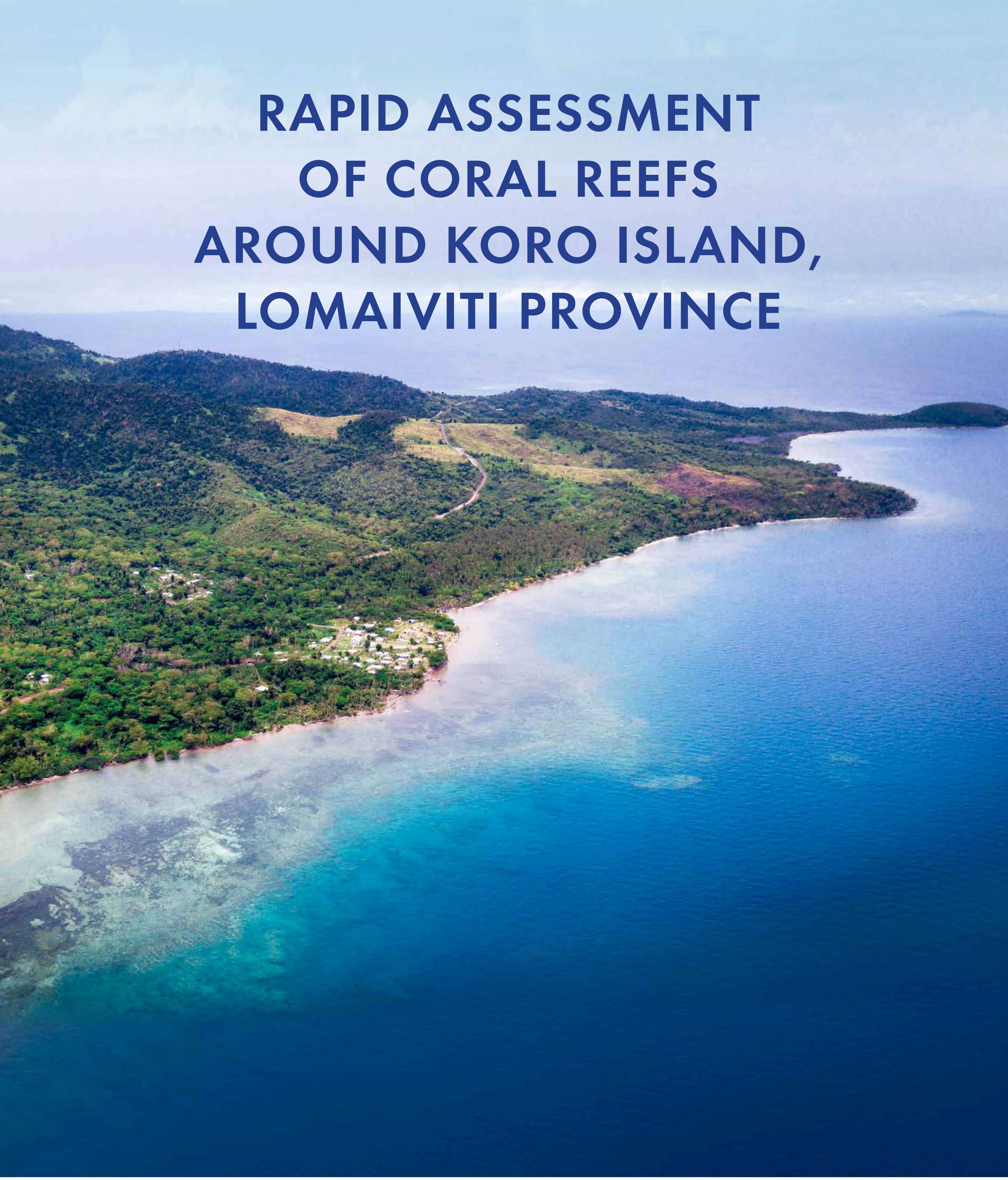
RAPID ASSESSMENT OF CORAL REEFS AROUND KORO ISLAND, LOMAIVITI PROVINCE



Wildlife Conservation Society

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WCS

ACKNOWLEDGEMENTS

Foremost, a heartfelt thanks to all the communities in the villages of Kade, Mudu, Nabasovi, Nabuna, Nacamaki, Nakodu, Namacu, Naqaidamu, Nasau, Navaga, Tavua, Tuatua, Sinuvaca, and Vatulele on Koro Island for inviting us to survey their customary fishing grounds. The data collected has contributed to the development of an island-scale ridge-to-reef management plan for Koro Island, and will continue to assist the communities with decisions on their fisheries resources. We are grateful to the Lomaiviti Provincial Office for supporting this work and to Akanisi Caginitoba and Epeli Loganimoce from the Wildlife Conservation Society for coordinating with the local communities and providing logistic support. We thank Sahar Kirmani for assisting with data entry and field work and Alyssa Thomas, Emily Darling and Elisabeth Matthews for their comments on this report. This work would not have been possible without the generous support of John D. and Catherine T. MacArthur Foundation (#17-1706-152078-CSD).

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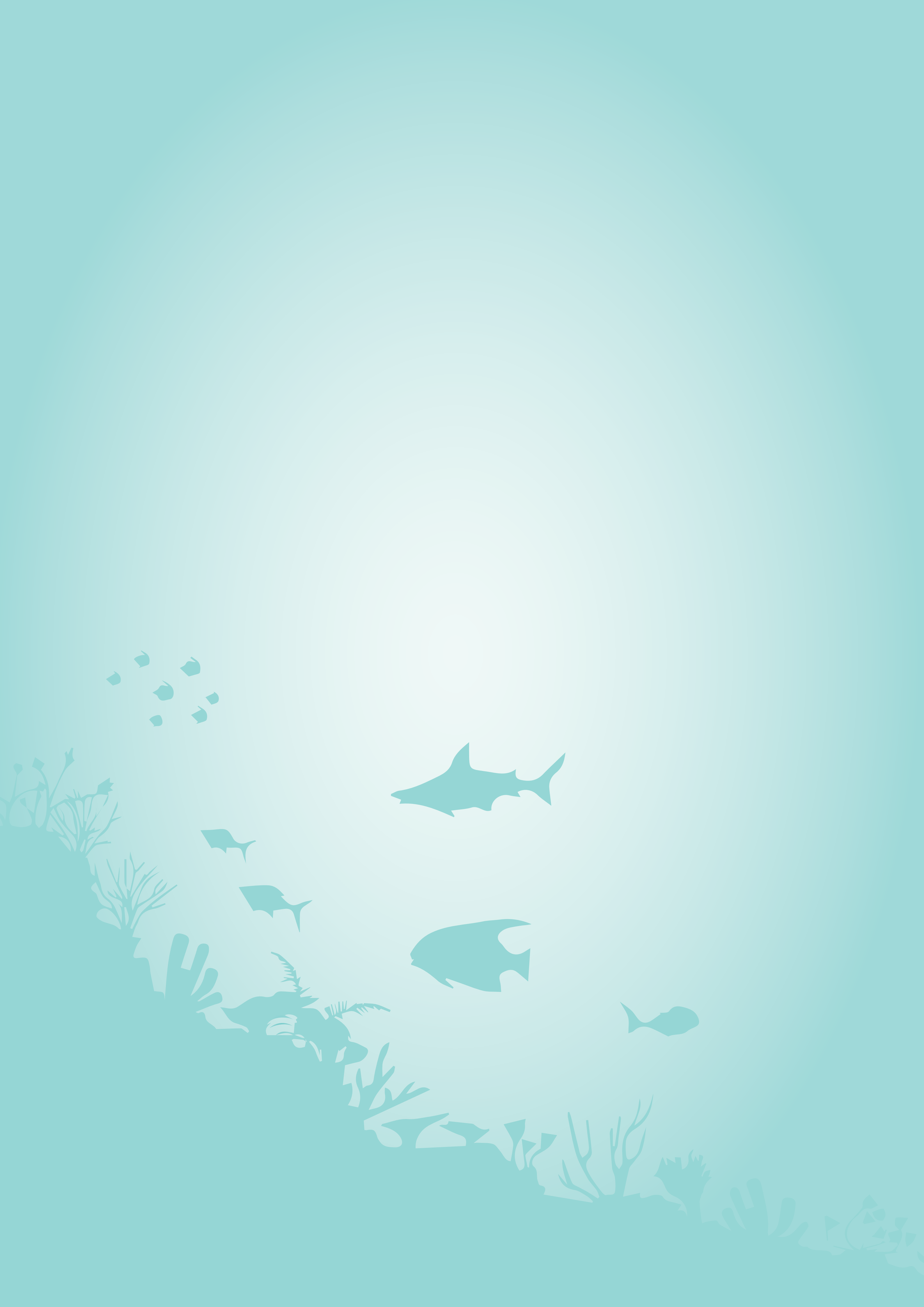
CONTENTS



EXECUTIVE SUMMARY

Koro Island is north of Suva in the Lomaiviti Province and is the sixth-largest island in Fiji. There are 14 traditional fishing grounds and at the time of the study, there were 7 *tabu* areas (periodically harvested closures). On 20 February 2016, one of the largest cyclones on record in the southern hemisphere passed through Fiji, leaving a trail of destruction, with some of the most impacted landscapes and communities located in the Vatu-i-Ra Seascape.

A detailed assessment of community fishing grounds (*qoliqoli*) around Koro Island in the Lomaiviti Province was conducted from 6–12 September, 2017. The objectives of these surveys were to: (a) to document the overall health of coral reefs around Koro Island; (b) assess impact and recovery of coral reefs within community fishing grounds 18 months after Cyclone Winston; and (c) provide recommendations to communities on the management of their traditional fishing grounds to maximise post-cyclone recovery, and support ridge-to-reef planning and implementation for Koro Island. Data were collected on the benthic cover, habitat structure, and fish size and abundance. Surveys were done both inside and outside *tabu* areas within community fishing grounds.

A total of 31 sites were surveyed, of which, 14 were previously surveyed in 2013 and 2014. Sites surveyed were from exposed and sheltered sides of the island within reefs protected (*tabu*) and open to fishing. WCS had pre-cyclone data from two fishing grounds (Tuatua and Nakodu); however, the data was collected immediately after a *tabu* harvesting event which made it difficult to differentiate the impact of the cyclone and the recovery potential of reefs. However, trends in benthic cover and composition and fish assemblages from the two fishing grounds, and overall data collected on the reef system around Koro Island, is still useful to communities making decisions on their natural resources.

The benthic composition differed between exposed and sheltered sites of Koro Island; exposed sites showed more signs of cyclone damage, while sheltered sites showed more signs of disturbance such as sedimentation from the land[1]. Unconsolidated substrate was the most dominant benthic substrate observed (average = 29.0±21.4%), and coral cover averaged 8.4±4.9%.

A high number of fish species (165 spp.) was recorded during the survey. Fish biomass was highly variable ranging from 158.7 kg/ha to 3347.3 kg/ha; however the average fish biomass was 1299.0 kg/ha indicating stocks were generally healthy. These results suggest that some reefs around Koro Island are in good health while others are struggling to maintain functional levels of fish biomass. Although only a few whitetip and blacktip reef sharks were observed, the study recorded several families of important functional groups of fish species such as siganids (rabbitfish), lethrinids (snappers) and serranids (groupers).

This study found that the majority of reefs had not recovered from the impact of Cyclone Winston. Tuatua and Nakodu fishing grounds showed a decreasing trend in coral cover, an increase in fish biomass, but a decline in fish species richness.

[1] This survey is unable to distinguish sedimentation from land-based activities and that from storm surges during Cyclone Winston.

RECOMMENDATIONS

a. The island scale ecosystem-based management plan launched in 2019 is fully implemented to ensure the recovery and long-term health of the island, its ecosystem and the people of Koro Island.

b. Actions should be taken to minimise human stresses to coral reefs, especially areas that are heavily impacted. This includes the control of gravel extraction and the clearing of forests and other vegetation on steep slopes.

c. Maintain the network *tabu* areas around the island for another 5 years to support reef recovery.

d. Extend monitoring programs to measure the recovery of coral reefs over the next 5 years, and ensure they are linked to management actions.

e. Extend the following *tabu* areas to the edge of the forereef to cover more complex and productive habitats.

f. Consider an additional *tabu* area on the northwestern corner of Koro Island to cover more exposed spur and groove habitat.

INTRODUCTION

Koro Island is a volcanic island located 133.3 km north of Suva in the Lomaiviti archipelago and is the sixth-largest island in Fiji with a land area of 105.3 km^2. The archipelago includes eight main islands covering 411 km^2 of land area (Brown 2009). The interior of Koro Island consists of an elevated plateau approximately 15 km long and 3–4 km wide and rests more than 300 m above sea level with the highest point at 514 m (UNESCO/UNFPA 1977). Koro Island has 14 traditional fishing grounds, one for each village covering a total area of 75.1 km^2, including 7 *tabu* areas (i.e. periodically harvested closures). Coral reef habitats around Koro Island include reef flats, forereef, fringing reefs, deep and shallow terraces, and lagoonal reefs.

On 20 February 2016, Category 5 Tropical Cyclone Winston passed through Fiji. It was one of the strongest cyclones Fiji had experienced since the 1970s with wind speeds up to 185 mph and gusts up to 225 mph. Over a 24-hour period, the cyclone left a trail of destruction across the country. A post-disaster needs assessment (PDNA) estimated damages and losses at FJ$1.99 billion[2], which included crop, livestock and agricultural damage (Government of Fiji 2016).

Some of the most affected people were the 116,000 people living in remote rural communities within the Vatu-i-Ra Seascape, which covers the provinces of Bua, Lomaiviti, Ra and Tailevu (Figure 1). Lomaiviti Province was badly hit with 100% of homes damaged or destroyed on Koro Island, and 80–90% of homes lost on Ovalau Island (Chaston Radway et al. 2016). The impact to the Lomaiviti Province extended as far south as the islands of Batiki and Narai. Many islands, including Koro, were struck by storm surges.

A 2016 study by the Wildlife Conservation Society (WCS), Fiji Locally Managed Marine Areas (FLMMA) network, University of the South Pacific (USP), Coral Reef Alliance and Global Vision International, examined the impact of the cyclone on fisheries-dependent communities (Chaston Radway et al. 2016). The damage and loss of boats and engines on Koro Island were estimated at FJ$64,035, and there was also a significant loss of fishing gear across the province which impacted the communities' ability to fish for food in the months after the cyclone. In addition to infrastructural damage, the PDNA also recorded an increase in rates of malnutrition amongst children (Government of Fiji 2016).

A rapid assessment of the impact of the cyclone on coral reefs documented significant damage to coral communities up to 20–30 m below the surface in the Vatu-i-Ra Seascape (Mangubhai 2016). Damage to coral reefs was highest in the north where the eye of the cyclone passed, lowest in the south, and was highly variable and patchy between reefs. There was extensive coral breakage, coral abrasion, dislodgement of large coral colonies and structural damage to the reef framework (Mangubhai 2016). However, the majority of sites surveyed were ones popular with tourists, particularly live-aboard dive boats, and did not include many of the inshore areas important to local communities for subsistence and fisheries livelihoods. An island-scale coral reef assessment survey has not been done for Koro Island, nor have any coral reef surveys been done since Cyclone Winston to document the impact on reef systems. However, WCS has pre-cyclone data from the *tabu* and adjacent fishing areas of two villages (Nakodu and Tuatua) on Koro Island (Goetze et al. 2016).

Due to the amount of structural damage from these types of disturbances, especially cyclones, recovery can take decades, depending on the frequency of the events, the scale and intensity of structural damage caused, and compounding anthropogenic stresses (e.g., pollution, overfishing) that might hinder or slow recovery (Beeden et al. 2015). Recovery and management of coral reef systems depend on our understanding of factors and processes causing the shift of a healthy system to a degraded system (Ridgway and Hoegh-Guldberg 2000). It will be important to ensure that any future fishing pressure does not impede the recovery of coral reefs and their ability to provide for fishery-dependent communities.

[2] At the time of the study 1 JFD was equivalent to 0.4957 USD.

WCS began working with the communities of Koro Island and the Lomaiviti Provincial Office in 2015 to develop an island-scale ridge-to-reef management plan that incorporated ecosystem-based management principles and approaches. The planning process was halted in February 2016 as communities focused on rebuilding their lives after Cyclone Winston. An integrated vulnerability analysis was conducted on June 2016 to inform decisions on the relocation of local communities and their vulnerability to future natural disasters and climate change (USP and WCS unpublished data). The island-wide planning process for Koro Island recommenced in July 2017, and was launched in December 2019. It is critical to understand the state of coral reefs within community fishing grounds around Koro Island to enable communities to make wise-decisions on the management of their fisheries resources.

The main objectives of the study were therefore to:

1. document the overall health of coral reef systems around Koro Island;
2. assess the impact and recovery potential of coral reefs in two customary fishing grounds 18 months after the Cyclone Winston; and
3. provide recommendations to communities on the management of their traditional fishing grounds to maximise post-cyclone recovery, and support ridge-to-reef planning and implementation for Koro Island.

