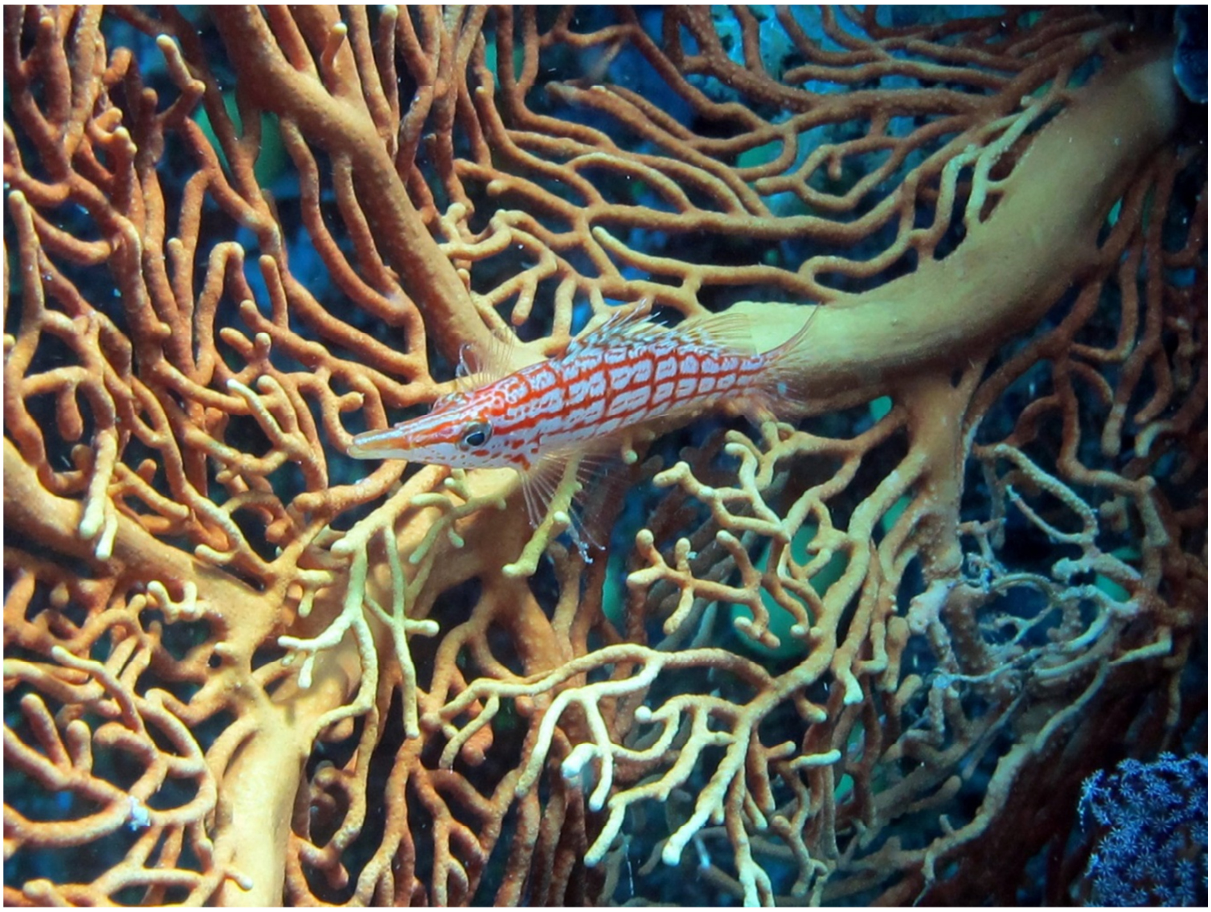
Impact of Tropical Cyclone Winston on Coral Reefs in the Vatu-i-Ra Seascape



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Photographs (front cover): Longnose hawkfish on gorgonian coral in the Namena Marine Reserve. ©Sangeeta Mangubhai/WCS

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EXECUTIVE SUMMARY

On 20 February 2016, one of the largest cyclones on record in the Southern Hemisphere passed through Fiji, with winds up to 185 mph, and gusts of 225 mph. Cyclone Winston left a trail of destruction, with some of the most impacted landscape and communities located in the Vatu-i-Ra Seascape. A rapid assessment of coral reefs in the Vatu-i-Ra Seascape was conducted from 6-15 March 2016 focusing on tourist sites, using rapid assessment techniques. The objectives of these surveys were to assess: (a) impact of Cyclone Winston on coral reefs in the Vatu-i-Ra Seascape; (b) extent and intensity of coral bleaching on corals; and (c) the health and diversity of areas being considered for inclusion in deeper water marine managed areas. Over 10 days, 26 sites were surveyed covering reef within and around the proposed Vatu-i-Ra Conservation Park in Nakorotubu District, Gau, Batiki and Wakaya Islands, the Namena Marine Reserve in Kubulau District, reefs in the Eastern Bligh Waters. Data were collected on benthic cover and coral bleaching, and observations were recorded of the damage to coral reefs.

