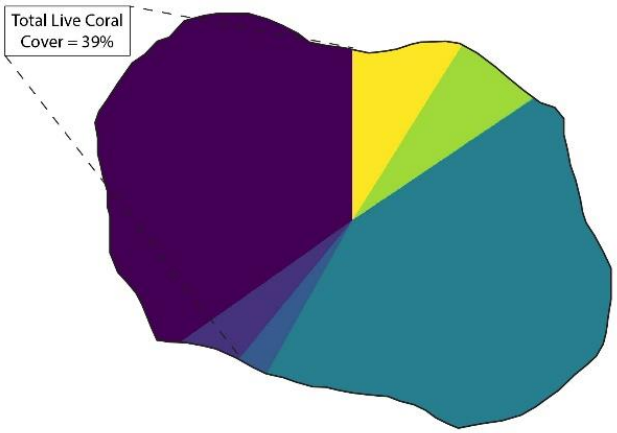
Mauke 2020



Hard coral cover in Mauke ranged from 19% at Te Pari Aanga to 44% at Oneunga and was consistently high across all sites. There was effectively no soft coral cover. The cover of unhealthy coral was relatively low, except at both Patito Raui and Takiore where the cover of unhealthy coral was 16%. The cover of total macroalgae and CCA were both greatest at the Te Ana O Ve site.

Overall, total live coral cover was 28% (28.5 ± 1.7%, n = 100), classified as fair.

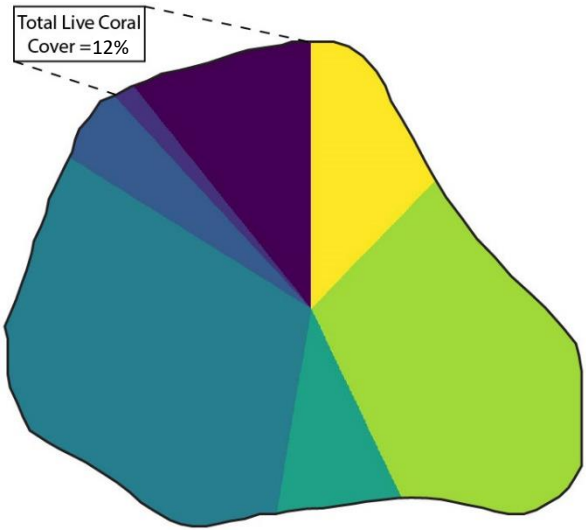
Rarotonga 2022



In Rarotonga in 2022 substrate cover was dominated by hard coral and other substrates (for example, rock, rubble and sand). Hard coral cover ranged from was fair to good across most sites. The hard coral cover ranged from 11% at Pouara on the eastern forereef slope to 52% at Titikaveka on the south of the island. The cover of other substrates was on average 43% across all sites. Soft coral cover was very low, except at Avavaroa (19%) and Tikioki Raui (14%) on the southern forereef slopes. The cover of unhealthy coral was low. Total macroalgae was low, except at Rutaki (20%) where cover was almost three times greater than the average (7%). There was moderate cover of CCA, ranging from 0-23% across all sites.

Overall, total live coral cover was 39% (39.1 ± 1.4%, n = 203), classified as fair and was the greatest compared to other Southern Group islands in this baseline snapshot.

Mangaia 2018



In Mangaia hard coral cover was highly variable and, for most sites, ranged from 4-14%. However, at two sites, Karanga Raui and Tamarua Control, hard coral cover was greater than 20% representing the greatest hard coral cover for Mangaia. Soft coral cover was observed but minimal across all sites. The cover of unhealthy coral, CCA and other substrate were low. The cover of total macroalgae was variable (ranging from 12-50%) with the greatest cover recorded at Keia Raui S on the western side of the island.

Overall, the average total live coral cover for Mangaia was 12% and classified as poor (11.9 ± 1.0%, n = 136).