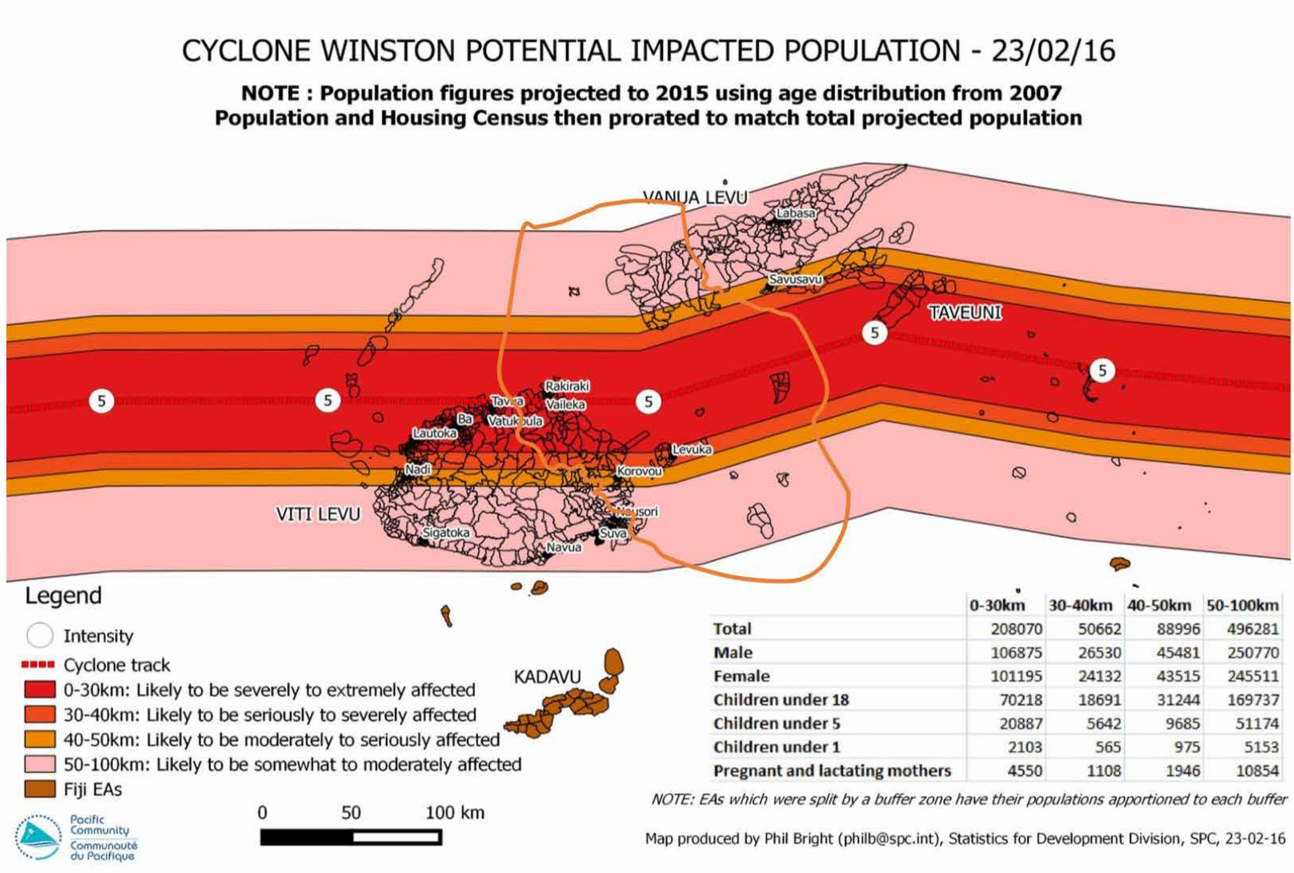


FIGURE 1. The pathway and predicted impacted population from Tropical Cyclone Winston. The orange line encompassing the land and sea between Viti Levu and Vanua Levu is the boundary of the Vatu-i-Ra Seascape. Source: The Pacific Community (SPC)

METHODS

Coral reef surveys of community fishing grounds around Koro Island in the Lomaiviti Province were conducted from 6–12 September 2017, using WCS' Standard Monitoring Protocol (WCS 2010). The reef systems around Koro are largely fringing reefs, with larger and more developed reefs on the eastern side of the island. A rapid assessment approach was taken to enable wide coverage of the island. A total of 31 sites were surveyed over 6 days including *tabu* and adjacent areas open to fishing.[3] WCS had previously carried out surveys in the fishing grounds of two villages: Tuatua in 2013 and Nakodu in 2013 and 2014 (Figure 2, Table 1). It is important to note that the majority of *tabu* areas around Koro Island are on the eastern exposed side of the island. Surveys were done on snorkel and SCUBA at shallow (3–5 m) and deeper (8–10 m) sites inside and outside *tabu* areas, respectively.

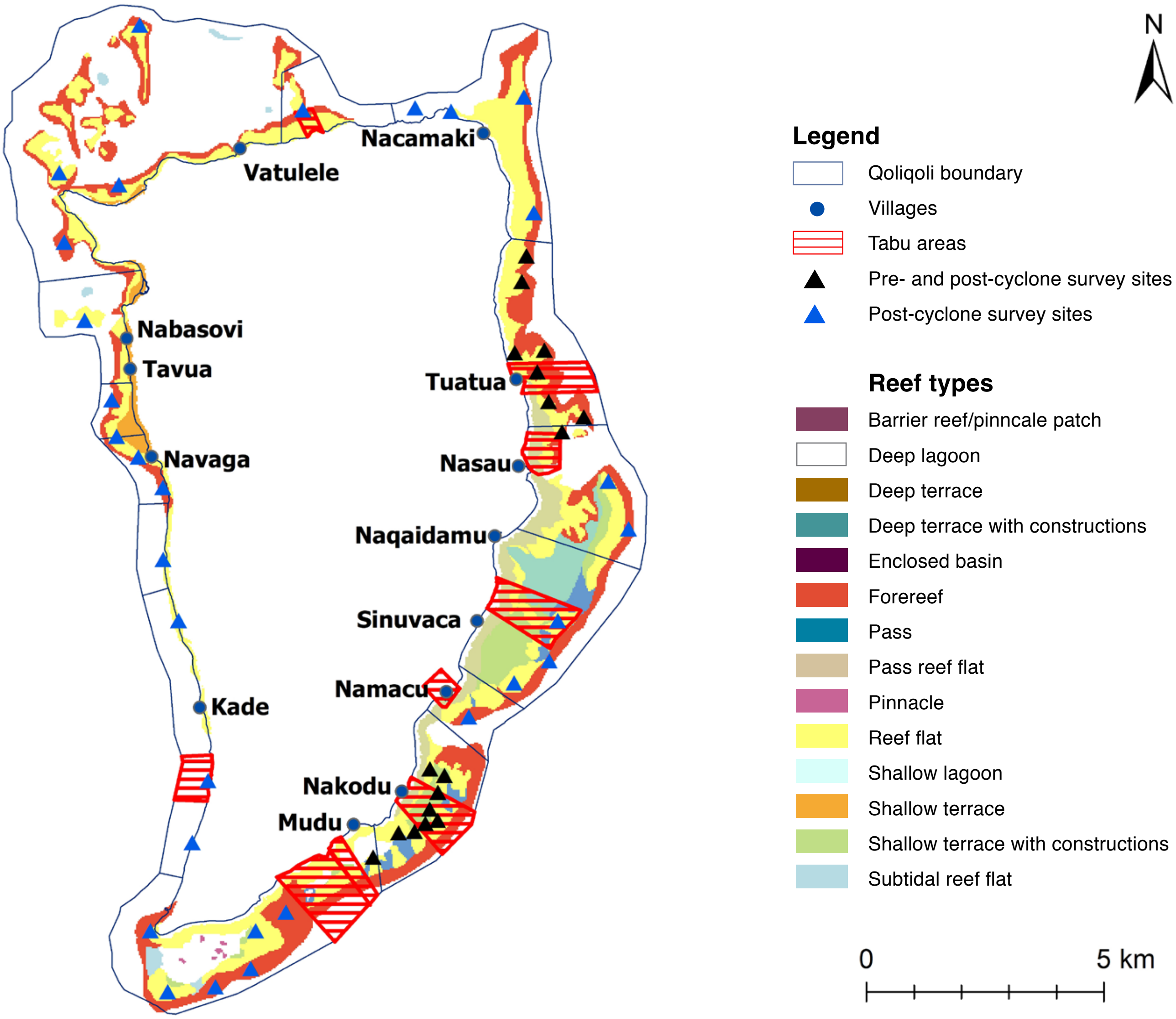


FIGURE 2. Sites surveyed around Koro Island in 2013, 2014 and 2017. Qoliqoli boundary is the outer edge of the community fishing grounds.

[3] Prior to the cyclone there were 18 known *tabu* areas around Koro Island. However, several of the *tabu* areas were opened to fishing after the cyclone to provide fish for communities (E. Loganimoce, pers. comm.). Only *tabu*s known to be closed at the time of the survey were listed a '*tabu'*.

TABLE 1. Coral reef sites surveyed around Koro Island in 2013, 2014 and 2017.

SITE	FISHING GROUND	MANAGEMENT	EXPOSURE	DEPTH (M)	YEAR(S) SURVEYED	COORDINATES
NF1	Nakodu	open	exposed	6.9	2013, 2014, 2017	-17.3848, 179.4099
NF3	Nakodu	open	exposed	5.4	2013, 2014, 2017	-17.3787, 179.4189
NF4	Nakodu	open	exposed	4.2	2013, 2014, 2017	-17.3709, 179.4239
NT1	Nakodu	*tabu*	exposed	6.2	2013, 2014, 2017	-17.3741, 179.4217
NT2	Nakodu	*tabu*	exposed	4.6	2013, 2014, 2017	-17.3774, 179.4206
NT3	Nakodu	*tabu*	exposed	5.1	2013, 2014, 2017	-17.3749, 179.4244
TF1	Tuatua	open	exposed	5.4	2013, 2017	-17.3022, 179.4477
TF4	Tuatua	open	exposed	6.5	2013, 2017	-17.2741, 179.4388
TF5	Tuatua	open	exposed	6.2	2013, 2017	-17.2692, 179.4396
TT2	Tuatua	open	exposed	6.0	2013, 2017	-17.2870, 179.4434
TT3	Tuatua	open	exposed	8.6	2013, 2017	-17.2876, 179.4375
TF2	Tuatua	open	exposed	7.5	2013, 2017	-17.2996, 179.4513
TF3	Tuatua	open	exposed	4.0	2013, 2017	-17.2968, 179.4444
TT1	Tuatua	*tabu*	exposed	7.6	2013, 2017	-17.2927, 179.4446
KD2	Kade	open	sheltered	1.5	2017	-17.3392, 179.3717
KD3	Kade	*tabu*	sheltered	6.3	2017	-17.3688, 179.3779
MD1	Mudu	open	sheltered	8.5	2017	-17.3951, 179.3662
MD4	Mudu	open	exposed	10.4	2017	-17.4045, 179.3866
MD6	Mudu	*tabu*	exposed	9.2	2017	-17.3865, 179.4036
NC1	Nacamaki	open	exposed	7.9	2017	-17.2389, 179.4391
NC2	Nacamaki	open	exposed	7.8	2017	-17.2511, 179.4384
NS1	Nasau	open	exposed	6.0	2017	-17.3378, 179.4467
NS3	Nasau	*tabu*	exposed	7.0	2017	-17.3741, 179.4217
NV1	Nabasovi	open	sheltered	6.0	2017	-17.2940, 179.3578
NV4	Navaga	*tabu*	sheltered	6.4	2017	-17.3146, 179.3684
V1	Vatulele	open	sheltered	3.9	2017	-17.2403, 179.3944
V2	Nabuna	open	sheltered	7.0	2017	-17.2263, 179.3613
V3	Nabuna	open	sheltered	4.3	2017	-17.2569, 179.3589
V4	Nabuna	open	sheltered	7.6	2017	-17.2554, 179.3447
V5	Nabuna	open	sheltered	6.2	2017	-17.2665, 179.3503
V6	Nabuna	*tabu*	sheltered	7.9	2017	-17.2801, 179.3525

BENTHIC COVER

Point intercept transects were done at 0.5 m intervals along 3 x 50 m transects and the benthic cover was recorded using a modified Global Coral Reef Monitoring Network category list (WCS 2010). Life form categories for benthos were recorded (Table 2), and coral identification was done to genus level. A list of coral genera was also compiled for the whole island, and notes were taken to document the reef types, level of cyclone damage observed at each site, signs of recovery (e.g., presence of coral recruits), and general condition of the reef (Appendix 1). To collect a long-term record of benthic cover, underwater photos were taken using a fixed camera-to-camera distance of 0.5–1 m and holding the camera perpendicular to the substrate, just to the side of the transect line. Benthic data were entered into MERMAID[4] and analysed in R software version 3.3.3 (R Development Core Team 2017).

FISH SURVEYS

Coral reef fish species, size and abundance were recorded in three 50 x 5 m belt transects, following the depth contour on the reef while attempting to stay on the reef substrate as much as possible. At least 5 m of space was left between each transect. All species are recorded in the families Acanthuridae (surgeonfish), Labridae (wrasses), Serranidae (groupers excluding Anthias), Balistidae (triggerfish), Lethrinidae (emperors), Siganidae (rabbitfish), Caesionidae (fusiliers), Lutjanidae (snappers), Scombridae (mackerel and tuna), Carangidae (jacks and trevallies), Mullidae (goatfish), Sphyraenidae (barracuda), Chaetodonotidae (butterflyfish), Nemipteridae (breams), sharks (all families), Ephippidae (spadefish and batfish), Pomacanthidae (angelfish), Haemulidae (sweetlips), Priacathidae (bigeyes), Kyphosidae (chubs and rudderfish), and Scaridae (parrotfish). The size of fish (fork length) was recorded in the following classes (to the nearest cm): 2–5, 6–10, 11–15, 16–20, 21–25, 26–30, 31–35, 36–40, and >40. For fish >40 cm, the number and the size of each of the fish were documented. Each transect took 15–20 minutes to complete.

DATA ANALYSIS

Benthic life forms were categorised into benthic categories (Table 2). Percentage cover for each benthic category was calculated by counting the number of times each category appeared along the 100-point transect. The percent cover was summed for major benthic categories on each transect, and averages were taken across transects for each site. In this report, crustose coralline algae, intact dead coral with algae and reef matrix are collectively referred to as 'consolidated' substrate since these surfaces generally form a stable reef structure (Ridgway and Hoegh-Guldberg 2000). Sand, rubble, silt and fragmented (broken) corals collectively are referred to as 'unconsolidated' substrate as they form an 'unstable' structure (Ridgway and Hoegh-Guldberg 2000). Unconsolidated substrate is a good indicator of disturbances such as cyclones, tsunamis and anthropogenic reef damage (from anchors, fishing, and/or boats). Turf algae, macroalgae, calcareous algae, and algal assemblage are collectively categorised as 'algae' in this report (Table 2). All errors presented in text, tables and graphs are standard deviations.

Fish biomass was calculated using the equation $W = aL^b$ where L represents the fish length (cm) estimated during the underwater visual census survey, 'W' the weight in grams, and a and b published species-specific conversion constants from Fishbase (www.fishbase.se). Where conversion constants were not available, genus averages were used for biomass calculations. Fish biomass was calculated for each species observed and total fish biomass by transect was calculated by summing all fish counted per transect. To calculated the fish biomass for each site, fish biomass was averaged by site. All errors presented in text, tables and graphs are standard deviations.

[4] MERMAID stands for Marine Ecological Research Management AID, is an online-offline web application for coral reef data collection and storage. MERMAID is a collaboration between the Wildlife Conservation Society, the World Wildlife Fund and Sparkgeo. https://datamermaid.org/

TABLE 2. Benthic code, life forms and categories used for benthic composition assessed around Koro Island.

BENTHIC CATEGORIES	LIFE FORMS	BENTHIC CODES
Hard coral	*Acropora* branching	ACB
	Acropora encrusting	ACE
	*Acropora tabu*late	ACT
	Acropora digitate	ACD
	Coral branching	CB
	Coral corymbose	CC
	Coral encrusting	CE
	Coral foliose	CF
	Coral submassive	CS
	Coral massive	CM
	Coral mushroom	CMR
Soft coral	Soft coral	SC
Algae	Coralline algae – calcareous algae	CA
	Halimeda – calcareous algae	HA
	Algal assemblage	AA
	Macroalgae	MA
	Turf algae	TA
Microbial	Microbial mats (cyanobacteria)	MC
Consolidated substrate	Crustose coralline algae	CCA
	Reef matrix	RM
	Dead coral with algae	DA
Unconsolidated substrate	Rubble	RB
	Sand	SD
	Silt	SI
Others	Others (invertebrates, ascidians)	OT
	Sponge	SP
	Zooanthids	ZO

RESULTS AND DISCUSSION

The study represents one of a very few assessments of coral reef systems around Koro Island, and was conducted 18 months after Tropical Cyclone Winston. WCS had pre-cyclone data from two fishing grounds (Tuatua and Nakodu); however, the data were collected immediately after a *tabu* harvesting event which made it difficult to assess the impact of the cyclone and the recovery potential of reefs. Based on the trends in benthic composition and fish assemblages from the two fishing grounds and overall data on the reef system around Koro Island, useful management recommendations to the communities could still be provided.

BENTHIC COMPOSITION AND FISH ASSEMBLAGES

CORAL COVER

A total of 39 coral genera were recorded for Koro Island over 31 sites (Appendix 2). *Porites, Acropora, Pocillopora, Cyphastrea* and *Montipora* were the most common hard coral genera on reef systems around Koro Island (Plate 1), while *Sinularia*, *Lobophyton* and *Sarcophyton* were the most common soft coral genera (Plate 2). Recruits and juvenile corals were observed on clean surfaces and on surfaces with macroalgae where there was intact consolidated reef matrix (Plate 3).

The study found that the coral community around Koro Island was in poor to moderate health with cover averaging 8.4±4.9%. The average coral cover was much lower than that recorded from the neighbouring islands of Gau, Wakaya and Batiki in Lomaiviti waters after Cyclone Winston (30–50%; Mangubhai 2016). There was variability in hard coral cover between sites around Koro Island, between sheltered and exposed sites, and between *tabu* and fished reefs (Table 3, Figure 3). The highest coral cover was recorded inside the Kade fishing ground at site KD2 (22±1.7) whilst the lowest was recorded inside the Nakodu fishing ground at site NT1 (1.0±1.0). Slightly higher coral cover was recorded on the sheltered side of the island compared to the exposed side (Figure 3).