Tropical Cyclone Winston not only altered landscapes and communities along its main pathway, but caused significant damage to coral reefs up to 20-30 m below the surface in the Vatu-i-Ra Seascape. Damage to coral reefs was highest in the north where the eye of the cyclone passed, and lowest in the south. However, the level of destruction was highly variable and patchy between reefs. There was no clear pattern to the damage, with both windward and leeward reefs equally impacted. There was extensive coral breakage, coral abrasion, dislodgement of large coral colonies and structural damage to the reef framework. While no data were collected on reef fish, there will likely be changes to fish species composition and biomass, especially in areas that sustained high coral and reef structural damage, like the Namena Marine Reserve. A reduction in corals and the reef structure will reduce the available habitat, which may make some species more vulnerable to predators.

Recovery from these types of disturbances, especially cyclones, can take decades, depending on frequency of these events, the scale and intensity of structural damage caused, and compounding anthropogenic stresses (e.g. pollution, overfishing) on coral reefs, that might hinder or slow recovery. However, in additional to mechanical and structural damage, Fiji's reefs have the additional stress of coral bleaching. At the time of the surveys, the bleaching was mild and the exception of Gau was <8% on most reefs. While the SSTs have dropped 1-2°C since the cyclone, corals had not returned to normal, a month after the cyclone.

The ability of Fiji's coral reefs to persist and recover from cyclone Winston and bleaching stress is dependent on a number of factors including the intensity, severity and frequency of the disturbance, successful reproduction, availability of viable larvae, oceanic current dynamics influencing larval dispersal, and settlement and recruitment processes. Given the findings of the study, it is recommended that:

i) actions should be taken to minimize human-stresses to coral reefs (e.g. overfishing, pollution), especially areas that are heavily impacted;
ii) protection should be provided to coral reefs that were undamaged by the cyclone, as these will play a critical role in the recovery of adjacent more impacted reefs;
iii) more comprehensive assessments should be undertaken of coastal coral reefs to document the intensity and scale of damage, to determine the potential impact to local subsistence and commercial fisheries, and inform marine resource management decisions;
iv) data from assessments should be reviewed in parallel with fisheries data Household Income Expenditure Surveys (HIES) and other socioeconomic surveys, to determine the impact of the cyclone on community food security and fisheries livelihoods; and
v) Lastly, monitoring programs be extended to measure the recovery of coral reefs over the next 2-5 years, and ensure they are linked to management actions.

INTRODUCTION

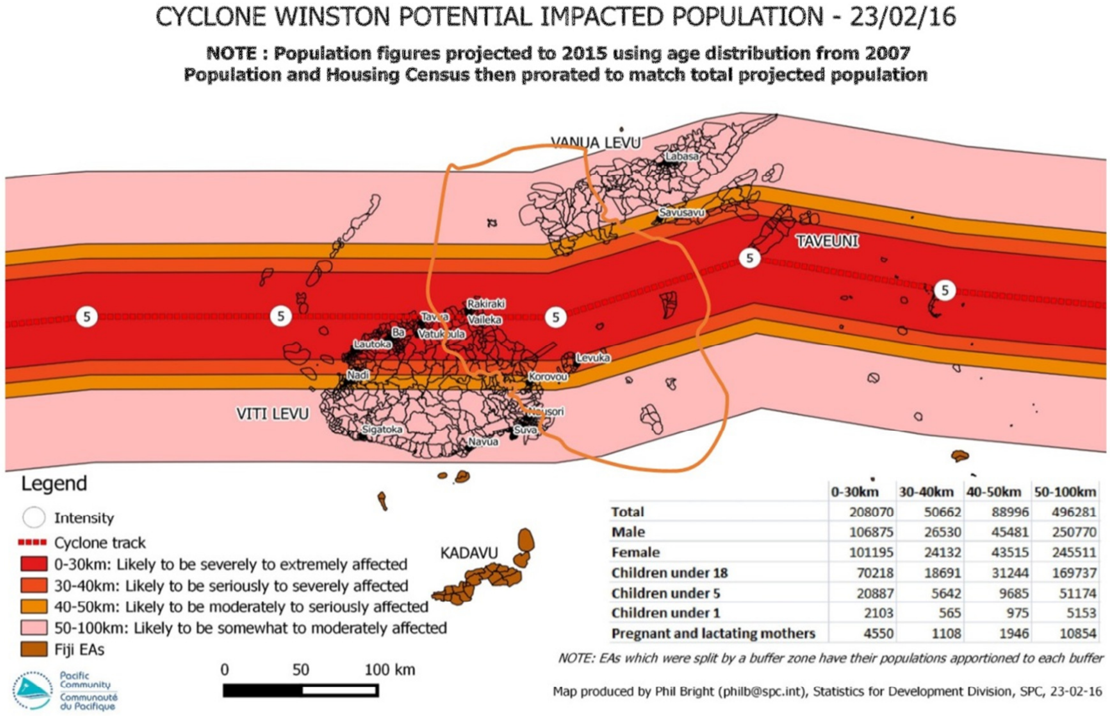
On 20 February 2016, Category 5 Tropical Cyclone Winston passed through Fiji (Fig. 1). It was one of the largest cyclones Fiji had experienced with winds up to 185 mph with gusts to 225 mph. Over a 24-hour period the cyclone left a trail of destruction across the country and the on 21 February 2016 Fijian Government announced a 30 day state of emergency. Total damage was estimated at US$470 million on 8 March 2016 (10% of Fiji's GDP, World Bank 2014), which included crop, livestock and agricultural damage.