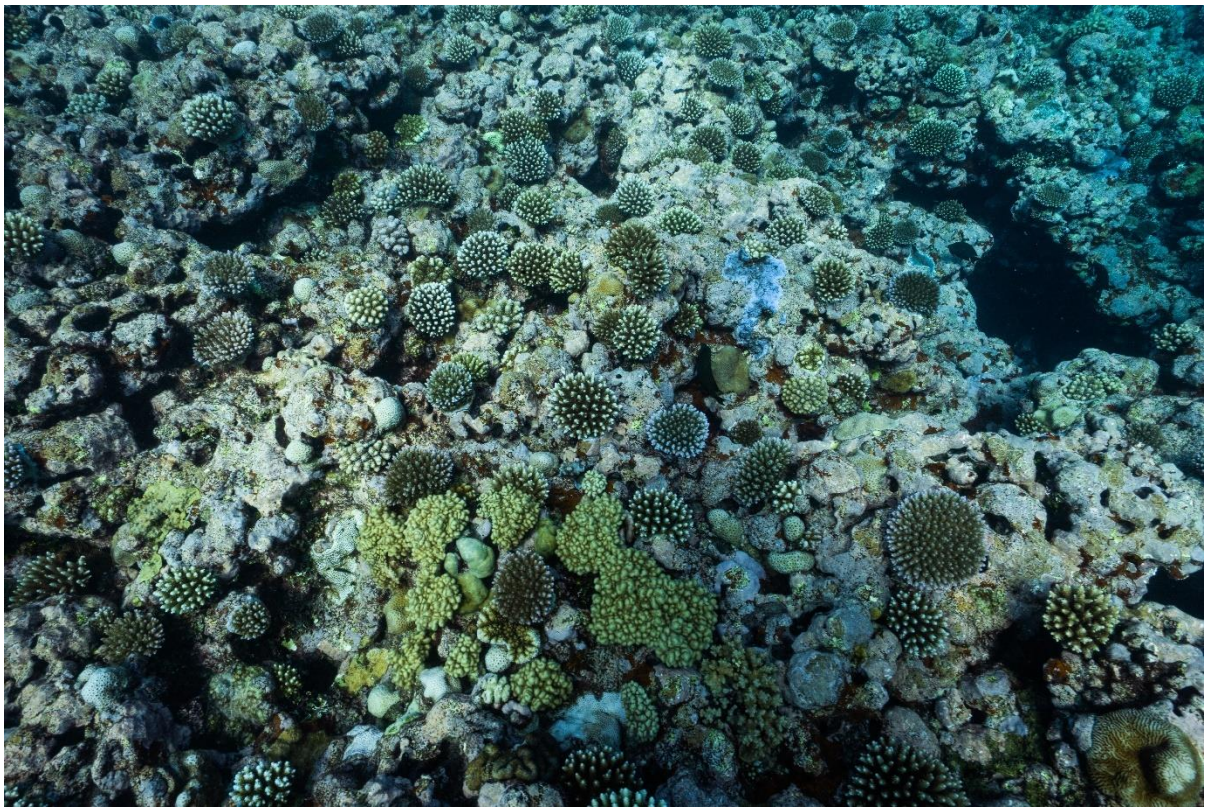


Image: A forereef slope in Aitutaki. Image copyright by Lara Ainley, MMR.

Results – Southern Group Comparisons

Live coral cover

Average live coral cover varied across all islands (Figure 1). In general, moving east to west coral cover may be considered as similar in Palmerston, Manuae, Atiu, Mitiaro and Mauke. Live coral cover was the greatest in Rarotonga and approximately 3.8 times greater than cover in Aitutaki, Takutea and Mangaia where hard coral cover was the lowest. While the low cover in Takutea may be an artefact of a small sample size and very low records skewing the average, the low cover in Aitutaki in 2017 and Mangaia in 2018 may be the result of increased impacts on the marine environment. In Aitutaki, the cover of crustose coralline algae (CCA) was dominant (> 50%) and in Mangaia cover was dominated by macroalgae (31%). This may indicate that the forereef slopes of these islands were undergoing a period of shift, away from a coral dominated reef community.