There was some variability in coral cover between reefs that were protected within *tabu* areas and those open to fishing. However, it was not possible to say if the low cover resulted from the cyclone or general degradation of the reef over many years. Such variability in coral cover could be due to multiple factors such as the physical environment, reef morphology, habitat complexity and effectiveness of existing traditional management systems. At some sites sedimentation from land-based sources could also contribute to variation in coral cover (Figure 3); some reefs had higher sediment cover and algal overgrowth. Lower coral cover was recorded inside *tabu* areas, with slightly higher percentage cover at sheltered (7.9±1.4) compared to exposed (5.6±3.2) sites (Table 3).

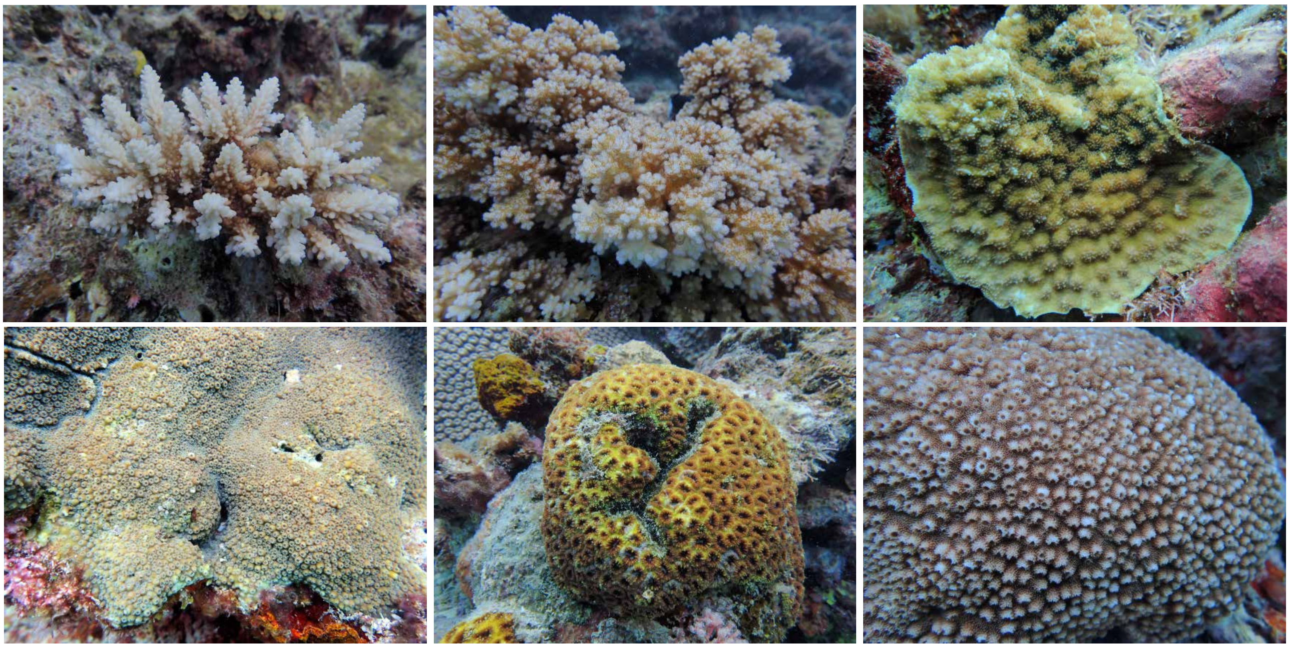


PLATE 1. Hard coral species on coral reefs around Koro Island. Top: *Acropora secale, Pocillopora damicornis*, and encrusting *Echinopora*. Bottom: encrusting *Cyphastrea,* and submassive or massive forms *Favia, Astreopora.* © Sangeeta Mangubhai/WCS

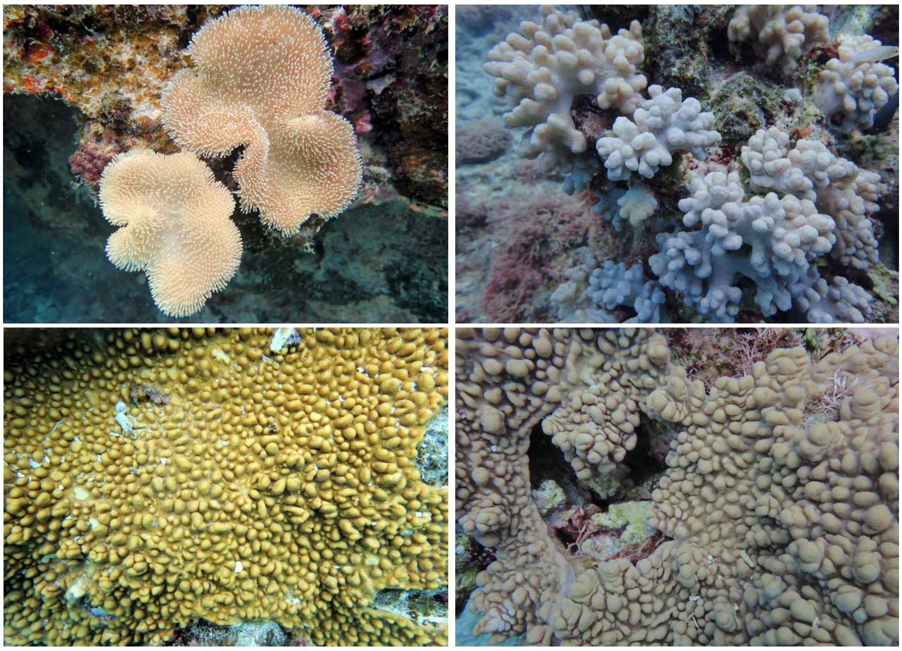


PLATE 2. Soft coral species on coral reefs around Koro Island. © Sangeeta Mangubhai/WCS

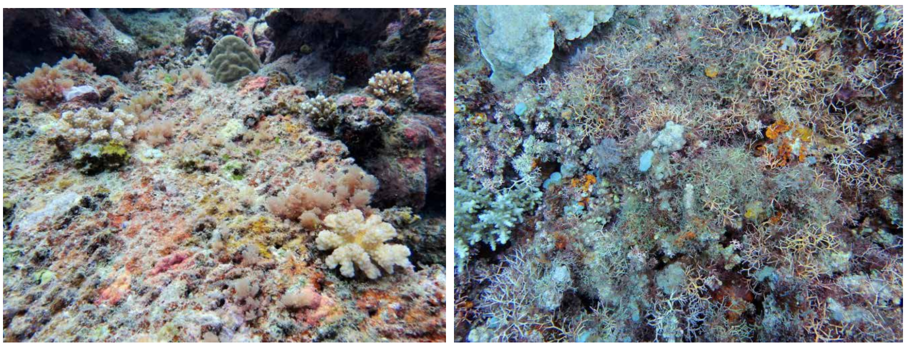


PLATE 3. Coral recruits observed on coral reefs on Koro Island. © Sangeeta Mangubhai/WCS

TABLE 3. Mean substrate cover for selected benthic categories across exposure types and management systems around Koro Island. Range and standard deviation also presented.

BENTHIC CATEGORY	EXPOSURE	MANAGEMENT	% COVER(±SD)	% RANGE
Hard coral	Exposed	Open	6.6±3.6	3–14
	Sheltered	Open	13.7±5.1	8–22
	Exposed	*Tabu*	5.6±3.2	1–9
	Sheltered	*Tabu*	7.9±1.4	6–9
Consolidated substrate	Exposed	Open	28.4±20.2	7–71
	Sheltered	Open	20.8±17.2	3–44
	Exposed	*Tabu*	16.6±8.2	2–24
	Sheltered	*Tabu*	15.7±12.5	3–28
Unconsolidated substrate	Exposed	Open	19.6±19.2	0–64
	Sheltered	Open	25.2±13.4	5–42
	Exposed	*Tabu*	50.3±24.5	3–63
	Sheltered	*Tabu*	40.6±3.6	30–53
Turf algae	Exposed	Open	11.8±9.9	0–38
	Sheltered	Open	8.1±7.7	0–25
	Exposed	*Tabu*	11.2±6.8	4–21
	Sheltered	*Tabu*	9.0±10.1	0–20
Macroalgae	Exposed	Open	11.3±8.5	1–28
	Sheltered	Open	7.7±7.1	0–18
	Exposed	*Tabu*	4.5±8.3	0–22
	Sheltered	*Tabu*	9.0±12.1	1–23

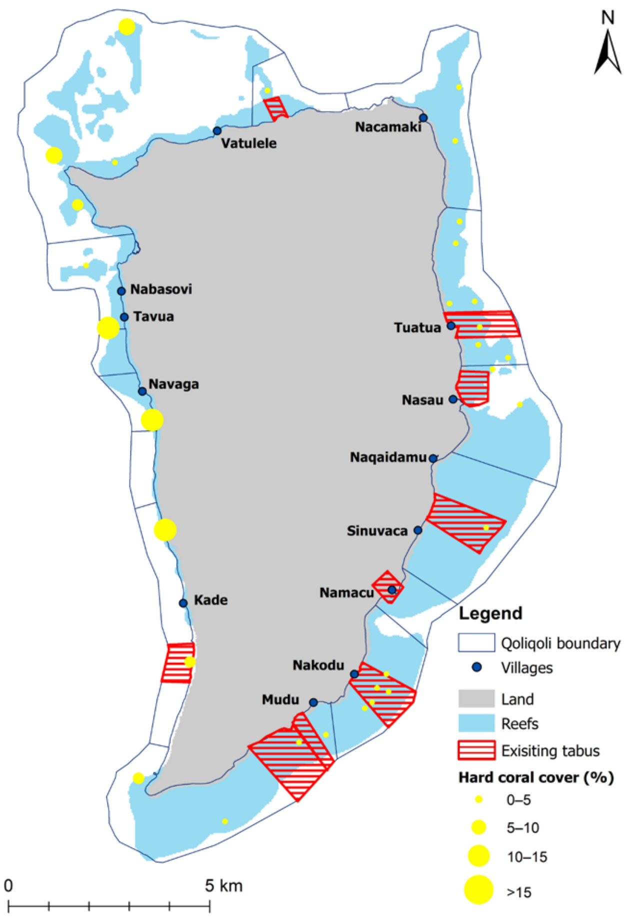


FIGURE 3. Percentage hard coral cover on reefs around Koro Island. The western side of the island is the sheltered side and the eastern side is the exposed side. *Qoliqoli* boundary represents the designated community fishing grounds around the island.

CONSOLIDATED AND UNCONSOLIDATED SUBSTRATES

Variability in consolidated and unconsolidated substrates on reefs around Koro Island are important indicators of reef health. Such variability likely reflects the diversity in the reefs around the island from overhangs and crevices to sandy bottoms (Appendix 1), differential impact (Mangubhai 2016) and recovery from Cyclone Winston, and other human pressures including fishing activities, terrestrial runoff, sedimentation, mechanical damage from boats. Sites with the highest unconsolidated substrate were NT1 (69.0±5.5%), NF4 (63.7±7.4%) and NT3 (62.3±16.0%), while those with the lowest were MD4 (4.0±6.9%), TT1 (3.3±3.5%) and TF5 (2.0±2.0%) (Appendix 1). *Tabu* areas had lower percentage consolidated substrate (16.6±8.2) and higher unconsolidated substrate (50.0±24.5), most likely a result of being mostly placed on the exposed side of the island in shallow waters (Table 3, Figure 4).

The results indicate that reefs are in a less stable state to provide a foundation for recruits to settle and grow (Heron et al. 2005). Therefore, the results imply that there could be high variability in the recovery potential of reefs around the island. Based on the results, sites with a higher cover of intact reef systems may have a faster recovery, provided land-based influences such as runoff and sedimentation is kept minimal (Van Woesik et al. 1995; Prasad et al. 2009). By contrast, sites with high cover of rubble and fragmented corals may take longer to recover as these reefs are unstable and less likely to support coral recruitment.

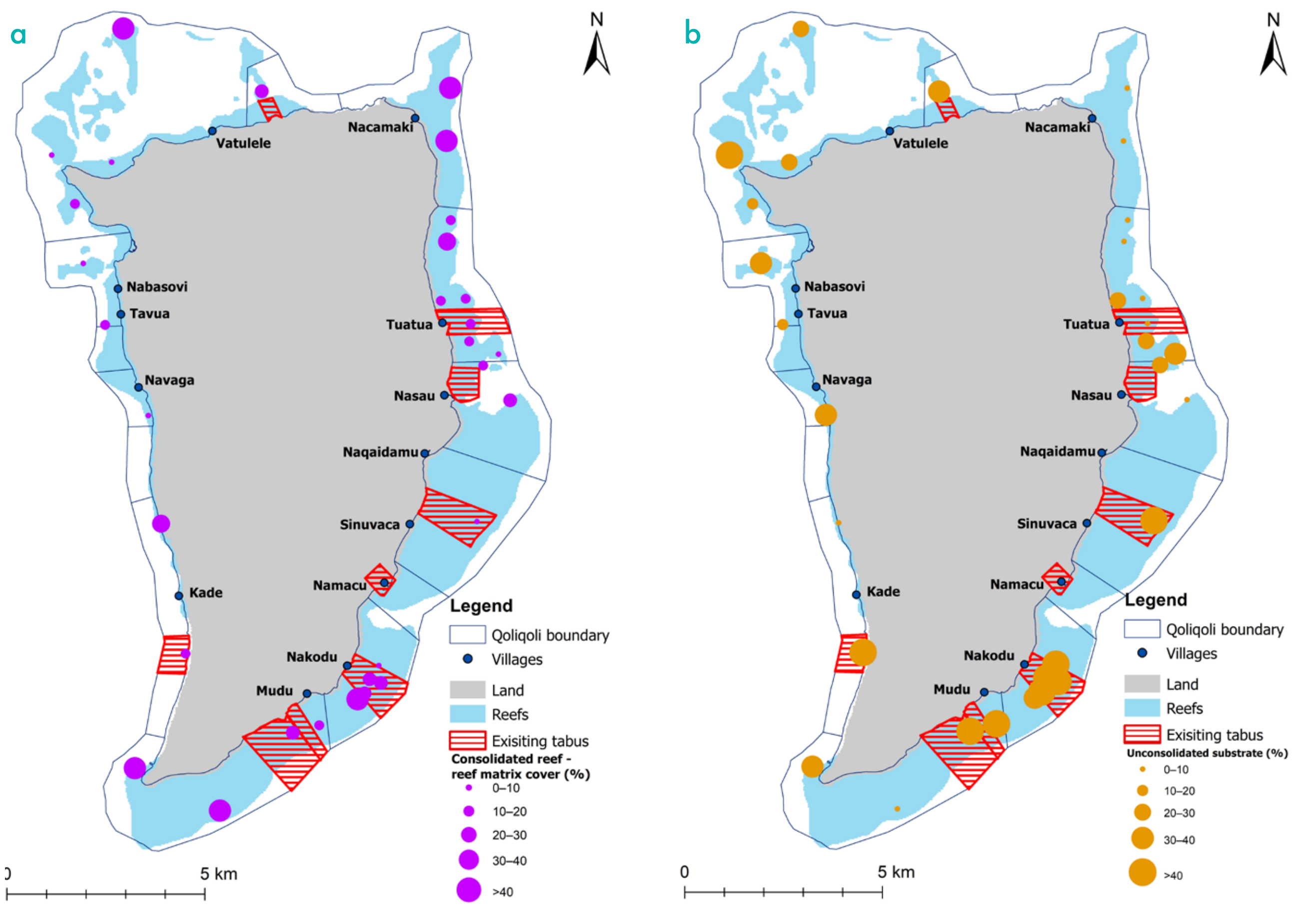


FIGURE 4. Percentage consolidated (a) and unconsolidated substrate (b) on coral reefs around Koro Island. The western side of the island is the sheltered side and the eastern side is the exposed side. *Qoliqoli* boundary represents the designated community fishing grounds around the island.

ALGAE COVER

A variety of algal groups were observed, with some thought to be rare, including a potential new species (Plate 4). Turf and macroalgae cover were assessed to understand the overall health of reef system as well as the extent of damage and potential to recover, based on the distribution patterns of these algae (Beeden et al. 2015).

There was some variability in macroalgae and turf algae distribution, due to difference in sites on coral reefs around Koro Island. Macroalgae cover was generally low (<5%) except for a few sites on the western and eastern sides of the island (Figure 5a). The lowest cover (0.3±0.6%) was observed at *tabu* sites NT1, NT2 and the highest cover (28.0±10.1) at open exposed site TF4 (Table 3, Figure 5a). Macroalgae was highest on exposed reefs open to fishing (11.3±8.5) and lowest on exposed *tabu* areas (4.5±8.3) (Table 3).

By contrast, turf algae cover was slightly higher and some variation was observed between the eastern and western sides of the island (Figure 5b). The lowest turf algae cover (0.3±0.6) was at site TF2 and the highest (38±7.6) was at TF5. Similar to macroalgae, turf algae was also highest on exposed reefs open to fishing (11.8±9.9) and lowest on sheltered reefs open to fishing (8.1±7.7) (Table 3).

Overall, there was very little difference in algal cover (all types of algae combined) between exposed and sheltered sites which averaged 22.9±14.2% on the exposed side compared to 27.6±17.7% on the sheltered side. Similarly, algal cover at *tabu* sites was averaged at 21.7±17.3% compared to 25.9±14.9% at sites open to fishing. Sites with the highest percentage algal cover were V3 (64.0±14.9%) and TF5 (54.3±8.7%), while those with the lowest were NT1 (5.0±7.0%) and MD1 (4.3±5.1%) (Appendix 1).