Because of the pathway of the cyclone, some of the most affected were the 116,000 people that live in remote rural communities within the Vatu-i-Ra Seascape, which covers the provinces of Bua, Lomaiviti, Ra and Tailevu (Fig. 1). Lomaiviti Province was badly hit with 100% of homes damaged or destroyed on Koro Island, and 80-90% of homes were lost on Ovalau Island. Over 80% of homes were damaged or destroyed in Ra Province, with many villages remaining cut off and reliant on aerial distribution of food, water and temporary shelter in the first two weeks after the cyclone. In Bua Province, there was extensive damage to homes, crops and water sources, especially for districts along southern Vanua Levu.

Mortality due to physical disturbances is a process vital to the maintenance of biodiversity in both marine and terrestrial ecosystems, including coral reef habitats (Connell 1978, Connell et al. 1997). Major disturbances experienced by coral reefs that cause widespread damage are cyclones, coral bleaching events, and crown-of-thorns (*Acanthaster planci*) outbreaks (Endean and Cameron 1990, Hoegh-Guldberg 1999, Adjeroud et al. 2002). In the case of cyclones, damage and can be severe and may include breakage of corals (especially branching growth forms), abrasion of coral tissue, burial under rubble or sand, dislodgement of large coral colonies and structural damage to the reef framework (Harmelin-Vivien 1994). The amount of structural damage is determined by the *intensity, circulation size and duration of extreme conditions near reefs* (Beeden et al 2015). Recovery from these types of disturbances, especially cyclones, can take decades, depending on frequency of these events, the scale and intensity of structural damage caused, and compounding anthropogenic stresses (e.g. pollution, overfishing) on coral reefs, that might hinder or slow recovery (Beeden et al. 2015).

Prior to Cyclone Winston, there were growing reports from dive operators and local scientists in Fiji of coral bleaching (pers. comm.) and local newspapers reported fish kills along the Coral Coast, associated with El-Niño weather conditions across the Pacific. However, scale and intensity of bleaching in Fiji at the time had not been documented. There was little information available on the impact to coral reefs from both the cyclone and coral bleaching. The objectives of these surveys were to assess:

a) impact of Cyclone Winston on coral reefs in the Vatu-i-Ra Seascape;
b) extent and intensity of coral bleaching on corals; and
c) health and diversity of areas being considered for inclusion in deeper water marine managed areas.



	0-30km	30-40km	40-50km	50-100km
Total	208070	50662	88996	496281
Male	106875	26530	45481	250770
Female	101195	24132	43515	245511
Children under 18	70218	18691	31244	169737
Children under 5	20887	5642	9685	51174
Children under 1	2103	565	975	5153
Pregnant and lactating mothers	4550	1108	1946	10854

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: Secretariat of the Pacific Community.

METHODS

Marine biological surveys of coral reefs in the Vatu-i-Ra Seascape were conducted from 6-15 March 2016. Surveys were undertaken on SCUBA using rapid assessment techniques and covered six main areas (in order): (i) reef within and around the proposed Vatu-i-Ra Conservation Park in Nakorotubu District, (ii) Gau Island, (iii) Batiki Island, (iv) Wakaya Island, (v) Namena Marine Reserve in Kubulau District, and (vi) Eastern Bligh Waters (Fig. 2, Table 1). The 26 sites selected for survey were those frequented by tourists on board the MV Nai'a, and are some of the most specular in the seascape, boasting a diversity of reef structure, habitats, colourful soft corals and sea fans, as well as an abundance of invertebrates, fish and sharks (Obura and Mangubhai 2002). The three survey methods used are described below.

a) Benthic Cover: quantitative data on benthic cover was collected at each site using an underwater digital camera. Photos were taken using a fixed camera-to-camera distance of 0.5 m and holding the camera perpendicular to the substrate. Most photos were taken at 12-15 m depth, though some sites were also sampled at deeper (20-25 m) and shallower depths (5-8 m). Five points were sampled per frame (photo image), and a total of 20 frames were used to calculate benthic cover from 100 points. Benthic categories recorded are shown in Table 2, and were consistent with previous surveys by Obura and Mangubhai (2002), with one exception. Rock and turf were combined in 2001, but were separated in 2016 surveys. Rock was used for rock surfaces that were clean, and devoid of turf algae to quantify newly available reef substrate.