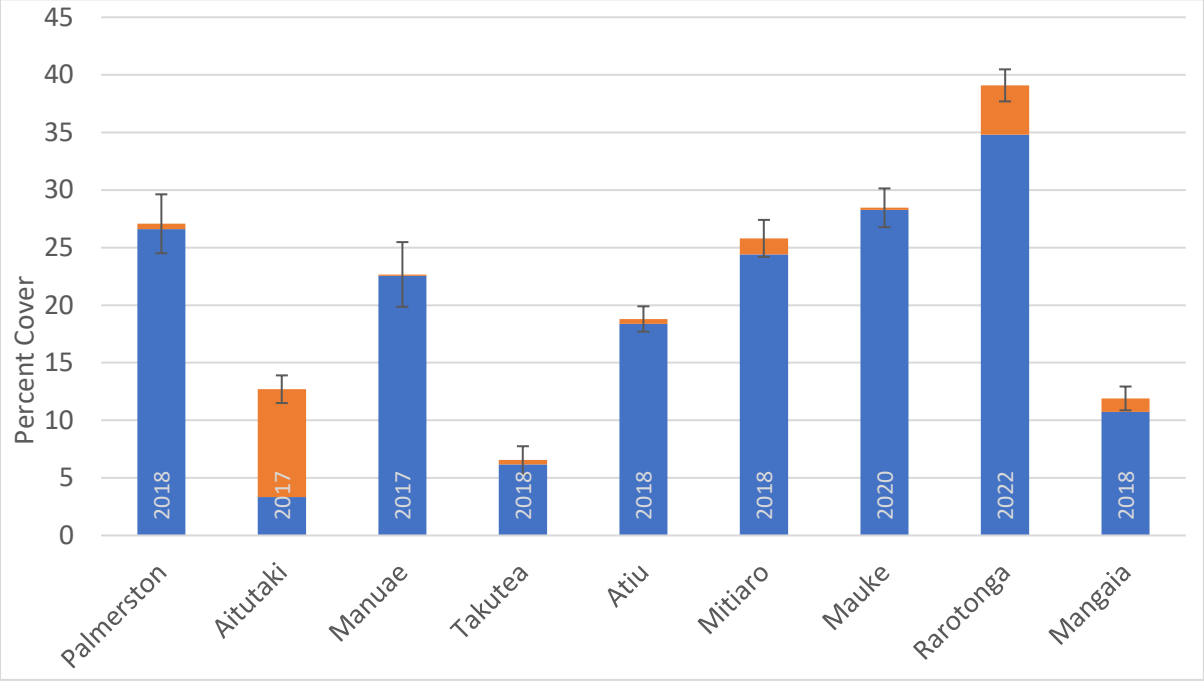


Figure 1. Average (± 1 S.E.) total live coral cover (%), comprised of hard coral (blue) and soft coral (orange) cover per island for Southern Group islands. The year of data collection is shown in each bar for each of the islands.

Macroalgae

Macroalage cover is normal in reef communities at low levels. Across the Southern Group islands, total macroalgae cover was observed to be high in several islands, particularly Mangaia, Mitiaro and Atiu (Figure 2). The cover of macroalgae may increase on forereef slopes following exposure to increased nutrient pollution and decreased cover of live coral.

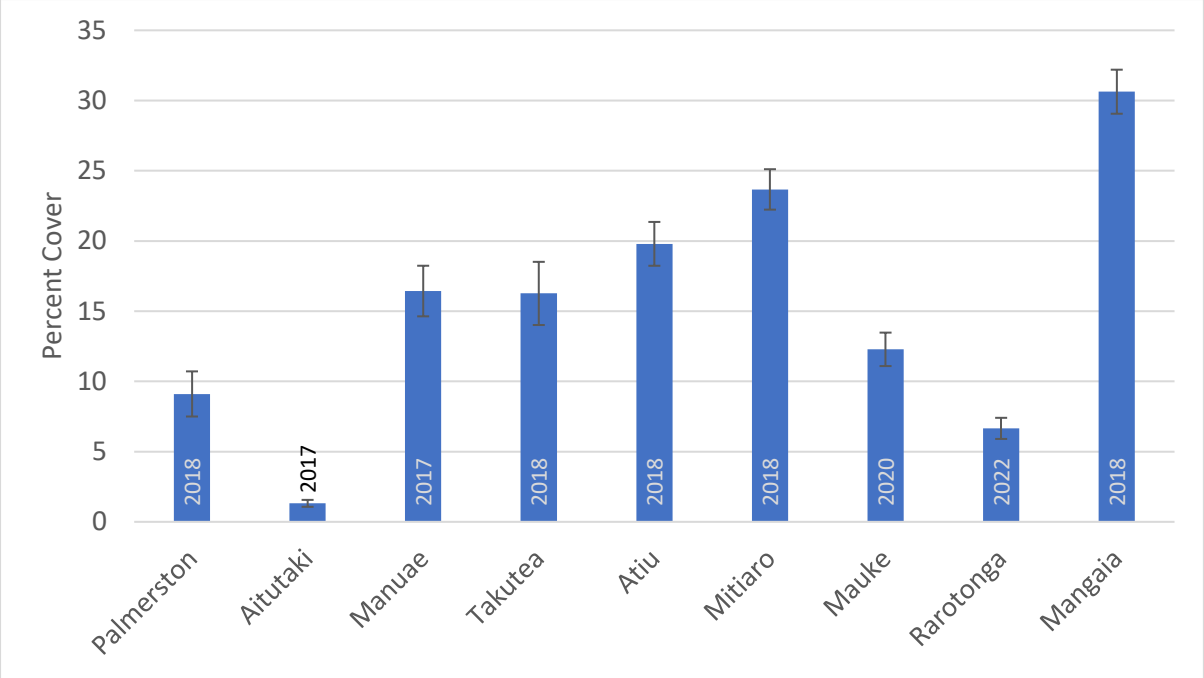


Figure 2. Average (± 1 S.E.) total macroalgae cover per island for Southern Group islands. The year of data collection is shown in each bar for each of the islands.