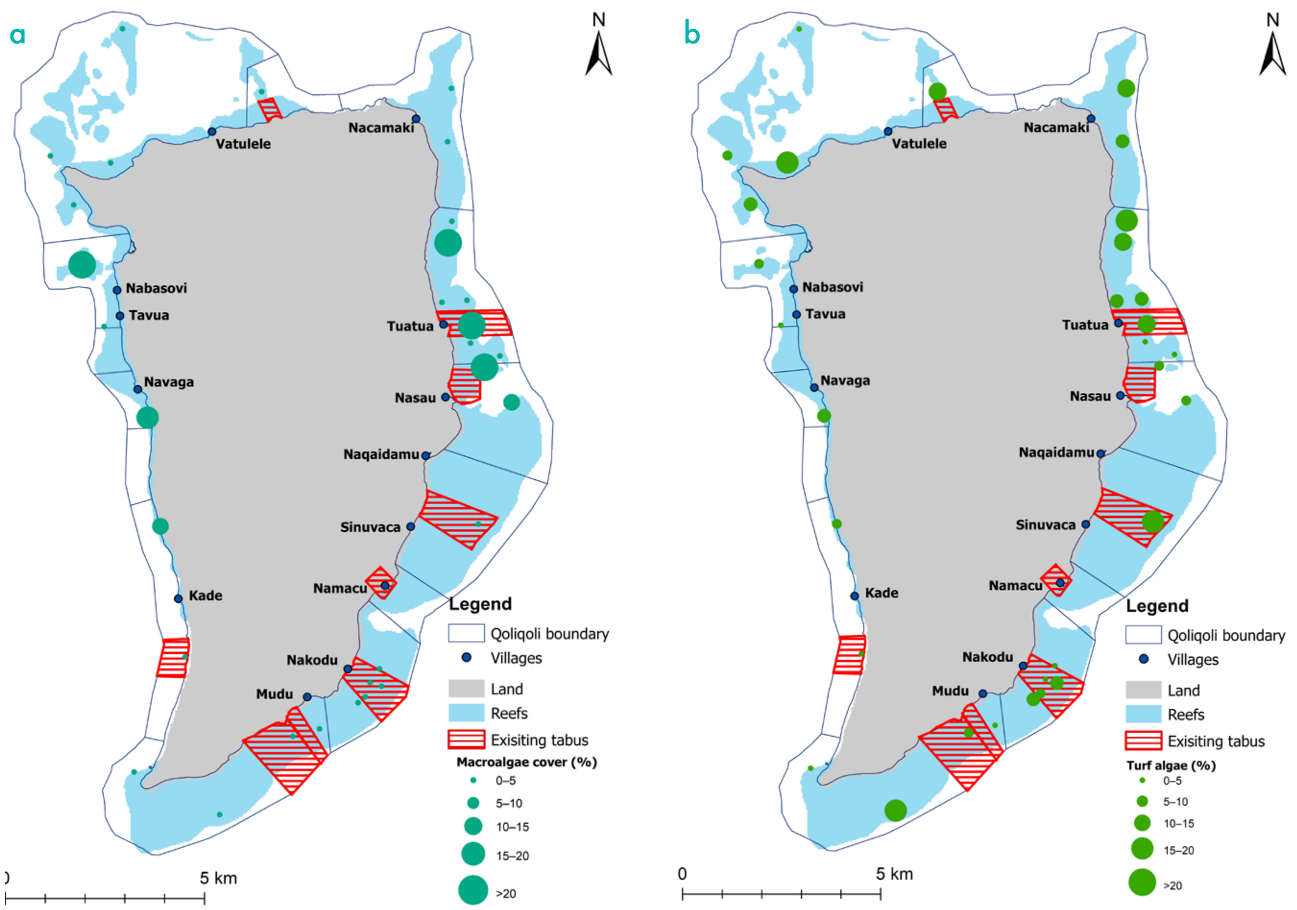


FIGURE 5. Percentage macroalgae (a) and turf algae (b) on coral reefs around Koro Island. The western side of the island is the sheltered side and the eastern side is the exposed side. *Qoliqoli* boundary represents the designated community fishing grounds around the island.

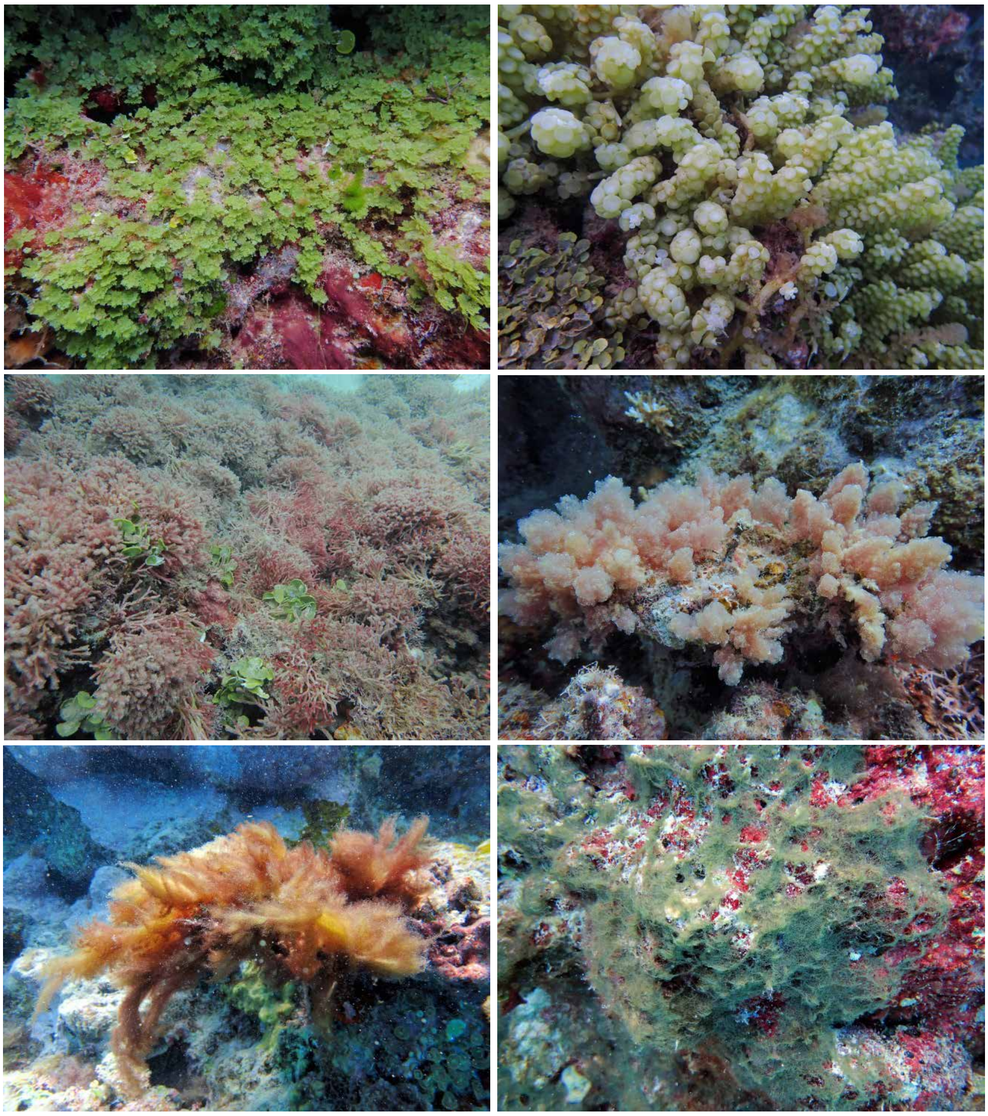


PLATE 4. Main algal assemblages observed on the coral reef around Koro Island. Top: green macroalgae (*Caulerpa* sp.). Middle: red macroalgae (*Galaxaura* sp.). Bottom: *Lyngbya* (cyanobacteria) mats. © Sangeeta Mangubhai/WCS

FISH BIOMASS

A high number of fish species (165 spp.) was recorded during the survey. Fish biomass was highly variable ranging from 158.7 kg/ha to 3347.3 kg/ha; however the average fish biomass was 1299.0 kg/ha indicating stocks were generally healthy. Larger-sized fish (e.g. *Gymnothorax javanicus*, *Sphyraena barracuda*, *Caranx melampygus*) were observed more frequently on intact reef systems in the deeper waters. The most common species observed were the groups' surgeonfish (*Ctenochaetus striatus*, *Acanthurus lineatus*), snappers (*Lutjanus gibbus*) and emperors (*Monotaxis grandoculis*).

Results showed that 54.8% (indicated by the green bubbles) of the sites had very high biomass (>1000 kg/ha) indicating a healthy system, 19.4% had a high enough biomass for the ecosystems to function properly (indicated by the yellow bubble, 500–1000 kg/ha) and 25.8% were below functional levels (indicated by orange and red bubbles, ≤500 kg/ha) (Figure 6, MacNeil et al. 2015). Reef systems that were open to fishing on the exposed side of the island had on average fish biomass that was slightly higher than *tabu* areas (Figure 6), and may reflect the amount of damage (i.e. rubble) at those sites (Figure 7). Overall, there was little difference in fish biomass on exposed (average = 868.8 kg/ha) in comparison to sheltered reefs (mean = 859.9 kg/ha).

Fish assemblage is another important factor that assists in the recovery of reef systems, as browsers and grazers aid in cleaning substrate for new recruits to settle in (Green and Bellwood 2009). This study found that 54.8% of the reefs surveyed had fish biomass above ecosystem functional levels of 500 kg/ha (MacNeil et al. 2015) indicating an overall good health of the reef system. However, fish biomass was calculated based on overall fish abundance and size and not individual species or functional groups (Green and Bellwood 2009; Bonaldo et al. 2017). It is therefore difficult to predict the recovery potential of reefs based on fish biomass alone. Differentiating fish biomass by trophic levels and functional groups and associating them with the reef structure and complexity could further explain the high fish biomass in >50% of the sites surveyed (Sandin et al. 2008).

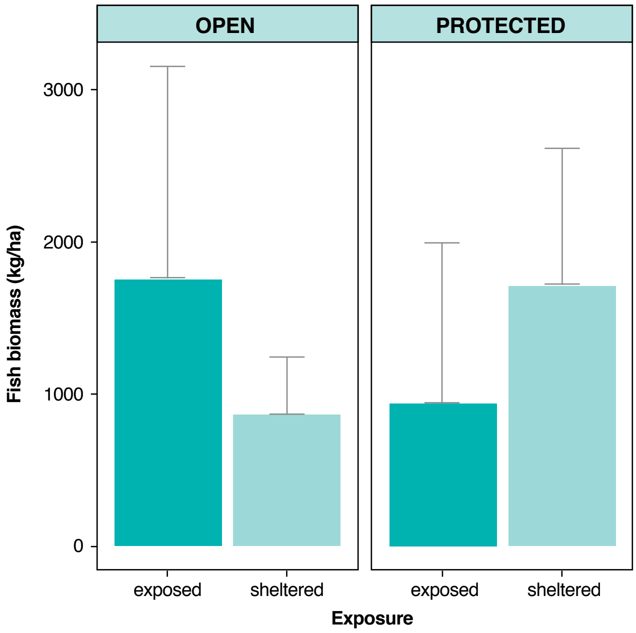


FIGURE 6. Mean fish biomass (kg/ha) recorded for *tabu* and open reef systems on exposed and sheltered sides of Koro Island. There was only one *tabu* on the sheltered side of the island. Error bars represent standard deviation.

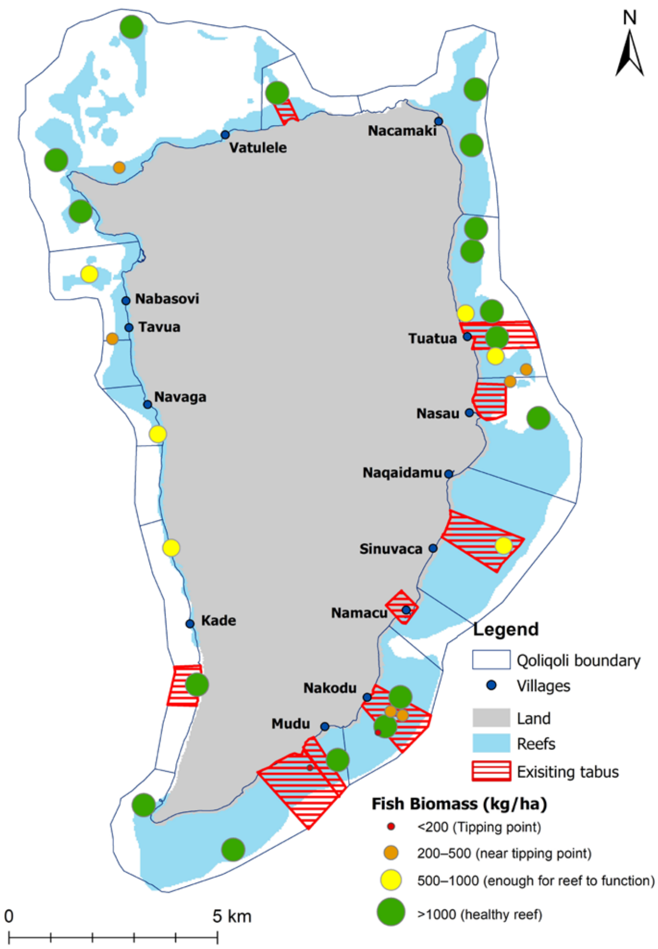


FIGURE 7. Mean fish biomass (kg/ha) across Koro Island. The western side of the island is the sheltered side and the eastern side is the exposed side. *Qoliqoli* boundary represents the designated community fishing grounds around the island.

OTHER OBSERVATIONS

Although no formal surveys were done, very few sea cucumbers were sighted on the reefs around Koro Island within transects, with no notable difference in populations inside versus outside *tabu* areas. The maximum number of sea cucumbers observed on a dive was two, and a total of 10 species were observed during the survey (Plate 5). These observations suggest there has been over-exploitation of sea cucumber populations on the island, given the low densities when compared to Pacific regional averages recommended for healthy stocks (see Table 6 in SPC 2014). However, without historical data and further discussions with local communities, it is difficult to assess if specific species have become locally extinct. Further, there was no coral bleaching or crown-of-thorns starfish (*Acanthaster planci*) observed during the surveys. Whitetip (*Triaenodon obesus*) and blacktip (*Carcharhinus melanopterus*) reef sharks were in low abundance, with <10 individual sightings of sharks for the whole survey.

PLATE 5. Sea cucumber species recorded on reefs around Koro Island. Clockwise: *Bohadschia argus* (tiger), *B. graeffei* (flowerfish), *Holothuria atra* (reef lollyfish), and *H. edulis* (pinkfish). © Sangeeta Mangubhai/WCS

IMPACT OF CYCLONE WINSTON ON CORAL REEF HEALTH

This 2017 study is the first comprehensive baseline survey of the health of coral reefs around Koro Island. However, the Wildlife Conservation Society (WCS) has data on Koro Island from a previous study to assess the effectiveness of *tabu* areas (Jupiter et al. 2017; Goetze et al. 2017a, 2017b). The sites surveyed in Tuatua and Nakodu fishing grounds in 2013 and 2014, respectively, were resurveyed in 2017, post-cyclone Winston. There are some limitations to assessing the post-cyclone recovery potential of coral reefs as a periodic harvest was done in 2013, and there are no benthic or fish data collected from 2013–2016. Therefore, this report only focuses on understanding the response of different communities on these reef systems over time, subjected to multiple stresses.

CHANGES IN HARD CORAL COVER

An overall decreasing trend was documented for hard coral cover in the Nakodu fishing ground and there was some variability between reefs that were inside versus outside of the *tabu* area (Figure 8). A decline in percentage coral cover from 2013 to 2014 at Nakodu within the *tabu* area (9.5%) and outside (18.0%) was documented, suggesting the harvest may have had a significant impact on coral cover (Figure 8). In 2017, there was an additional 8.0% decline in percentage coral cover on fished reefs outside the *tabu* area, while a 2.0% increase was recorded inside.

Prior to the harvest, coral cover inside and outside the *tabu* area was almost equal (2% difference) in the Tuatua fishing ground. No data were collected from Tuatua following the harvest in 2013. However, there was a significant difference in the percentage of coral cover between 2013 and 2017 (Figure 8). Specifically, the study documented 20.8% decline in coral cover within the t*abu* area between 2013 and 2017, and 21.2% decline outside the *tabu* area in the Tuatua fishing ground.

Based on the results, it was difficult to assess recovery potential of the reefs in Tuatua post-harvesting of the community *tabu* (2013) and the additive impact of Cyclone Winston (2016). Regardless the coral cover currently in the *tabu* area is low (<10%) and recovery will be slow, especially given coral cover around Koro Island is generally very low (<10%). Without data, it is impossible to know if other events (e.g. storm impacts, predators or disease) have contributed to the larger decline around these reefs. Given their isolation, it is highly likely these reefs may be reliant on self-seeding for recovery.