b) Observations of damage: during each dive, notes were taken on the level of damage observed at each sites, focusing on the genera of coral most affected, scouring of surfaces, presence of new turf algae and rubble fields.

c) Coral bleaching: because of time limits on recreational dives, a simple rapid assessment method was used to assess the level and scale of bleaching at each of the sites developed by the Wildlife Conservation Society (Darling and McClanahan 2016). Tailor's tape was used to estimate a 1.4 x 1.4 quadrat (2 m^2). Within each quadrat each hard coral colony was identified to genus level. For each coral, bleaching condition of coral was assessed as follows: Normal (unbleached), Pale, 0-20% bleaching, 21-50% bleaching, 51-80% bleaching, 81-100% bleaching, and Recently Dead (i.e., skeleton covered in recent turf growth). Once all the corals are counted, a visual assessment of the percent cover of hard corals, soft corals and macroalgae for each quadrat was made. Quadrats were separated by 5-10 fin kicks. Only quadrats that landed on hard substrate were counted. Bleaching surveys were carried out at sites around Gau and Wakaya Islands, the Namena Marine Reserve and Eastern Bligh Waters.

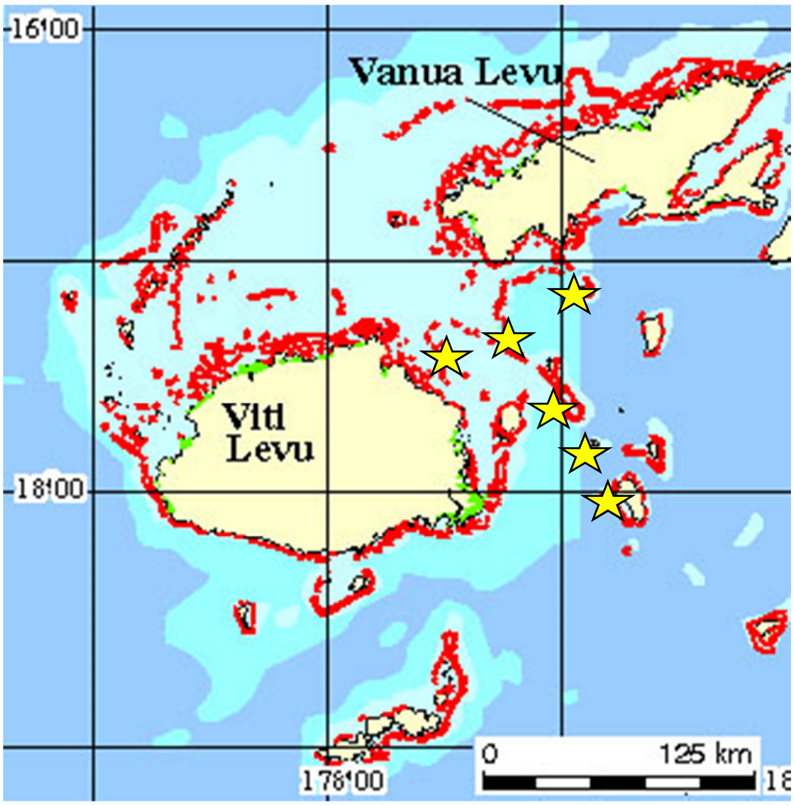


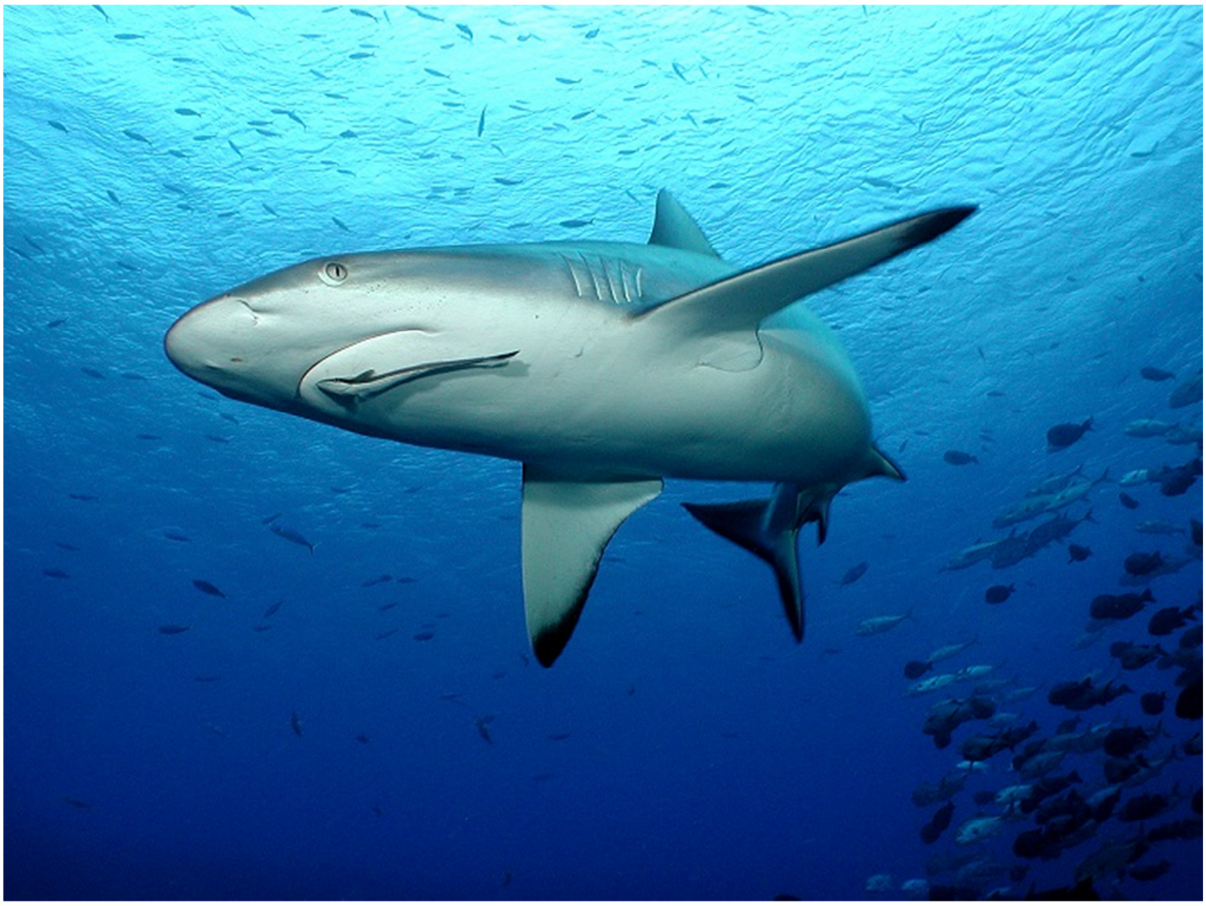
Figure 2. The six regions surveyed in the Vatu-i-Ra Seascape, post-cyclone Winston.

Table 1. Sites and reef types surveyed in the Vatu-i-Ra Seascape in March 2016. GPS points are not provided to protect the privacy of the tourism sector, and can be obtained from Nai'a Cruises.