Recommendations

Currently, monitoring and reporting on coral health is limited to reporting only on the percent cover of total live coral. The Cook Islands has several national and international reporting obligations relating to reef health and coral cover.

MMR reports on a national level to the NSDP on indicators relating to total live coral cover. Recently it was suggested that the Cook Islands develop indicators and monitoring that looks beyond total live coral cover to include more detail and aspects of reef health, providing better snapshots and time series data.

This report provides a baseline snapshot of the state of the corals in the Southern Group of the Cook Islands which can be used for future monitoring. Since the collection of this baseline data, MMR have been able to collect additional data from Aitutaki, Manuae and Mangaia. The collection of photoquadrats and coral substrate data should be continued using the same methodology, but the analysis could be expanded to cover more than just reporting on live coral cover such as differentiating hard and soft coral, coral species/genus diversity and the prevalence of coral disease. Other variables relating to the coral reef ecosystem are also measured when the photoquadrat data is collected (for example, fish diversity) and could be included in future reporting.

Continuing data collection and building time series of coral health data from these baselines provides valuable information on the overall state of the reef, and highlight where there are current or imminent issues, driving responses and management decisions.

Appendix

Tables of values with average (± 1 standard error, to 2 d.p.) percent cover for major substrate categories and number of replicates used (N) per site. Values marked in bold indicate the site with the greatest measured value in each substrate category.

Island: Palmerston, 2018									
Site	Hard Coral	Soft Coral	Unhealthy Coral	Total Substrate	Unknown	Other Live	Total Macroalgae	Crustose Coralline Algae	N
Site 1	26.78 ± 7.02	0	**37.38 ± 8.73**	0	0	0	0	17.03 ± 3.86	6
Site 2	9.84 ± 2.86	0	13.01 ± 3.73	0	0	1.01 ± 1.01	9.23 ± 3.55	11.27 ± 3.33	7
Site 3	28.66 ± 5.35	0	7.16 ± 3.01	**27.06 ± 2.94**	0	0	11.97 ± 2.68	**25.21 ± 4.31**	10
Site 4	19.35 ± 5.32	1.05 ± 1.05	5.70 ± 2.82	0	0	0	11.68 ± 4.39	14.83 ± 5.97	6
Site 5	**34.16 ± 6.72**	1.93 ± 1.93	3.34 ± 2.52	0	0	0.84 ± 0.84	**17.66 ± 6.24**	18.4 ± 5.10	8
Site 6	**34.48 ± 4.76**	0	21.22 ± 6.94	0	0	0	3.23 ± 1.08	8.39 ± 1.38	10