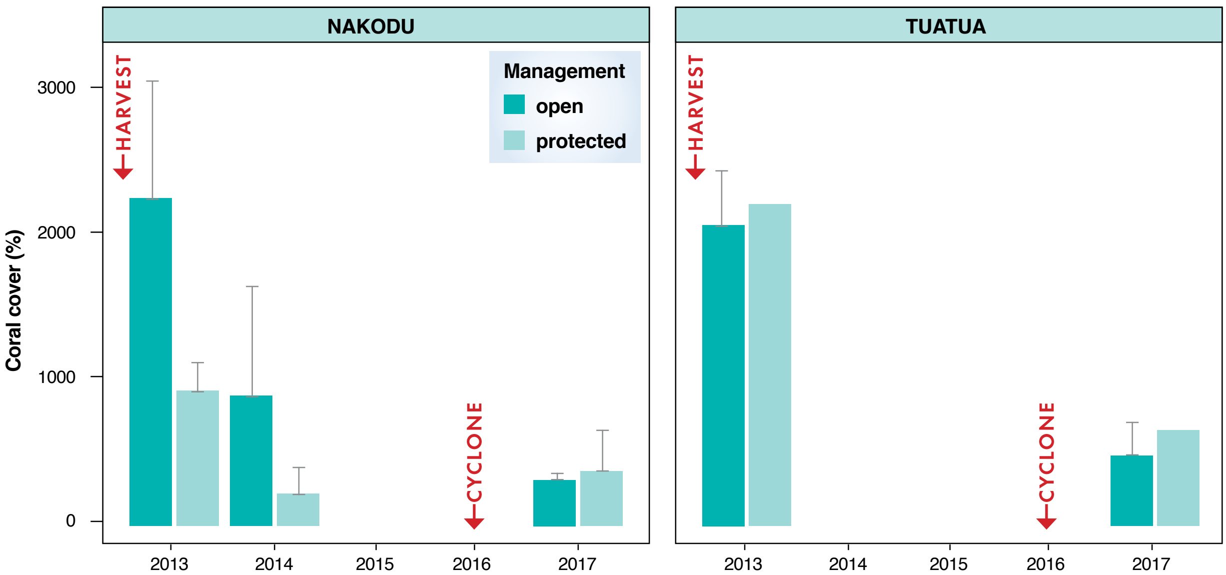


FIGURE 8. Change in percentage hard coral cover between 2013 and 2017 for Tuatua and Nakodu *tabu* areas and broader fishing grounds. No data were collected at Tuatua in 2014, or at both sites in 2015 and 2016. Error bars represent standard deviation.

CHANGES IN UNCONSOLIDATED AND CONSOLIDATED SUBSTRATE COVER

Unconsolidated substrate, especially rubble and fragmented corals are good indicators of strong wave action or disturbance that has dislodged parts of the reefs. Overall, unconsolidated substrate was significantly higher in the Nakodu fishing ground compared to Tuatua and the study documented incremental increases between years. In Nakodu, the overall increase in unconsolidated substrate cover was approximately 2% inside the *tabu* and 5% outside the *tabu* area in 2014 (Figure 9a). Unconsolidated substrate cover increased in the fishing ground a year after the harvest, but then decreases slightly post-cyclone Winston in the Nakodu fishing ground. The study is unable to determine if these changes recorded are a result of increased damage to reefs creating more space for settlement, or if movement in rubble exposed underlying substrate (Mangubhai 2016).

The data from Tuatua are somewhat limited; there does not appear to be a notable difference in unconsolidated substrate between 2013 and 2017. However, it was not possible to assess any changes directly after the harvesting event (2013) since there was no data collected in 2014. There was a small increase in consolidated substrate in Tuatua fishing ground in 2017.

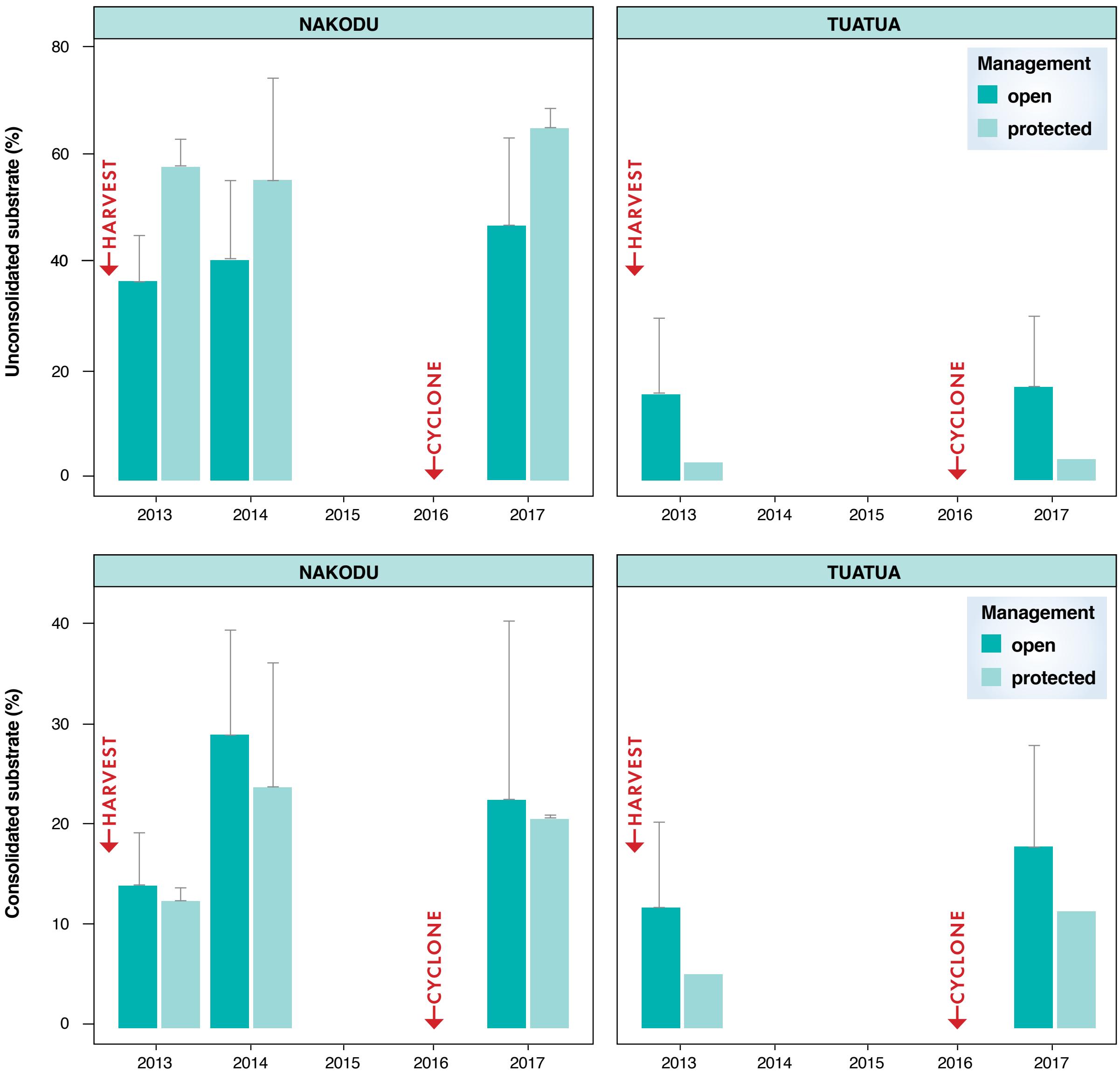


FIGURE 9. Change in unconsolidated and consolidated substrate cover since 2013 for Tuatua and Nakodu fishing grounds. No data were collected at Tuatua in 2014 or at both sites in 2015 and 2016. Error bars represent standard deviation.

CHANGES IN ALGAE COVER

Macroalgae and turf algae are known to compete with corals for space. Disturbances to the reef systems sometimes favor algal growth. A recent study on intergenerational effects of macroalgae showed that stressors such as abnormally high temperature, pollution and overfishing may sometimes lead to a proliferation of macroalgae, which affects coral health and growth (Beatty et al. 2018) with macroalgae suppressing coral recovery. Understanding how macroalgae affect corals require comparing algae with coral-dominated reefs without confounding aspects of time and geography. Assessing changes in algal cover (macroalgae and turf algae) over time, including before and after disturbances, would improve our understanding of the intensity of different types of impact to the reef system and the need to strengthen management actions that enhance recovery potential.

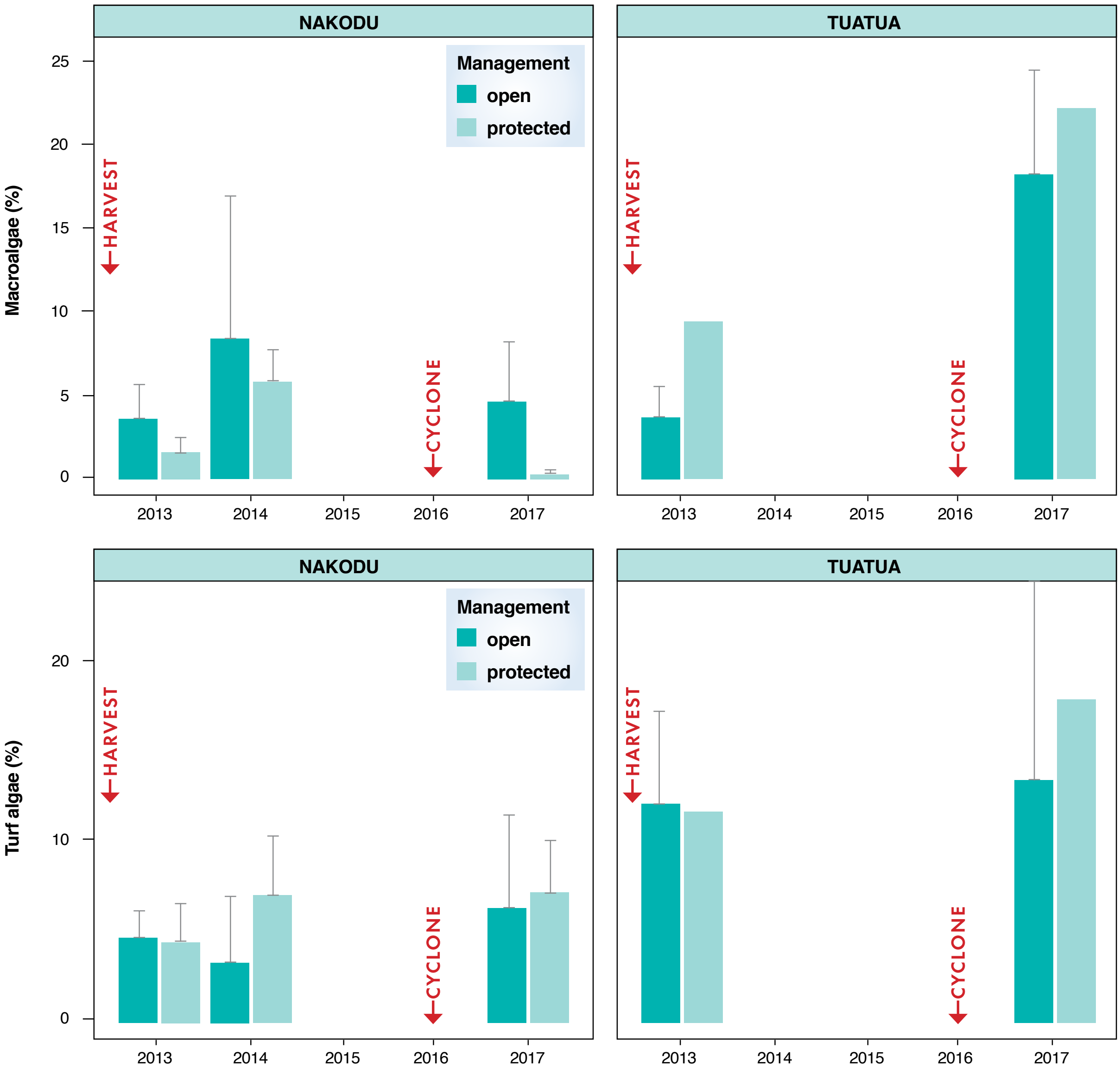


FIGURE 10. Change in macroalgae and turf algae percentage cover for Tuatua and Nakodu fishing grounds. No data were collected at Tuatua in 2014 or at both sites in 2015 and 2016. Error bars represent standard deviations.

In the Nakodu fishing ground, macroalgae cover increased by 9.1% from 2013 to 2014. However, in 2017 a 5.6% decrease in macroalgae cover inside the *tabu* and 3.8% decrease outside the *tabu* compared to 2013 was documented (Figure 10). In contrast, changes in turf algae cover ranged from 2–5% (decrease) from 2013 to 2014 and ~5% (increase) in 2017. In Tuatua fishing ground, macroalgae cover was higher within *tabu* areas compared to fished areas. A 12.8% increase in macroalgae cover inside the *tabu* area and 14.5% in fished areas between 2013 to 2017 was recorded. Furthermore, a difference of 10% was observed in percentage macroalgae cover in 2013 between reefs within and outside the *tabu* area, whilst the difference was 5% in 2017 for the same.

Similarly, turf algae cover was also much higher in the Nakodu fishing ground and the difference in cover between reefs inside and outside the *tabu* area was <2% in 2013, which increased to 5% in 2017 (Figure 10b). The overall increase in turf algae cover from 2013 to 2017 for reefs inside the *tabu* area was by 5% whilst there was 3% decrease on reefs outside between the two years surveyed.

The results presented in the report do not reflect on any direct relationship between damage to reefs caused by disturbances (unsustainable harvesting and cyclone) and algae cover. However, there is a possibility that an increase in macroalgae observed in the Nakodu fishing ground could be due to the loss of herbivorous fish as a result of fishing pressure in 2013. In addition, the decrease in macroalgae and turf algae in 2017 could potentially be associated with the loss of habitat/structure of reefs. The trends observed in the Tuatua fishing ground could be associated with loss of habitat and herbivorous fish, but there was insufficient data to support this conclusively.

FISH COMMUNITY

Fish biomass is often used to assess changes in the fish community (Jennings and Polunin 1995). In the Nakodu fishing ground, there was a 459.3 kg/ha increase in fish biomass inside the *tabu* and 572.4 kg/ha increase outside the *tabu* between 2013 to 2014. There was a further 562.5 kg/ha increase in fish biomass inside and 617.3 ka/ha increase outside the *tabu* areas in 2017 (Figure 11).

Similarly, the fish biomass recorded for the Tuatua fishing ground also had an increasing trend from 2013 to 2017. However, fish biomass for Tuatua was much higher than that recorded in Nakodu.

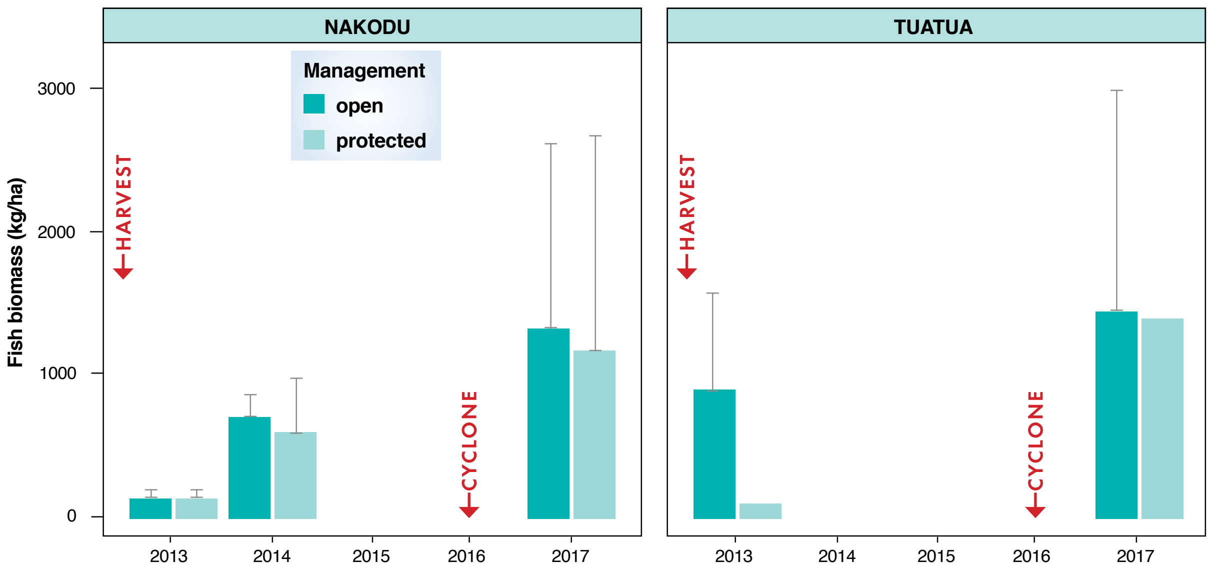


FIGURE 11. Change in fish biomass (kg/ha) since 2013 for Tuatua and Nakodu fishing grounds. Error bars represent standard deviations.

One of the possible reasons for such high fish biomass in the Tuatua fishing ground is the highly complex and intact structure that makes up the majority of the reefs in this area. The fish biomass for Tuatua increased by 1301.6 kg/ha inside and 533.0 kg/ha outside *tabu* areas between 2013 to 2017 (Figure 11). However, in 2013, the fish biomass for reefs inside the *tabu* area was much lower than outside. This could be due to the intense harvesting on reefs within *tabu* areas in 2013. By contrast, in 2017, the fish biomass on reefs both inside and outside of the *tabu* area was almost the same (Figure 11). Despite an increase in fish biomass over time, the study was unable to accurately assess the individual impact of disturbances (fishing pressure and cyclone) on reefs due to lack of data in consecutive years.

In addition, an increase in fish species richness in the Nakodu fishing ground from 2013 (95 spp.) to 2014 (138 spp.), and a decrease in species richness in 2017 (89 spp.) was observed. A slight decrease in fish species richness from 2013 (117 spp.) to 2017 (111 spp.) in the Tuatua fishing ground was documented. The data from the Nakodu fishing ground suggests that cyclones may have negatively impacted fish species richness.

A study from New Caledonia found a decrease in fish species richness and biomass as a result of cyclone damage (Wantiezz et al. 2006). Modification in fish community was also highlighted as an important aspect of cyclones (Bouchon et al. 1994; Wantiezz et al. 2006) which also corresponds to the change in species richness. For instance, the coral reef systems in Nakodu had the highest richness of *Chaetodon* spp. in 2013, while in 2014 the same reef system was dominated by *Scarus* spp. which remained the dominant species 18 months after the cyclone. A similar trend was observed in the Tuatua fishing ground where *Chaetodon* spp. dominated reef systems even after the cyclone (Table 4). The two most dominant groups in terms of fish species richness were also from the functional group of browsers/grazers and a recent study documented increase in browser/grazer richness and biomass post-cyclone events to maintain algal cover on reef systems (Ceccarelli et al. 2016).