Date	Region	Site Name	Reef type
6/3/16	Nakorotubu	Western Reef	Barrier reef
6/3/16	Nakorotubu	Gomo	Patch reef
6/3/16	Nakorotubu	Lighthouse	Patch reef
6/3/16	Nakorotubu	Charlie's Garden	Patch reef
6/3/16	Nakorotubu	Howard's Diner	Patch reef
7/3/16	Gau	Nigali Passage	Channel
7/3/16	Gau	Jim's Alley	Pinnacles
7/3/16	Gau	Jungle Jig	Barrier reef
8/3/16	Batiki	Coral Castles	Patch reef
9/3/16	Wakaya	Lion's Den	Bommie
9/3/16	Wakaya	Vatu Vai	Pinnacle
9/3/16	Wakaya	Hole in One	Bommie
10/3/16	Namena	North Save-a-Tack	Barrier reef
10/3/16	Namena	Kansas	Pinnacles
10/3/16	Namena	2 Thumbs Up	Pinnacles
10/3/16	Namena	Teton	Pinnacles
11/3/16	Namena	Namena Channel	Channel
11/3/16	Namena	Fantasea	Barrier reef
12/3/16	E. Bligh Waters	Cat's Meow	Bommie
12/3/16	E. Bligh Waters	Vatu Vonu	Bommie
12/3/16	E. Bligh Waters	Humann Nature	Bommie
12/3/16	E. Bligh Waters	Undeniable	Bommie
13/3/16	E. Bligh Waters	Ravai's Wives	Bommie
13/3/16	E. Bligh Waters	E6	Seamount
14/3/16	Nakorotubu	Mellow Yellow	Bommie
14/3/16	Nakorotubu	Maytag	Bommie

Table 2. Benthic categories recorded for photo quadrats.

Substrate	Hard corals	Soft corals	Algae	Other
Rubble (RU)	*Acropora* (AC)	Carpeting	Turf (TU)	Corallimorphs
Sand (S)	Branching (CB)	Fans	Rock (RK)	Zooanthids
	Encrusting (EN)	Tree-shaped fans	Fleshy (MA)	Anemones
	Plate (PL)	Black coral	Coralline (CCA)	Hydroids
	Mushroom (MU)	Whispy-shaped	Halimeda (HA)	Bacterial mat
	Massive (MA)	Nepthiid		Sponges
	Submassive (SM)	Whips		Oysters
	Bleached			Unknown
	Dead			