Island: Aitutaki, 2017									
Site	Hard Coral	Soft Coral	Unhealthy Coral	Total Substrate	Unknown	Other Live	Total Macroalgae	Crustose Coralline Algae	N
Akaiami15	3.93 ± 2.66	10.64 ± 6.53	0	2.5 ± 1.38	2.52 ± 1.03	0	0	**75.48 ± 7.71**	10
Akaiami16	0.63 ± 0.63	15.02 ± 9.19	1.25 ± 1.25	0.63 ± 0.63	6.27 ± 2.09	0	0	**76.28 ± 9.26**	10
Long Reef Con.13	0.63 ± 0.63	3.88 ± 1.72	7 ± 3.07	1.26 ± 0.84	9.6 ± 2.58	0	**7.11 ± 2.25**	67.39 ± 5.19	10
Long Reef Con.14	2.79 ± 2.12	8.62 ± 3.27	17.67 ± 3.46	2.78 ± 2.78	19.1 ± 4.21	0	**7.01 ± 2.64**	42.16 ± 8.66	9
Long Reef Ra.7	2.59 ± 1.45	5.21 ± 3.64	17.27 ± 2.7	17.21 ± 3.15	18.72 ± 2.17	0	1.3 ± 0.87	35.23 ± 2.28	10
Long Reef Ra.8	3.8 ± 1.68	1.88 ± 1.34	**22.32 ± 4.59**	19.54 ± 4.96	9.56 ± 2.56	0	2.52 ± 1.03	39.22 ± 4.31	10
Maina Nursery5	2.74 ± 1.12	1.44 ± 0.96	0.67 ± 0.67	9.79 ± 2.06	10.57 ± 2	0	0.67 ± 0.67	74.16 ± 4.19	10
Maina Nursery6	1.88 ± 1.88	4.38 ± 2.96	0.63 ± 0.63	12.88 ± 3.8	11.98 ± 3.55	0	0	66.44 ± 2.99	10
Motukitiu11	7.78 ± 2.29	0	16.07 ± 3.07	25.68 ± 3	4.47 ± 1.64	0	1.43 ± 1.43	43.29 ± 5.53	10
Motukitiu12	5.85 ± 2.65	0	0	2.5 ± 1.67	16.37 ± 4.55	0	0	70.15 ± 6.88	10
O'otu1	0	15.37 ± 6.41	2.28 ± 1.27	27.24 ± 5.69	12.34 ± 2.84	0	0	42.79 ± 3.93	11
O'otu2	5.9 ± 1.82	13.6 ± 4.7	3.93 ± 1.42	18.51 ± 3.37	9.99 ± 2.29	0	0	48.12 ± 3.93	10
Pacific Resort21	0.61 ± 0.61	6.25 ± 5.65	0.57 ± 0.57	1.14 ± 0.76	13.69 ± 3.93	0	0.57 ± 0.57	68.01 ± 6.39	11
Pacific Resort22	1.93 ± 0.98	0.63 ± 0.63	4.43 ± 2.48	13.3 ± 5.02	11.59 ± 4.47	0	1.3 ± 0.87	61.81 ± 7.45	10
Papau Bonefish17	1.89 ± 0.96	13.14 ± 5.85	0.63 ± 0.63	0	8.14 ± 2.48	0	0	71.89 ± 5.61	10
Papau Bonefish18	3.21 ± 1.73	20.37 ± 6.88	0	2.5 ± 2.5	11.98 ± 3.27	0	0	60.12 ± 9.81	10
Papau Con.19	3.83 ± 1.95	24.77 ± 9.21	1.33 ± 1.33	1.3 ± 0.86	3.22 ± 1.42	0	0.67 ± 0.67	55.96 ± 7.19	10
Papau Con.20	3.14 ± 1.93	**25.19 ± 9.7**	3.22 ± 1.42	4.64 ± 2.65	4.57 ± 1.74	0	0	49.94 ± 8.6	10
Runway3	6.9 ± 1.97	3.76 ± 1.67	1.26 ± 0.84	21.38 ± 3.25	11.94 ± 2.36	0	1.3 ± 0.87	53.57 ± 4.21	10
Runway4	**9.2 ± 2.45**	7.84 ± 3.99	0.63 ± 0.63	22.73 ± 2.75	11.2 ± 2.84	0	0	48.47 ± 4.3	10
Takitaki Bonefish10	1.89 ± 0.96	2 ± 2	3.22 ± 1.94	23.47 ± 5.02	**22.24 ± 2.69**	0	5.22 ± 2.09	34.14 ± 4.56	10
Takitaki Bonefish9	2.56 ± 1.05	21.91 ± 8.72	5.98 ± 2.73	**27.98 ± 2.21**	7.14 ± 2.05	0	0.63 ± 0.63	33.23 ± 5.06	10

Island: Manuae, 2017									
Site	Hard Coral	Soft Coral	Unhealthy Coral	Total Substrate	Unknown	Other Live	Total Macroalgae	Crustose Coralline Algae	N
ORT01	27.9 ± 5.61	0	5.09 ± 1.83	35.91 ± 6.52	0	0.63 ± 0.63	19.21 ± 3.31	11.35 ± 3.45	10
ORT02	21.47 ± 4.06	0	**17.14 ± 4.14**	19.76 ± 3.58	0	0	22.56 ± 4.47	19.18 ± 2.73	10
ORT03	7.24 ± 2.31	0	**16.92 ± 3.74**	34.61 ± 7.23	0	0	9.27 ± 2.66	**32.06 ± 4.67**	10
ORT04	**38.62 ± 7.45**	**0.67 ± 0.67**	6.91 ± 2.71	**39.76 ± 8.45**	0	0	6.83 ± 3.13	7.28 ± 3	10
ORT05	17.91 ± 6.37	0	19.21 ± 2.78	17.83 ± 4.09	6.08 ± 2.36	0	**23.59 ± 3.72**	15.41 ± 4.28	11