TABLE 4. Fish species richness of the most commonly observed genera of fish in Nakodu and Tuatua.

LOCATION	GENUS	FISH SPECIES RICHNESS 2013	2014	2017
Nakodu	*Chaetodon*	14	12	7
	Scarus	12	16	10
	Acanthurus	5	8	7
	Parupeneus	5	7	7
	Lutjanus	4	6	5
	Siganus	4	5	2
Tuatua	*Chaetodon*	17	–	11
	Scarus	11	–	10
	Lutjanus	7	–	6
	Acanthurus	6	–	7
	Parupeneus	6	–	6
	Siganus	5	–	7

RECOMMENDATIONS

Given the findings of this study, a number of general and site-specific recommendations are made.

a. Implementation of the Koro Island ecosystem-based management plan to ensure the recovery and long-term health of the island, its ecosystem and the people of Koro Island.

b. Actions should be taken to minimise human stresses to coral reefs, especially areas that are heavily impacted. This includes the control of gravel extraction and prevention of the clearing of forests and other vegetation on steep slopes.

c. Maintain the network *tabu* areas around the island for another 5 years to support reef recovery.

d. Extend monitoring programs to measure the recovery of coral reefs over the next 5 years, and ensure they are linked to management actions.

e. Extend some of the *tabu* areas to the edge of the forereef to cover more complex and productive habitats.

f. Consider an additional *tabu* area on the northwestern corner of Koro Island to cover more exposed spur and groove habitat.

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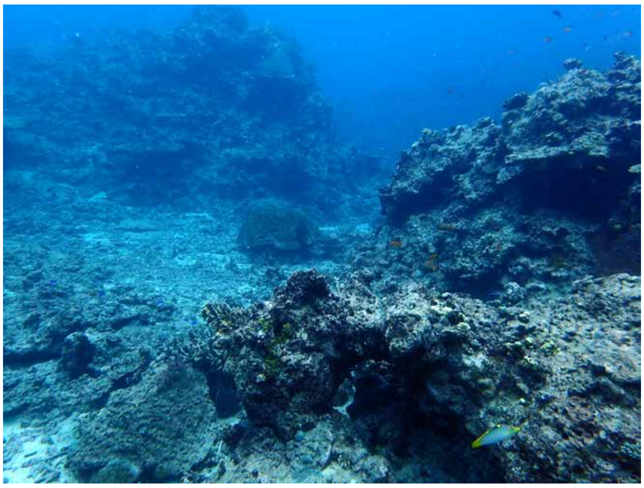
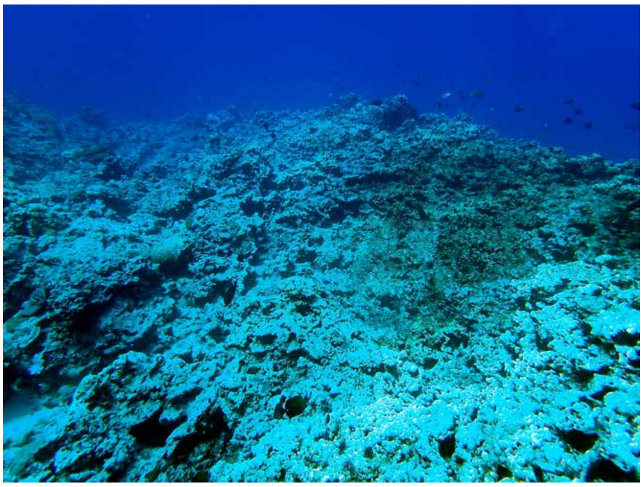
APPENDIX 1 SITE DESCRIPTIONS

SITE #	MANAGEMENT STATUS	REEF TYPE
MD1	Open	Fringing forereef



This reef is located off the south-western point of Koro Island, close to the lighthouse and the ferry jetty. The top of the reef started <0.5 m and sloped sharply (80°) to a sand-rubble bottom at 8 m. The reef was highly degraded with little live coral. The average hard coral cover was 9% (mostly encrusting corals), and the most dominant cover was rubble (29.7%) and sand (10.3%). There were some coral recruits on surfaces, but the numbers were low given the amount of available substrate for colonisation. Fish biomass averaged 1213.2 kg/ha. This site was surveyed with the reef on the left.

SITE #	MANAGEMENT STATUS	REEF TYPE
MD4	Open	Fringing forereef

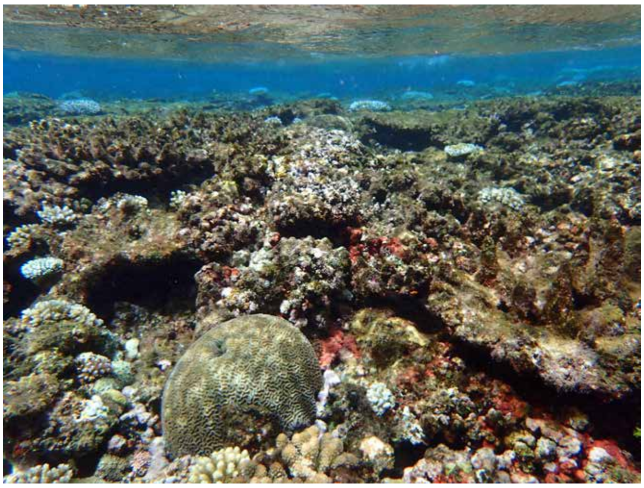
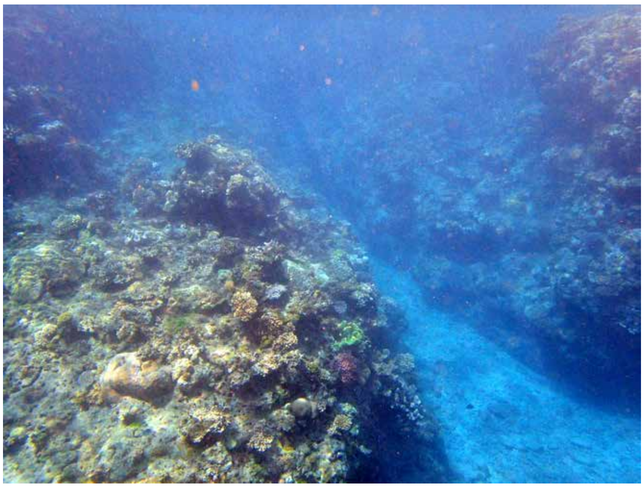


This reef is located off the south eastern point of Koro Island, and has an extensive spur and grove structures (left). The top of the reef is at 7–9 m, and slopes (45°) to a base at 10–15 m. Below that the reef sloped away gently (20–30°) and was largely sand and rubble with small patches of reef. In general, there was very little coral life except for encrusting and branching forms (right), and little signs of coral recruitment. The average hard coral cover was 14.3% and the dominant cover was crustose coralline algae (43.7%) and turf algae (21.3%). Fish biomass averaged 1347.5 kg/ha. The reef matrix (6.7% cover) was clean with lots of crustose coralline algae, and there was not a lot of evidence of cyclone damage other than the large volumes of rubble accumulated in the grooves. This site was dived with the reef on the right.

SITE #	MANAGEMENT STATUS	REEF TYPE
MD6	*Tabu*	Fringing reef flat

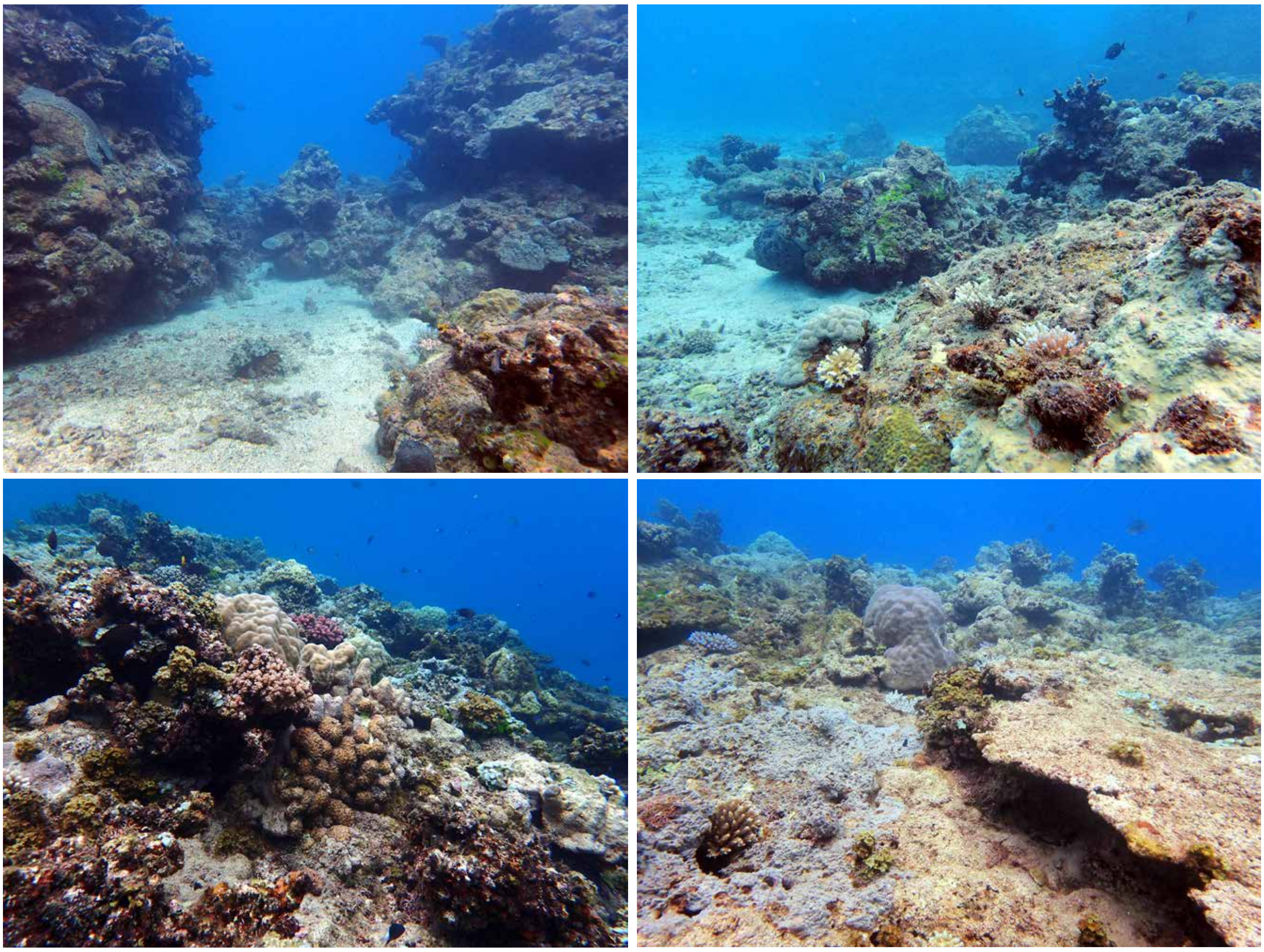

This site was within the Mudu village *tabu* area on the south-eastern side of Koro Island. The reef was largely scattered coral heads in <3 m water, on a sand-rubble base. The reef and was generally devoid of coral or fish life. The average hard coral cover was 7.3%, and the most dominant cover was rubble (48%), sand (13%) and crustose coralline algae (11%). Fish biomass averaged 158.8 kg/ha. This site was dived with the reef on the left.

SITE #	MANAGEMENT STATUS	REEF TYPE
KD2	Open	Fringing forereef

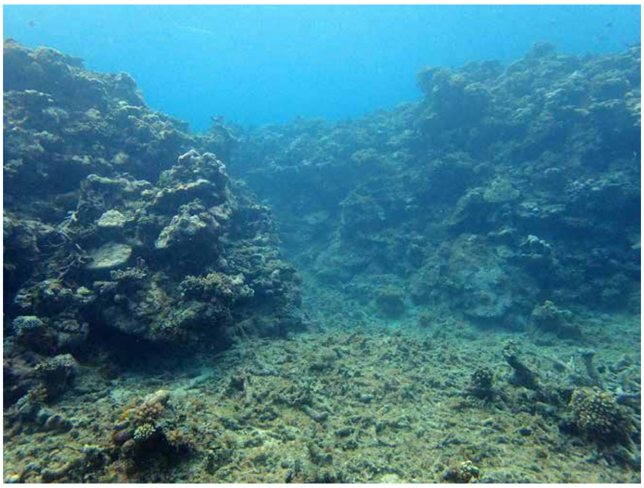
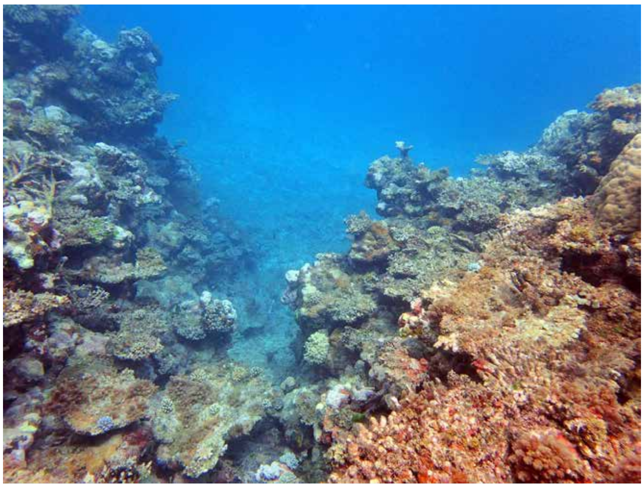
This site is on the western side of Koro Island, within 15–20 m of the shore. Surveys were done of the reef top, 0.5 m below the surface. The top of the reef was in <0.5 m depth and sloped sharply (80°) to a 6–7 m sand-rubble base. The upper sides of the reefs were fairly diverse in terms of coral, with branching corals dominating. Some of the branching *Acropora* on the top of the reef seemed partly bleached likely due to exposure stress. The reef cover was dominated by reef matrix (29.7%), hard corals (22.0%), and macroalgae (11.0%). Fish biomass averaged 759.5 kg/ha. This site was snorkelled with the reef on the left. However, it is best to dive this site in the future for consistency with other sites surveyed.

SITE #	MANAGEMENT STATUS	REEF TYPE
KD3	*Tabu*	Fringing forereef



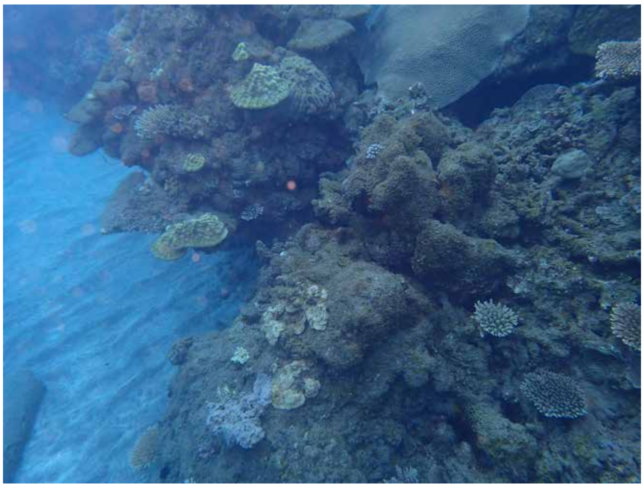
This site is on the western side of Koro Island in the Kade village *tabu* area. This was a series of bommies (top left) on sand-rubble with smaller scattered patch reefs (bottom right) at 7.4 m very close to shore. There was not a lot of rubble and much of it looked fairly old (pre-cyclone). The site was dominated by branching and encrusting corals, but there were also submassive corals. There was evidence of recruitment, particularly on large clean surfaces (bottom right). The average hard coral cover was 9.0%, and the dominant cover was sand (37.0%), reef matrix (16.0%), and rubble (16.0%). Fish biomass averaged 2733.3 kg/ha. There was a diversity of algae at the site including coralline algae, crustose coralline algae, turf algae, fleshy algae and mixed algal assemblages (14.7% cover). There was a large area of sand with garden eels. This site was dived with the reef on the left.

SITE #	MANAGEMENT STATUS	REEF TYPE
NV1	*Tabu*	Fringing forereef

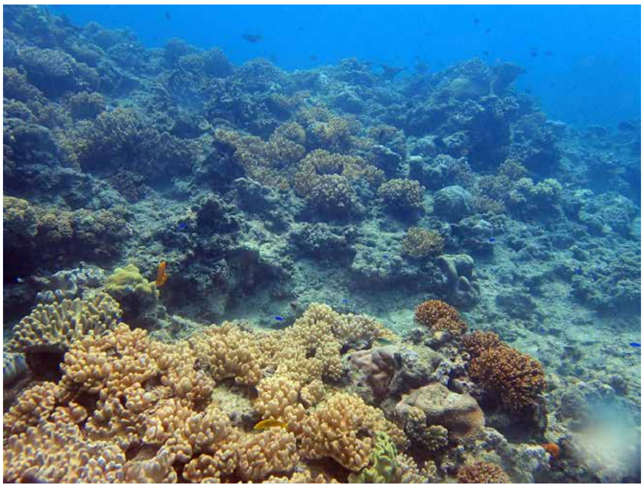
This site was within the Tavua *tabu* area on the western side of Koro Island. There were a series of patch reefs or bommies on a sandy bottom at 4.9–7.7 m. Each reef sat 1–2 m below the surface. The average hard coral cover was 17.0% and the dominant cover was coralline algae (19.7%), sand (13.0%), and reef matrix (10.7%). Fish biomass averaged 401.0 kg/ha. There was a lot of green fleshy macroalgae on surfaces (17.3% cover), especially a ref fleshy algae on the reef matrix and on the top of rubble. Although this was listed as a *tabu* area, there were people fishing on it, suggested the *tabu* may have been opened since the cyclone. This site was dived with the reef on the left.