Healthy grey reef shark populations in the Namena Marine Reserve. ©Cat Holloway

RESULTS

Cyclone damage to coral reefs

Descriptions of the impact to each of the six regions surveyed are provided in Table 3, and the overall impacts to reefs in the Vatu-i-Ra Seascape from Cyclone Winston are summarised below, and shown in Plates 1 and 2. The main impacts documented were:

a) damage to coral reefs was highest within the Namena Marine Reserve in the north, and lowest on reefs around Gau Island in the south;
b) both windward and leeward reefs appeared to have equally sustained damage;
c) while all reefs in the main pathway of the cyclone sustained some damage, the level of destruction was highly variable and patchy between reefs (including those immediately adjacent to each other);
d) there were significant losses of sea fans (gorgonian corals) from sites, with many torn out by their roots, and many of the remaining fans partially-damaged (50-75% loss). No large sea fans (2-3 m) remained intact at any of the sites;
e) many soft corals were removed completely from wall surfaces and were likely carried away by water currents and storm surge;
f) table and staghorn *Acropora* corals and branching *Tubastrea* were broken off at the stems, often sitting upside down on the substrate or fragmented into rubble size pieces;
g) in some areas, the force of the waves had dislodged large massive corals and moved boulders down reef slopes;
h) there was partial-damage to the reef framework in many areas, especially of overhang structures;
i) many corals showed partial mortality and/or signs of abrasion with tissue repair and regrowth observed;
j) damage to corals and reef structure was observed down to 20-30 m depths;
k) fringing reefs, bommies and pinnacles had large areas that had been scoured out, leaving clean white surfaces, or surfaces with a fine layer of turf algae;
l) large volumes of old and new rubble accumulated in between reef structures and were shifting around with the currents;
m) the Nasi Yalodina, a shipwreck sitting at 30m in the eastern Bligh waters, had been pushed down to deeper depths and was no longer visible;
n) almost 100% loss in foliage on the islands of Vatu-i-Ra and Namena, and significant damage to vegetation on Wakaya Island.

Despite the scale of the damage, there were clear areas of reef that were largely untouched by the cyclone. Sites popular with tourists like the 'Two Thumbs Up' and 'Kansas' in Namena Marine Reserve and 'Mellow Yellow' and 'Maytag' in the proposed Vatu-i-Ra Conservation Park (north of Vatu-i-Ra Island) were for most part, intact, and continued to flourish all the way from the base of pinnacles and bommies to just below the water surface (Plate 3). Despite damage on land and on fringing reefs around Batiki Island, the reefs around Gau Island in the south were largely untouched by the cyclone, with almost no damage to corals on fringing, channel and lagoonal reefs.

Hard coral cover ranged from 0-53% (mean=25.7, sd=14.4) across the sites surveyed, while soft coral cover ranged from 1-30% (mean=10.3, sd=9.2) (Table 4). Overall, branching (42.2%), encrusting (27.6%) and sub-massive (23.6%) dominated the coral reefs surveyed (Fig. 4). Branching corals were highest in Gau (63.3%) and Wakaya (43.2%), and lowest at Nakorotubu (14.3%), while encrusting corals were highest at Nakorotubu (42.2%) and Eastern Bligh Waters (39.2%). Sub-massive and massive corals dominated at Namena (40.2%) and Batiki (29.3%), respectively (Fig. 4).

Halimeda and fleshy macroalgae cover were generally low (<3%) to absent at sites, with the highest recorded at Teton1 (8%) (Table 4). Crustose coralline algae cover ranged from 1-40% (mean=12.6, sd=10.6), rock from 1-42% (mean=13.3, sd=10.3) and turf from 3-59% (mean=26.5, sd=15.7), representing the available hard substrate for colonization. In contrast, rubble cover ranged from 0-37% (mean=10.7, sd=11.3) and sand from 0-30% (mean=5.8, sd=8.7), representing mobile substrate unsuitable for colonization. It is important to note that the percentage cover of rubble and sand, does not accurately represent what was present at the sites post-cyclone, as many of the habitats surveyed were on slopes of 85-90% (e.g. bommies, pinnacles) at 15 m depth, with most of the rubble and sand accumulated at the base (>20 m).

Unfortunately, pre-cyclone or long-term monitoring data were not available for analysis to quantify the percent changes in benthic cover at individual sites, or within the six areas surveyed prior to the cyclone. Surveys conducted in 2001 were after a coral bleaching event (Obura and Mangubhai 2002), and therefore do not allow pre-cyclone comparisons. The closest comparison can be made to study in 2003 which covered the Vatu-i-Ra Seascape (and some of the same dive sites) and found hard coral cover ranging from 40-60% and soft corals cover up to 34% (Marmane et al. 2003). Only 5 of the 26 sites had hard coral cover within the range recorded in 2003, and 17 sites had soft coral cover <10%. These figures are indicative of the losses of hard and soft coral in the Vatu-i-Ra Seascape, caused by cyclone Winston.