Island: Takutea, 2018									
Site	Hard Coral	Soft Coral	Unhealthy Coral	Total Substrate	Unknown	Other Live	Total Macroalgae	Crustose Coralline Algae	N
Aumatangi	7.71 ± 2.64	0	20.37 ± 4.49	40 ± 6.39	3.17 ± 1.93	0	19.87 ± 4.81	8.87 ± 1.92	10
Taupoto	1.29 ± 0.86	0	11.67 ± 3.2	**61.17 ± 5.03**	4.42 ± 2.1	0	10.96 ± 3.28	**10.5 ± 3.62**	10
Tautara	**10.44 ± 2.43**	0	4.84 ± 2	53.61 ± 7.73	1.02 ± 1.02	0	**23.66 ± 6.04**	6.43 ± 3.45	7
Te-mangauri	6.58 ± 1.8	**1.67 ± 1.1**	**23.12 ± 2.56**	46.84 ± 4.89	3.18 ± 1.69	0	11.92 ± 2.96	6.7 ± 2.49	8

Island: Atiu, 2018									
Site	Hard Coral	Soft Coral	Unhealthy Coral	Total Substrate	Unknown	Other Live	Total Macroalgae	Crustose Coralline Algae	N
1	**21.3 ± 4.71**	0.69 ± 0.69	10.46 ± 2.07	57.08 ± 4.83	2.82 ± 1.53	0	7.64 ± 3.26	0	9
2	16.86 ± 3.97	0	12.88 ± 4.24	**61.09 ± 5.32**	1.53 ± 1.02	0	7.64 ± 2.71	0	9
3	15.29 ± 1.92	0	**14.5 ± 4.35**	37.67 ± 3.51	2.58 ± 1.06	0	22.42 ± 2.96	7.54 ± 6.83	10
4	17.92 ± 3.05	0.63 ± 0.63	7.22 ± 1.22	39.79 ± 4.47	1.25 ± 1.25	0	21.39 ± 3.47	11.8 ± 3.42	10
5	15.96 ± 4.64	0	5.26 ± 1.87	53.56 ± 9.04	1.25 ± 0.83	0	18.88 ± 8.1	5.09 ± 2.61	10
6	21.23 ± 5.06	0	9.75 ± 5.09	38.44 ± 7.28	5.43 ± 2.28	0	24.48 ± 4.9	0.67 ± 0.67	10
7	18.85 ± 2.19	0	5.27 ± 1.63	43.68 ± 5.06	**7.81 ± 2.44**	0	21.7 ± 3.12	2.69 ± 1.1	10
8	20.81 ± 2.85	0	7.76 ± 3.1	33.09 ± 5.17	3.92 ± 1.46	0	**29.92 ± 5.47**	4.51 ± 1.65	10
9	17 ± 3.95	**2.77 ± 2.16**	5.89 ± 2.21	38.09 ± 4.65	3.21 ± 1.94	0	16.69 ± 6.13	**16.35 ± 3.93**	10
10	18.79 ± 2.4	0	3.94 ± 1.43	41.74 ± 4.3	1.88 ± 1.33	0	24.79 ± 2.54	8.87 ± 2.68	10

Island: Mitiaro, 2018									
Site	Hard Coral	Soft Coral	Unhealthy Coral	Total Substrate	Unknown	Other Live	Total Macroalgae	Crustose Coralline Algae	N
Kovea	**31.71 ± 6.14**	0	9.37 ± 1.89	36.23 ± 6.1	4.22 ± 1.81	0	18.56 ± 4.93	0	9
Nanamaru	14.88 ± 3.68	**5.75 ± 2**	5.13 ± 2.98	**48.12 ± 6.28**	2.55 ± 1.4	0	20.39 ± 3.41	3.21 ± 1.73	10
Okarava	29.13 ± 4.12	3.21 ± 1.94	10.52 ± 2.02	29.73 ± 3.53	3.23 ± 1.08	0	21.74 ± 6.59	2.5 ± 2.5	10
Oponi	19.43 ± 5.76	0	4.5 ± 1.92	41.24 ± 5.36	**8.7 ± 3.72**	0	24.91 ± 3.03	1.25 ± 1.25	10
Patiare	29.81 ± 4.24	0	11.8 ± 3.89	24.03 ± 4.2	1.34 ± 0.89	0	**31.73 ± 2.02**	1.34 ± 0.9	10
Poavea	17.17 ± 3.42	0.67 ± 0.67	**14.55 ± 3.5**	26.6 ± 5.33	8.17 ± 2.09	0	27.19 ± 5.41	5.72 ± 2.21	10
Tepari	23.75 ± 3.15	2.84 ± 2.29	**15.61 ± 4.43**	27.15 ± 7.45	4.11 ± 1.3	0	16.18 ± 3.54	**10.42 ± 2.61**	11
Teuru	17.17 ± 3.42	0.67 ± 0.67	**14.55 ± 3.5**	26.6 ± 5.33	8.18 ± 2.09	0	27.19 ± 5.41	5.71 ± 2.21	10