SITE #	MANAGEMENT STATUS	REEF TYPE
NV4	*Tabu*	Fringing forereef



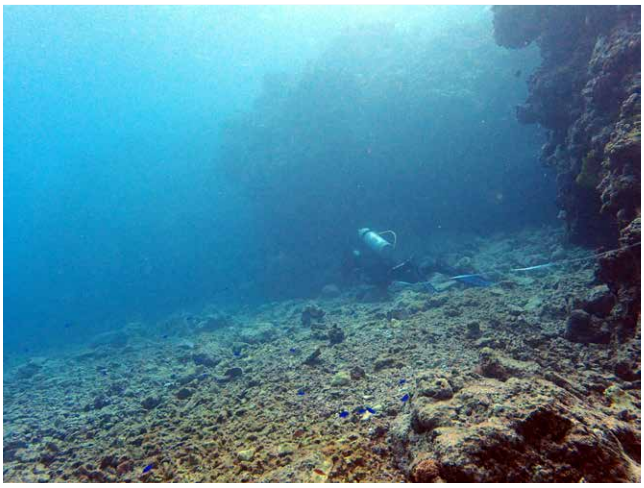

This site was within the Navaga *tabu* area on the western side of Koro Island. The reef was largely coral bommies on sand, with most bommies covered in algae, some table, encrusting and massive corals. The majority of corals appeared to be smothered by turf algae and/or sand. The average hard coral cover was 18.0%, and the dominant cover was macroalgae (18%) and sand (27.7%). Fish biomass averaged 520.3 kg/ha. This site was surveyed with the reef on the right.

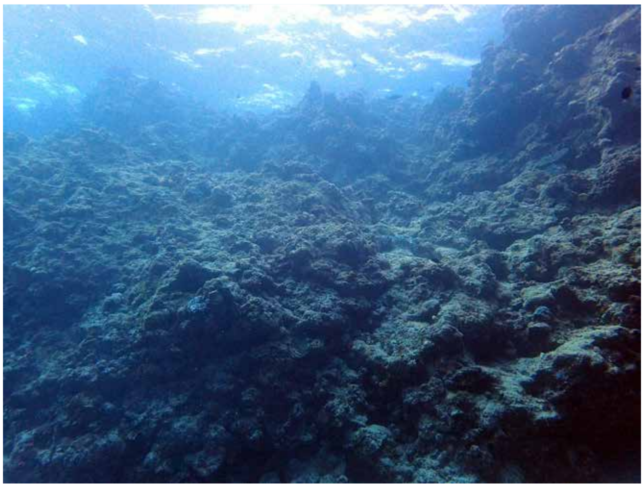
SITE #	MANAGEMENT STATUS	REEF TYPE
V1	*Tabu*	Fringing forereef



This site is within the Vatulele *tabu* area on the north side of Koro Island, and is made up of small patch reefs on a sand-rubble base in 4 m of water. There were large patches of rubble as well as overturned *Porites*, but overall the site did not look as damaged as Site V1, surveyed closer to shore which was decimated with little living reef left. Soft coral species were notable at the site, as well as the presence of a large number of surgeonfish. The average hard coral cover was 8.3% and the dominant cover was rubble (24.7%), turf algae (20.0%), reef matrix (15.0%), sand (13.3%) and crustose coralline algae (13.0%). Fish biomass averaged 1447.95 kg/ha. This site was dived with the reef on the left.

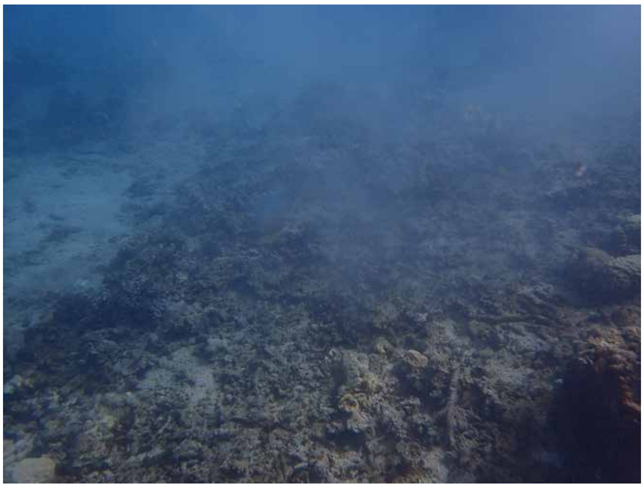
SITE #	MANAGEMENT STATUS	REEF TYPE
V2	Open	Fringing forereef





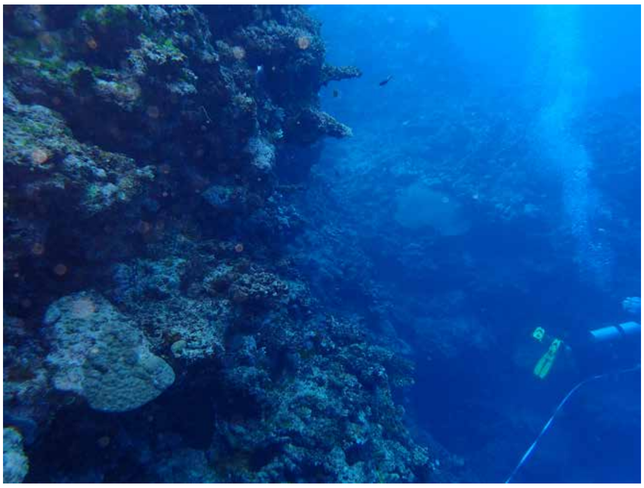
These reefs were off the northwestern point of Koro Island and were largely patch reefs on a rubble bottom at 7.6 m. The reefs were largely walls with steep slopes (90°) and some overhangs. At the base of the reefs were large accumulations of boulders and rubble that looked like they had been pushed up against the reef by Cyclone Winston. Most of the boulders (and the reef) were bare, and there was little evidence of coral recruitment on surfaces suggesting that recovery was slow. The average hard coral cover was 13.0% and the dominant cover was rubble (25.0%), and crustose coralline algae (12.3%). Fish biomass averaged 1593.4 kg/ha. This site was dived with the reef on the right.

SITE #	MANAGEMENT STATUS	REEF TYPE
V3	Open	Fringing forereef

This reef was off the northern point of Koro Island, and was largely a continuous reef that started 5 m below surface and sloped gently (10–15°) to approximately a 15 m sandy bottom with small coral patches. The most dominant types of corals were massive and encrusting forms with some branching colonies. The average hard coral cover was 8.7%, rubble was 10.7%, and sand was 13.7%. Fish biomass averaged 493.3 kg/ha. There were areas with overturned boulders and a large percent of the reef was rubble accumulated. The reefs showed high average cover of microbial (35.3%) and turf (24.7%) algae. This site was dived with the reef on the left.

SITE #	MANAGEMENT STATUS	REEF TYPE
V4	Outside	Fringing forereef

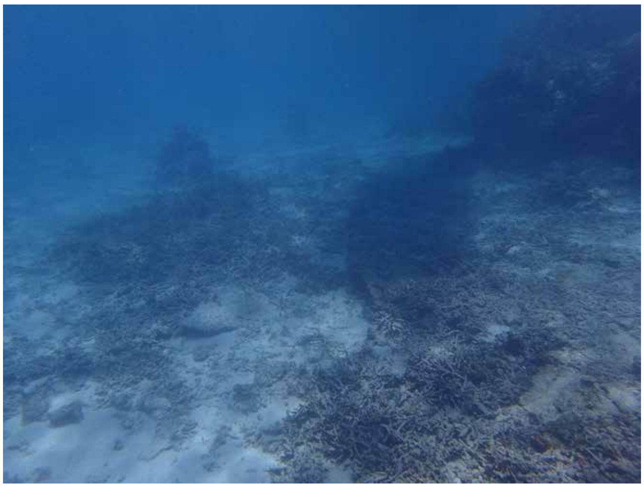



The reef sits off the north eastern point of Koro Island. The top of the reef flat starts at 5 m and has a gentle slope (10–15°) dominated by turf algae. The reef then slopes more sharply (50°) to a sand-rubble bottom. The reef had massive corals such as *Porites* and *Diploastrea heliopora,* encrusting and branching colonies. Some table *Acropora* were observed on the reef. The reef was largely intact with a clean reef matrix. Soft corals and sea fans were found on the steeper parts of the reef slope. The average hard coral cover was 14%, and the site was dominated by rubble (28.3%), sand (13.7%) and coralline algae (10.3%). Fish biomass averaged 1024.8 kg/ha. This site was surveyed with the reef on the right.

SITE #	MANAGEMENT STATUS	REEF TYPE
V5	Open	Fringing forereef


These reefs were off the north-western point of Koro Island and were largely patch reefs (<0.5 m below the surface) on a sandy bottom at 6.2 m. There were complex overhangs, crevices and caves and patch reefs around the base of the reef. The site was dominated by encrusting and small branching corals. The average hard coral cover was 8.0% and the dominant cover was coralline algae (22.0%), microbial (22.0%) and turf algae (11.3%). There was evidence of potential damage from the cyclone with broken *Acropora* corals, and corals on their side at the base of the reefs and areas where boulders and rubble accumulated. The walls of the reefs were intact. Fish biomass averaged 1251.7 kg/ha. This site was dived with the reef on the left.

SITE #	MANAGEMENT STATUS	REEF TYPE
V6	Open	Fringing reef flat

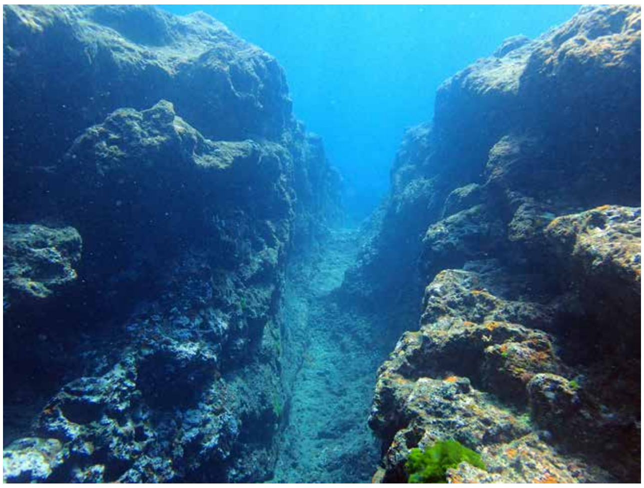



This reef was on the western site of Koro Island and is a reef flat with small coral heads at 4 m. There were some *Acropora, Pocillopora* and *Porites* colonies, and a high accumulation of rubble and overturned corals and reef matrix. The average hard coral cover was 6.3%, and the site was dominated by macroalgae (23%), sand (21%), microbial algae (13.3%), and rubble (9.3%). Fish biomass averaged 985.9 kg/ha. This site was surveyed with the reef on the right.

SITE #	MANAGEMENT STATUS	REEF TYPE
NC1	Open	Fringing forereef

This reef was off the north eastern point of Koro Island and was largely a spur and groove structure, that sloped (20–30°) to approximately 10 m. Some recruits were seen on clean surfaces. The reef was largely covered in macroalgae and turf algae, and there was very little coral cover. There were areas with parts of the reef matrix broken up, and areas where rubble had accumulated. The average hard coral cover was 6.7%, and the dominant cover was crustose coralline algae (43.7%), and turf algae (16.7%). Fish biomass averaged 3347.3 kg/ha. This site was dived with the reef on the left.

SITE #	MANAGEMENT STATUS	REEF TYPE
NC2	Open	Fringing reef flat

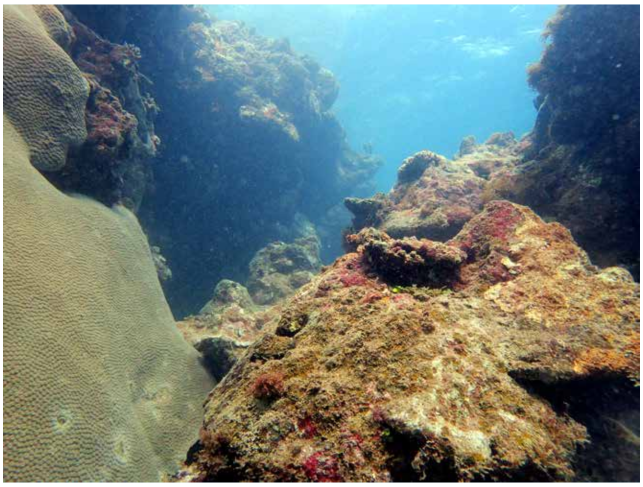


This site is on the north eastern side of Koro Island. The reef is largely a spur and groove structure, that slopes (60–75°) to a 15 m sand-ruble base. The reef matrix was fairly clean, largely devoid of corals, with the exception of small branching and encrusting corals. The average hard coral cover was 4.3%, and the dominant cover was reef matrix (37.3%), crustose coralline algae (34.0%) and turf algae (11.3%). Fish biomass averaged 3312.7 kg/ha. This site was dived with the reef on the right.

SITE #	MANAGEMENT STATUS	REEF TYPE
TF1	*Tabu*	Fringing forereef

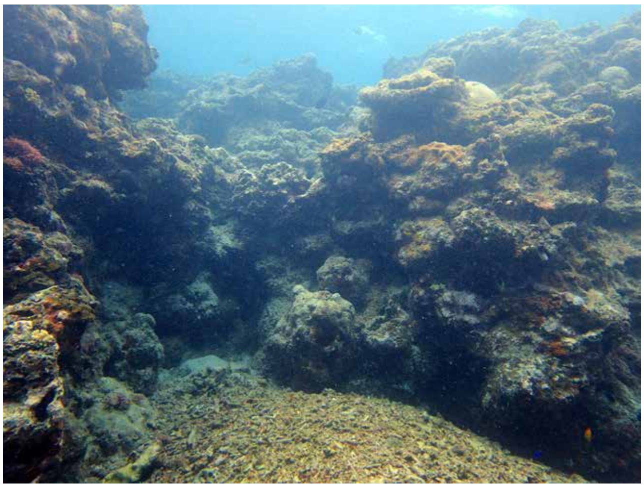

This site was previously in an open area between Nasau and Tuatua village, but may be included within a newly extended *tabu* area. This site started off as a vertical wall (90°) with a bottom at around 11 m. The reef then slopes gently at 30° to a sandy bottom around 15 m. Corals were sparse and dominated by encrusting forms. The second and third transects were on shallow patch reefs that were sitting on sand and rubble. The average hard coral cover was 3.7% and the dominant cover was coralline algae (27.7%), macroalage (23.0%), rubble (14.3%), and sand (11.0%). There were little live coral and little evidence of recruits and recovery. The site was covered in red macroalgae on hard reef surfaces, as well as on rubble which was plentiful at the site and the average cover was 37.3%. Fish biomass averaged 358.7 kg/ha. This site was originally outside the *tabu* area, but looks like it is now within. This site was dived with the reef on the left.

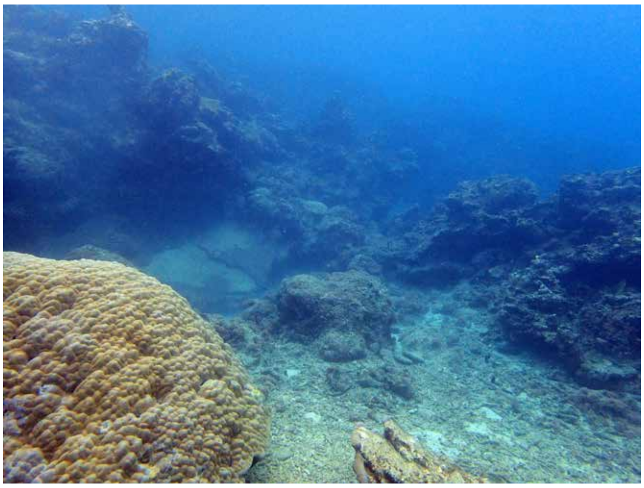
SITE #	MANAGEMENT STATUS	REEF TYPE
TF2	Open	Fringing forereef

This site is on the western side of Koro Island just outside the Tuatua village *tabu* area. This site is dominated by patch reefs on a sand-rubble base. The reef slopes at 80–90° to a base at 5–7 m. There were very few corals at the site, though there were large colonies of *Diploastrea heliopora* and *Porites* species. The average hard coral cover was 10.3% and the dominant cover was coralline algae (32.3%), sand (17.0%), and rubble (15.3%). There was a lot of red algae at the site especially on rubble, and a high amount of silt on surfaces. Fish biomass averaged 364.7 kg/ha. This site was dived with the reef on the left, away from the *tabu* area.

SITE #	MANAGEMENT STATUS	REEF TYPE
TF3	Open	Fringing forereef





This site is on the western side of Koro Island just outside the Tuatua village *tabu* area. This site is dominated by patch reefs on a sand-rubble base. The reef slopes at 45–85° to a base at 7 m. There were very few corals at the site, though there were large colonies of *Diploastrea* and *Porites* species. The average hard coral cover was 7.7% and the dominant cover was coralline algae (20.3%), macroalgae (19.7%), reef matrix (17.3%), rubble (15.7%) and sand (10.7%). There was a lot of red algae at the site especially on rubble, and a high amount of silt on surfaces. Fish biomass averaged 627.9 kg/ha. This site was dived with the reef on the right, away from the *tabu* area.