While no underwater visual census of coral reef fish populations were done, semi-pelagic fish (e.g. trevally, barracuda) and sharks seemed to be largely unaffected. White tip (*Triaenodon obesus*) and grey reef (*Carcharhinus amblyrhynchos*) sharks were observed, particularly in the Nigali Passage and the Namena Marine Reserve. Large schools of big-eyed trevally, fusiliers and surgeonfish were observed at more than 50% of sites (Plate 4). However, very few butterflyfish, groupers, snappers and lethrinids were observed at impacted sites, as well as smaller fish (e.g. *Anthias*) that live in or around branching corals. More detailed studies of fish species and populations are required to quantify potential impacts to fisheries. Studies from the Great Barrier Reef suggest that fisheries may be impacted up to two years after a cyclone event (P. Marshall, pers. comm.).

The data collected in March 2016, will serve as a valuable baseline for measuring coral community recovery on these reefs following one of the largest cyclones on record.

Healthy soft and hard coral dominated reefs in the Vatu-i-Ra Seascape prior to cyclone damage. ©Cat Holloway

Table 3. Summary of cyclone damage to coral reefs in the Vatu-i-Ra Seascape.

Region	Sites	Description
Nakorotubu	Western Point, Gomo, Lighthouse, Charlie's Garden, Howard's Diner, Mellow Yellow, Maytag	This region has lost many of the colourful soft corals and fans, popular amongst divers. Large *Acropora* plates and branching *Pocillopora* corals have been broken, as well as larger sub-massive and massive corals (e.g. *Montastrea, Porites*). There are large areas that have been scoured, leaving bare rock that is now covered by fine turf algae. Rubble fields have shifted, and new rubble has been added. Many of these rubble fields were covered in fine turf algae. Mellow Yellow and Maytag appeared for most part, intact, with soft corals and fans present at both sites. Recovery is likely given these areas are further from human habitation than coastal reefs, and are currently being proposed for protection within the Vatu-i-Ra Conservation Park.
Gau	Nigali Passage, Jim's Alley, Jungle Jig	There was almost neglible cyclone damage to coral reefs at Gau Island (as well as on the island). The reefs were intact both within channels, the lagoon and on the outer fringing reef.
Wakaya	Lion's Den, Vatu Vai, Hole in One	There was a fair amount of cyclone damage around Wakaya, especially on the fringing reef and on bommies. There were large areas of accumulated sand and rubble, some of which had smothered live corals. Table corals were overturned and staghorn corals were broken up. However, there was still a lot of intact hard coral at the sites. While initially impacted, this area is likely to recover given there is no fishing pressure and there is abundant live coral that survived the cyclone.
Namena	North Save-a-Tack, Kansas, 2 Thumbs Up, Teton, Namena Channel, Fantasea	This is the most damaged site surveyed over the 10 days, though the damage was extremely patchy. Significant damage to fans which were completely uprooted, or ripped into half. Soft coral species had been removed, leaving only small patches of colour on walls. Most *Acropora* tables had been broken off from the reef and were lying upside down on the substrate, or partially buried in rubble, and branching *Tubastrea* species were broken off, and had tips that were badly abraded. Sub-massive and massive coloinies (e.g. *Porites, Montastrea, Favites*) had been dislodged. There was notable damage to the reef structure, with pieces of reef dislodged and turned upside down, killing the corals that had been growing on surfaces. In some areas rubble had accumulated between bommies, and in other places the rubble had been moved off to deeper waters, leaving behind clear bare substrate, ready for colonization. The recovery of these reefs will be dependent on communities remaining committed to protecting the Namena Marine Reserve.

Table 4. Percentage benthic cover for sites surveyed in the Vatu-i-Ra Seascape in Fiji. Sites are ordered from highest hard coral cover to lowest.

Reef	Site	Depth	HC	SC	HA	MA	CCA	RK	TURF	RUB	SAND	OT
Wakaya	Lion's Den	15	53	4	2		12	6	18	5		0
Gau	Jungle Jig	15	48	2	3		20	5	6	12	4	0
E. Bligh Waters	Humann Nature	15	47	9		1	12	5	23	0		3
Batiki	Coral Castles	15	41	5				22	14	14	4	0
Gau	Nigali Passage	15	41	3			2	16	22	2	2	12
E. Bligh Waters	Ravai's Wives	15	38	2			8	7	16	26	3	0
Nakorotubu	Howard's Diner	15	37	4			3	15	31	8		2
Wakaya	Hole in Wall	15	35				12	10	9	21	13	0
Nakorotubu	Western Point	15	30	4			8		57			1
Wakaya	Vatu Vai	15	30	2	1	2	1	12	18	2	30	2
E. Bligh Waters	E6	15	29	4		1	8	30	13	14		1
E. Bligh Waters	Vatu Vonu	15	29	6			9	8	36	11		1
Nakorotubu	Charlie's Garden	15	29					42	3	26		0
E. Bligh Waters	Cat's Meow	15	24	24	1	1	6	16	17	1		10
Namena	2 Thumbs Up	15	23	14			6	10	42		2	3
Nakorotubu	Mellow Yellow	15	22	30	2		14		26			6
Namena	North-Save-a-Tack	15	20	12			18	4	41	5		0
Nakorotubu	Coral Corner	15	19	21	1		5	18	17	12	3	4
Namena	Namena Channel Bommie	15	17	25	0	0	22	9	27	0	0	0
Namena	Kansas	15	16	7	1		40	9	24	1		2
Namena	Channel	15	12	2			6	35	35	10		0
E. Bligh Waters	Undeniable	15	11	20			7	18	40	2		2
Gau	Jim's Alley	15	9	11			4	10	59	1	3	3
Namena	Fantasea	15	9	1			35	2	37			16
Nakorotubu	Gomo	15	9	2		3	13	23	46	1		3
Nakorotubu	Maytag	15	2	19	1		39		32			7
Namena	Teton1	15	0	30	8		8	1	50			3
E. Bligh Waters	Undeniable	20	19	11	0	0	16	11	7	35	0	1
E. Bligh Waters	Cat's Meow	24	47	4	1		6	2	3	37		0