Island: Mauke, 2020									
Site	Hard Coral	Soft Coral	Unhealthy Coral	Total Substrate	Unknown	Other Live	Total Macroalgae	Crustose Coralline Algae	N
Anaoake	26.76 ± 4.05	0	1.92 ± 0.98	28.82 ± 6.12	0	0	17.33 ± 3.59	23.92 ± 5.33	10
Anareia	20.5 ± 4.92	0	7 ± 3.01	**45.83 ± 4.9**	0	0	12 ± 4.44	14.67 ± 3.05	10
Aretoa	37.29 ± 7.62	0	8.38 ± 2.76	32.04 ± 7.32	0	0	2.54 ± 1.4	19.75 ± 5.28	10
Oneunga	**44.25 ± 6.15**	0	3.79 ± 1.67	14.46 ± 5.51	0	0	10.29 ± 4.47	27.21 ± 5.02	10
Patito Raui	26.46 ± 4.64	0	**16.23 ± 1.96**	43.09 ± 5.66	0	0	11.68 ± 3.74	2.54 ± 1.04	10
Poutukawa	20.27 ± 4.13	0	1.38 ± 0.92	**45.72 ± 7.43**	0.67 ± 0.67	0	7.97 ± 1.95	23.99 ± 7.18	10
Takiore	26.46 ± 4.64	0	16.23 ± 1.96	43.09 ± 5.66	0	0	11.68 ± 3.74	2.54 ± 1.04	10
Te Ana O Ve	26.86 ± 4.57	1.88 ± 1.88	0	14.35 ± 3.71	0	0	**24.14 ± 4.39**	**32.77 ± 4.58**	10
Te Pari Aanga	19.81 ± 3.98	0	3.21 ± 1.73	37.14 ± 5.57	0	0	17.22 ± 3.21	22 ± 4.67	10
Tukume	33.99 ± 4.47	0	6.73 ± 2.1	41.45 ± 6.02	0	0	7.98 ± 1.98	9.85 ± 3.01	10

Island: Rarotonga, 2022									
Site	Hard Coral	Soft Coral	Unhealthy Coral	Total Substrate	Unknown	Other Live	Total Macroalgae	Crustose Coralline Algae	N
Akaoa	30.98 ± 4.67	3.29 ± 1.78	11.11 ± 3.55	41.92 ± 5.02	0	0	7.88 ± 2.89	4.82 ± 2.98	10
Aroa	45.12 ± 4.03	0	4.78 ± 1.44	40.48 ± 5.28	0	0	0.67 ± 0.67	8.96 ± 2.45	10
Aroko	25.29 ± 4.44	11.09 ± 6.97	1.54 ± 1.54	42.18 ± 6.31	0	0	6.35 ± 1.87	13.56 ± 3.8	13
Avaavaroa	18.79 ± 4.60	18.91 ± 8.98	0	38.95 ± 5.06	0	0	10.61 ± 3.67	12.73 ± 4.23	11
Edgewater	37.50 ± 6.34	0	2.08 ± 1.47	45.14 ± 7.12	0	0	3.47 ± 2.35	11.81 ± 3.03	9
Edgewater Raui	30.00 ± 2.92	1.88 ± 0.95	3.13 ± 1.92	45 ± 4.64	0	0	2.5 ± 1.91	17.5 ± 4.55	10
Fishing Club	44.70 ± 5.57	1.14 ± 0.76	2.84 ± 2.84	44.47 ± 6.68	0	0	1.17 ± 0.79	5.68 ± 2.72	11
Nikao 1	41.89 ± 4.59	1.14 ± 1.14	2.88 ± 1.31	49.47 ± 5.78	0	0	0.57 ± 0.57	4.05 ± 1.57	11
Nikao 2	22.21 ± 4.56	5.07 ± 2.51	5.52 ± 2.22	41.12 ± 4.54	0	0	16.15 ± 5.03	9.93 ± 2.71	10
Papua	28.88 ± 4.95	0.63 ± 0.63	8.57 ± 2.3	59.96 ± 6.37	0	0	0.71 ± 0.71	1.25 ± 0.83	10
Parliament	45.47 ± 3.19	1.21 ± 0.81	1.78 ± 1.29	47.96 ± 3.2	0	0.57 ± 0.57	0	3.01 ± 1.35	11
Pouara	11.11 ± 1.74	0	0.69 ± 0.69	77.08 ± 3.29	0	0.69 ± 0.69	10.42 ± 3.76	0	9
Pouara Raui	32.08 ± 4.72	0	0	61.46 ± 4.04	0	0	2 ± 2	4.46 ± 1.67	10
Rutaki	39.42 ± 6.56	11.38 ± 5.19	2.58 ± 1.06	16.58 ± 3.43	0	0	19.83 ± 3.46	10.21 ± 3.17	10
Sails	19.80 ± 3.17	0.65 ± 0.65	0	59.11 ± 4.06	0	0	17.33 ± 4.96	3.12 ± 1.7	11
Tikioki	32.04 ± 3.14	2.58 ± 1.41	3.13 ± 2.13	27.12 ± 4.38	0	0	12.63 ± 4.46	22.51 ± 5.04	10
Tikioki Raui	47.78 ± 4.74	13.65 ± 5.77	2.59 ± 1.05	24.19 ± 3.75	0	0	0.89 ± 0.61	10.9 ± 2.59	15
Titikaveka	51.84 ± 4.15	1.63 ± 1.18	1.08 ± 0.73	21.88 ± 3.81	0	0	13.96 ± 3.56	9.62 ± 1.83	12
Tupapa	47.50 ± 2.18	0	0	38.46 ± 3.3	0	0	1.25 ± 0.83	12.79 ± 3.46	10