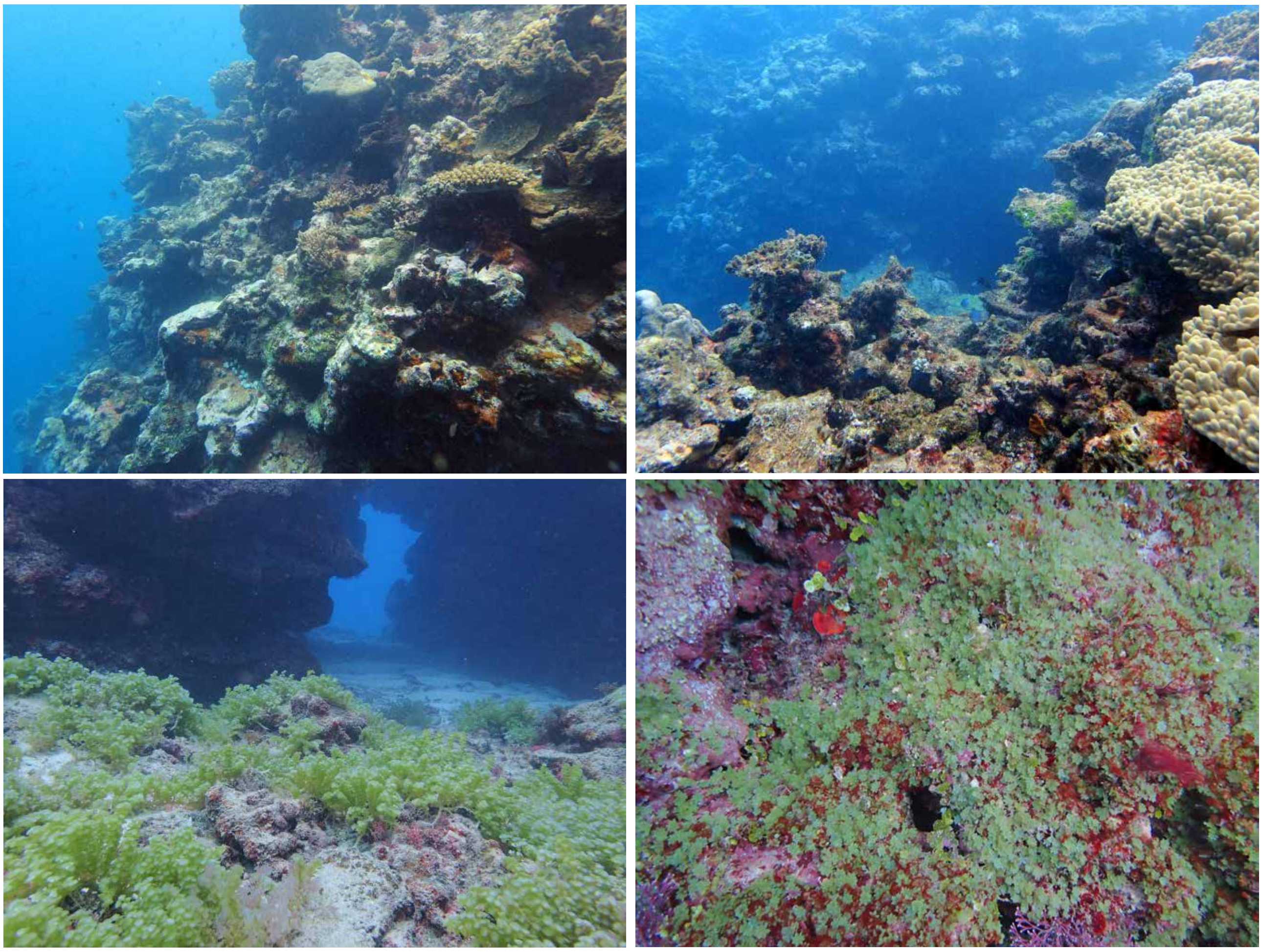
SITE #	MANAGEMENT STATUS	REEF TYPE
TF4	Open	Fringing forereef

This site is on the north-eastern side of Koro Island and is largely a fringing reef with some spur and groove formation. The majority of the reef was devoid of corals, though recruits were observed on the top of the reef (5 m depth). The average hard coral cover was 3.0% and the dominant cover was macroalgae (28.0%), reef matrix (22.0%), turf algae (17.3%) and crustose coralline algae (17.0%). Turtleweed was the dominant macroalgae at the site. There was a large school of surgeonfish and parrotfish. Fish biomass averaged 2513.41 kg/ha. No photos were taken. This reef was surveyed with the reef on the right.

SITE #	MANAGEMENT STATUS	REEF TYPE
TF5	Open	Fringing forereef

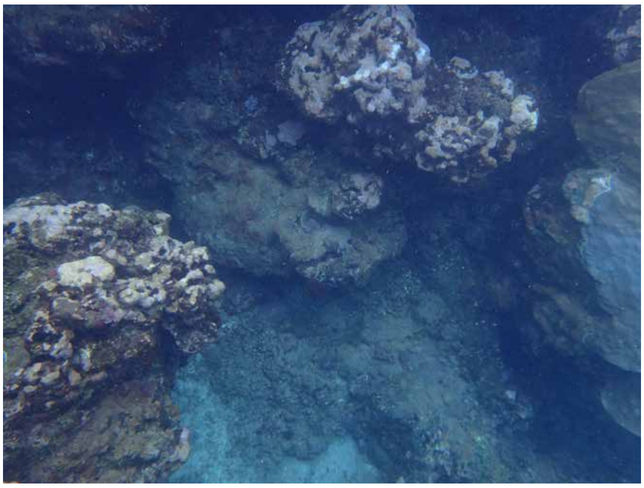
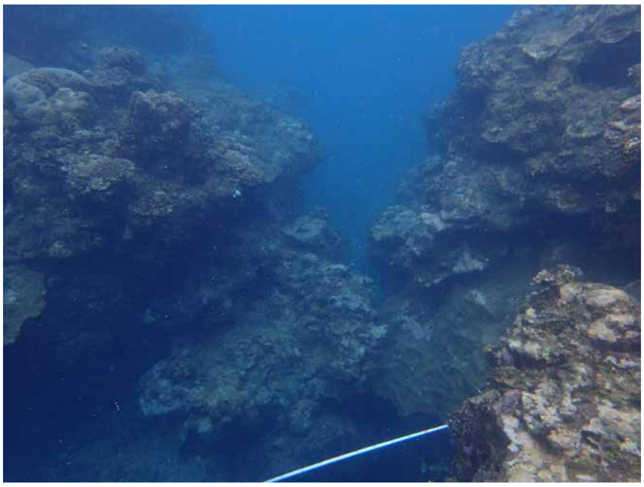
This site is on the north eastern side of Koro Island and is bommies or patch reefs that start at 2 m, that slope (40°) to a 7 m base. The reef then slopes away (20°) to a 15 m sand-rubble base. The reef system is fairly intact with some recruits observed. Site was surveyed with the reef on the left. The average hard coral cover was 5.3% and the dominant cover was turf algae (37.7%), coralline algae (19.7%), crustose coralline algae (16.0%) and macroalgae (14.3%). Fish biomass averaged 1476.0 kg/ha.

SITE #	MANAGEMENT STATUS	REEF TYPE
TT1	Open	Fringing reef flat



This site is just north of the Tuatua *tabu* area. This reef was a wall reef (85–90° slope) with a base at 11 m. The reef then sloped (45° slope) to a sandy bottom at 15 m. The average hard coral cover was 8.7% and the dominant cover was coralline algae (27.0%), macroalgae (22.0%) and turf algae (17.7%). Fish biomass averaged 1396.8 kg/ha. The majority of the surfaces of the reef was clean, with high abundance of turf algae and crustose coralline algae, and very little cyanobacteria mats compared to other sites. There were large patches of green macroalgae on surfaces (bottom left) as well as large amount of *Racemosa* sp. at the base of some of the slopes which were distinctive. The site did not seem badly damaged from the cyclone, due to the reef type. This site was dived with the reef on the left.

SITE #	MANAGEMENT STATUS	REEF TYPE
TT2	*Tabu*	Fringing forereef

This site is on the north-eastern side of Koro Island. The reef started at 4–5 m, and sloped (20–25°). The site had some large colonies of *Porites* and *Diploastrea heliopora,* as well as encrusting and foliose colonies. The average hard coral cover was 10.7% and the dominant cover was coralline algae (27.3%), macroalgae (16.7%), turf algae (14.3%), and crustose coralline algae (11.7%). Fish biomass averaged 1608.9 kg/ha. This site was dived with the reef on the left.

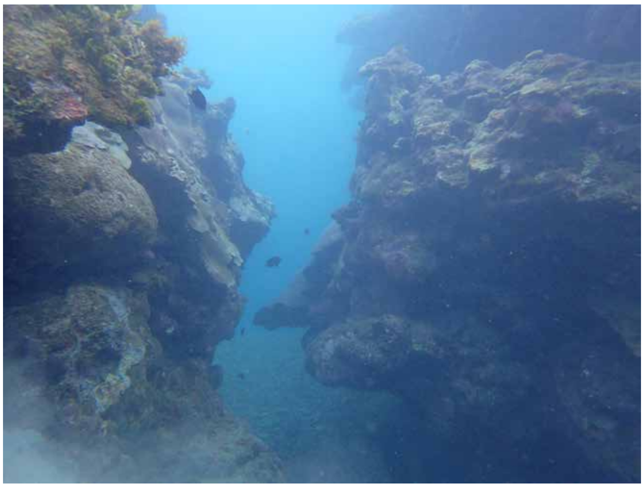
SITE #	MANAGEMENT STATUS	REEF TYPE
TT3	*Tabu*	Fringing forereef


This site was on the north-eastern side of Koro Island and was largely a fringing forereef that started at 2 m depth, and slopes gently (10–15°) to a sand-rubble base. There were notable overturned corals at the site, as well as small branching colonies on consolidated reefs. The average hard coral cover was 3.7% and the dominant cover was coralline algae (30.7%), macroalgae (15.3%), turf algae (14.7%), sand (13.0%) and rubble (11.0%). Fish biomass averaged 811.7 kg/ha. This site was dived with the reef on the left.

SITE #	MANAGEMENT STATUS	REEF TYPE
NS1	Open	Fringing forereef

This reef is on the eastern side of Koro Island. It is a reef flat with a sharp drop that slopes (75–85°) to 7 m depth, and then gently slopes (10–15°) to 12 m depth. The slope is dominated by encrusting corals and there were very few branching colonies (*Acropora, Pocillopora*). There are overhangs and crevices on the reef, creating complex macro-structure. There was rubble covered in turf algae below 7 m, and a large number of broken boulders with partly dead massive colonies (*Porites* spp. and *Dipoastrea heliopora*) covered turf algae. The average hard coral cover was 10.7%, and the dominant cover was coralline algae (33.3%), crustose coralline algae (22.7%), and macroalgae (11%). There was little evidence of coral recruitment on surfaces. Fish biomass averaged 2725.5 kg/ha. This site was dived with the reef on the left.

SITE #	MANAGEMENT STATUS	REEF TYPE
NS3	*Tabu*	Fringing reef flat



This site was on the eastern side of Koro Island and comprised of shallow bommies and patch reefs (4–7 m depth). The reef sloped gently (10–15°) to a sand-rubble base at 8–10 m. there were some small encrusting corals (*Porites, Pocillopora, Acropora*) with notable areas of broken reef matrix with massive species of *Diploastrea heliopora* and *Porites* spp. The average hard coral cover was 3.0% and the dominant cover was sand (25.3%), coralline algae (22.3%), turf algae (21.3%), and rubble (18.7%). Fish biomass averaged 829.9 kg/ha. This site was dived with the reef on the left.

SITE #	MANAGEMENT STATUS	REEF TYPE
NT1	*Tabu*	Fringing reef flat

This site is within the Nakodu *tabu* area and is a typical reef flat, with shallow reefs, patchy in distribution on a sand-rubble base. Massive and submassive forms of *Porites* spp. were the most dominant genus and form. Most of the reef matrix was clean, and only a small number of recruits were observed. The average hard coral cover was 1.0%, and the dominant cover was sand (51.0%), rubble (18.0%), and crustose coralline algae (10.7%). Fish biomass averaged 220.9 kg/ha. This site was dived with the reef on the right.

SITE #	MANAGEMENT STATUS	REEF TYPE
NT2	*tabu*	Fringing reef flat

This site is within the Nakodu *tabu* area and is a typical reef flat, with shallow reefs, patchy in distribution on a sand-rubble base (left). Massive and submassive forms of *Porites* spp. were the most dominant genus and form. The average hard coral cover was 8.7%, and the dominant cover was rubble (46.0%), sand (16.0%) and crustose coralline algae (12.3%). Most notable were the large accumulations of rubble likely from Cyclone Winston (right). Fish biomass averaged 2923.8 kg/ha. This site was dived with the reef on the left.

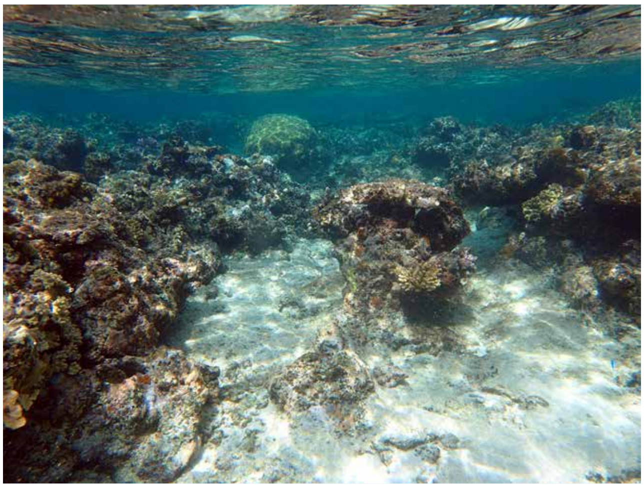
SITE #	MANAGEMENT STATUS	REEF TYPE
NT3	*Tabu*	Fringing reef flat

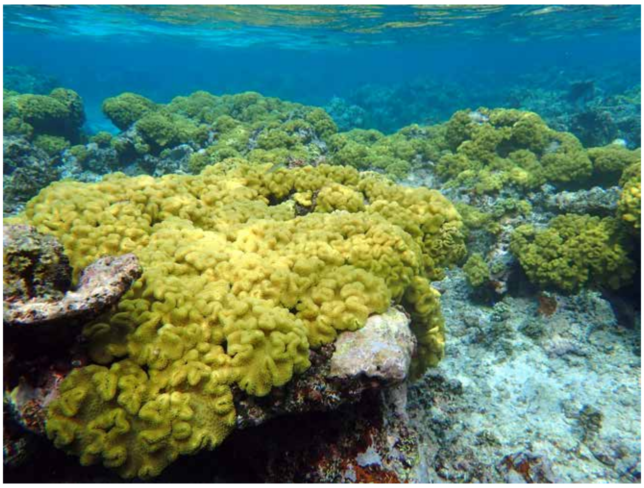
This site is within the Nakodu *tabu* area and is a typical reef flat, with shallow reefs, patchy in distribution on a sand-rubble base. Massive and submassive forms of *Porites* were the most dominant genus and form (left). Average hard coral cover was 5.0% and the dominant cover was rubble (62.3%), reef matrix (11.0%) and turf algae (10.3%). Fish biomass averaged 364.3 kg/ha. This site was dived with the reef on the left.

SITE #	MANAGEMENT STATUS	REEF TYPE
NF1	Open	Fringing reef flat

This site is on the eastern side of Koro Island and was comprised as a series of large bommies on sand-rubble with smaller patch reefs interspersed between. The reef sloped at 70–90° to a 5 m base and there was a notable amount of sit mixed in with the sand. Average hard coral cover was 4% and the dominant cover was rubble (23.7%), coralline algae (21.0%), sand (20.7%), and reef matrix (13.7%). Silt also covered a lot of surfaces and there was a fair amount of red algae at the site (8.7%) on rubble. Fish biomass averaged 2740.6 kg/ha.

SITE #	MANAGEMENT STATUS	REEF TYPE
NF3	Open	Fringing reef flat





This site is just north of the Nakodu *tabu* area on the eastern side of Koro Island. This site is a typical reef flat, with shallow reefs (3–5 m depth), patchy in distribution on a sand-rubble base. Massive and submassive forms of *Porites* were the most dominant genus and form. There were a few small patches of colourful soft coral. Most of the reef matrix was clean, and only a small number of recruits were observed. Average hard coral cover was 4.7%, and the dominant cover was crustose coralline algae (31.0%), rubble (19.7%), reef matrix (11.7%), sand (12.3%) and turf algae (12%). Fish biomass averaged 173.1 kg/ha. This site was dived with the reef on the left.

SITE #	MANAGEMENT STATUS	REEF TYPE
NF4	Open	Fringing reef flat

This site was on the south-eastern side of Koro Island, and was a typical reef flat, with shallow reefs (3–5 m depth), patchy in distribution on a sand-rubble base. *Porites, Pocillopora, Acropora,* and *Diploastrea heliopora* species dominated the site, especially encrusting and massive forms. The average hard coral cover was 3.6%, and the dominant cover was rubble (46.3%), sand (17.3%), and coralline algae (13.7%). Fish biomass averaged 1080.3 kg/ha. This site was dived with the reef on the left.

APPENDIX 2
CORAL GENERA PRESENT (X) ON KORO ISLAND SURVEYED IN 2017

GENERA	PRESENT
Acanthastrea	X
Acropora	X
Astreopora	X
Coscinaraea	X
Ctenactis	X
Cyphastrea	X
Diploastrea	X
Echinophyllia	X
Echinopora	X
Favia	X
Favites	X
Fungia	X
Galaxea	X
Gardinoseris	X
Goniastrea	X
Herpolitha	X
Hydnophora	X
Leptastrea	X
Leptoria	X
Leptoseris	X

GENERA	PRESENT
Lobophyllia	X
Merulina	X
Millepora	X
Montastrea	X
Montipora	X
Pachyseris	X
Pavona	X
Pectinia	X
Platygyra	X
Pocillopora	X
Podobacia	
Polyphyllia	X
Porites	X
Psammacora	X
Sandolitha	X
Stylophora	X
Symphyllia	X
Tubastrea	X
Turbinaria	X

Wildlife Conservation Society