Island: Mangaia, 2018									
Site	Hard Coral	Soft Coral	Unhealthy Coral	Total Substrate	Unknown	Other Live	Total Macroalgae	Crustose Coralline Algae	N
Ivirua Control	12.61 ± 4.87	0	0	32.01 ± 4.2	9.91 ± 3.34	0	27.73 ± 2.43	17.79 ± 3.68	9
Karanga Ra'ui	20.48 ± 5.01	0.67 ± 0.67	**12.35 ± 2.82**	21.63 ± 6.43	7.26 ± 2.72	0	17.62 ± 4.67	20.05 ± 4.35	10
Keia Control	0	0	2.09 ± 1.48	8.39 ± 4.29	8.54 ± 2.8	0	49.42 ± 5.86	**31.62 ± 7.66**	9
Keia Permanent Ra'ui	4.74 ± 1.79	0	1.97 ± 1.01	28.58 ± 3.78	15.21 ± 1.86	0	36.04 ± 4.22	13.51 ± 4.05	10
Keia Ra'ui N	8.41 ± 2.08	1.4 ± 0.93	7.19 ± 3.72	38.53 ± 7.77	9.06 ± 3.48	0	33.49 ± 7.9	1.4 ± 0.93	9
Keia Ra'ui S	12.82 ± 2.78	0.67 ± 0.67	4.58 ± 1.96	13.64 ± 5.26	6.5 ± 1.93	0	**50.43 ± 3.97**	11.38 ± 5.16	10
Tamarua Control	**24.79 ± 6**	3.13 ± 3.13	1.33 ± 1.33	14.76 ± 3.65	10.39 ± 2.74	0	30.23 ± 2.84	15.46 ± 4.99	10
Tamarua Ra'ui	8.94 ± 2.87	1.88 ± 1.34	7.61 ± 2.6	34.39 ± 2.95	5.73 ± 1.46	0	40.93 ± 3.07	0.63 ± 0.63	10
Tavaenga Control	11.61 ± 2.61	0	4.55 ± 1.69	**54.45 ± 5.1**	11.16 ± 2.71	0	14.36 ± 3.47	3.93 ± 1.42	10
Tavaenga Permanent Ra'ui	10.99 ± 2.91	2.5 ± 2.5	9.93 ± 7.84	48.24 ± 7.69	11.02 ± 2.5	0	12.07 ± 4.1	5.3 ± 2.76	10
Tavaenga Ra'ui N	14.49 ± 2.03	0	2.18 ± 1.55	50.23 ± 6.01	9.48 ± 1.93	0	15.46 ± 3.38	8.27 ± 2.76	9
Tavaenga Ra'ui S	6.91 ± 2.18	0.63 ± 0.63	2.63 ± 1.46	37.02 ± 5.11	**17.64 ± 4.3**	0	25.94 ± 4.4	9.29 ± 2.42	10
Veitatei Control	7.94 ± 3.02	1.88 ± 1.34	0.67 ± 0.67	9.73 ± 3.15	7.36 ± 2.07	0	41.02 ± 5.75	**31.47 ± 7.05**	10
Veitatei Ra'ui	4.66 ± 1.75	**3.38 ± 2.69**	1.3 ± 0.87	45.81 ± 5.32	7.26 ± 3.89	0	34.43 ± 5.91	2.6 ± 1.06	10