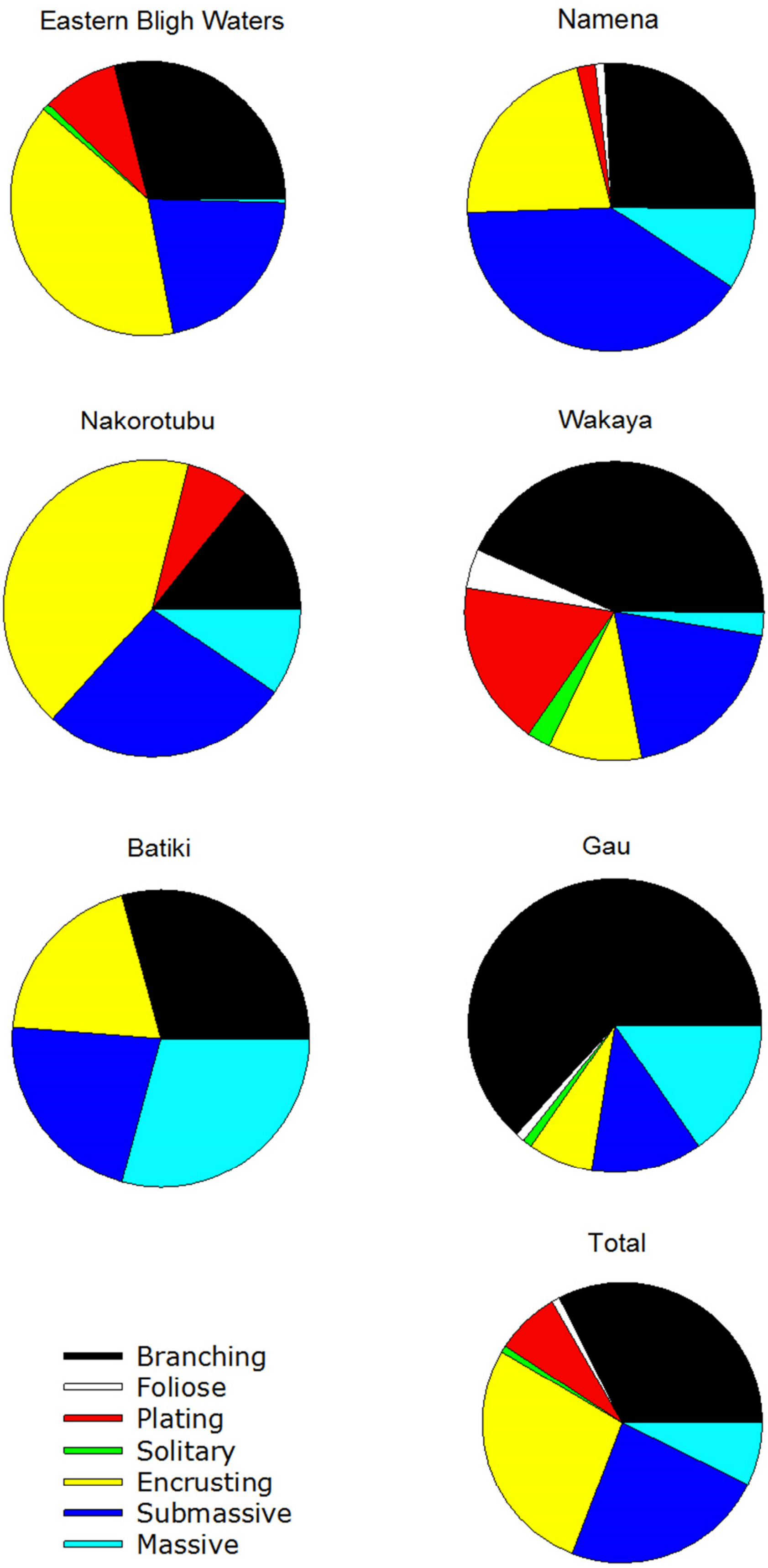


Figure 3. Percent composition of hard coral life forms in the six areas surveyed, post-cyclone.

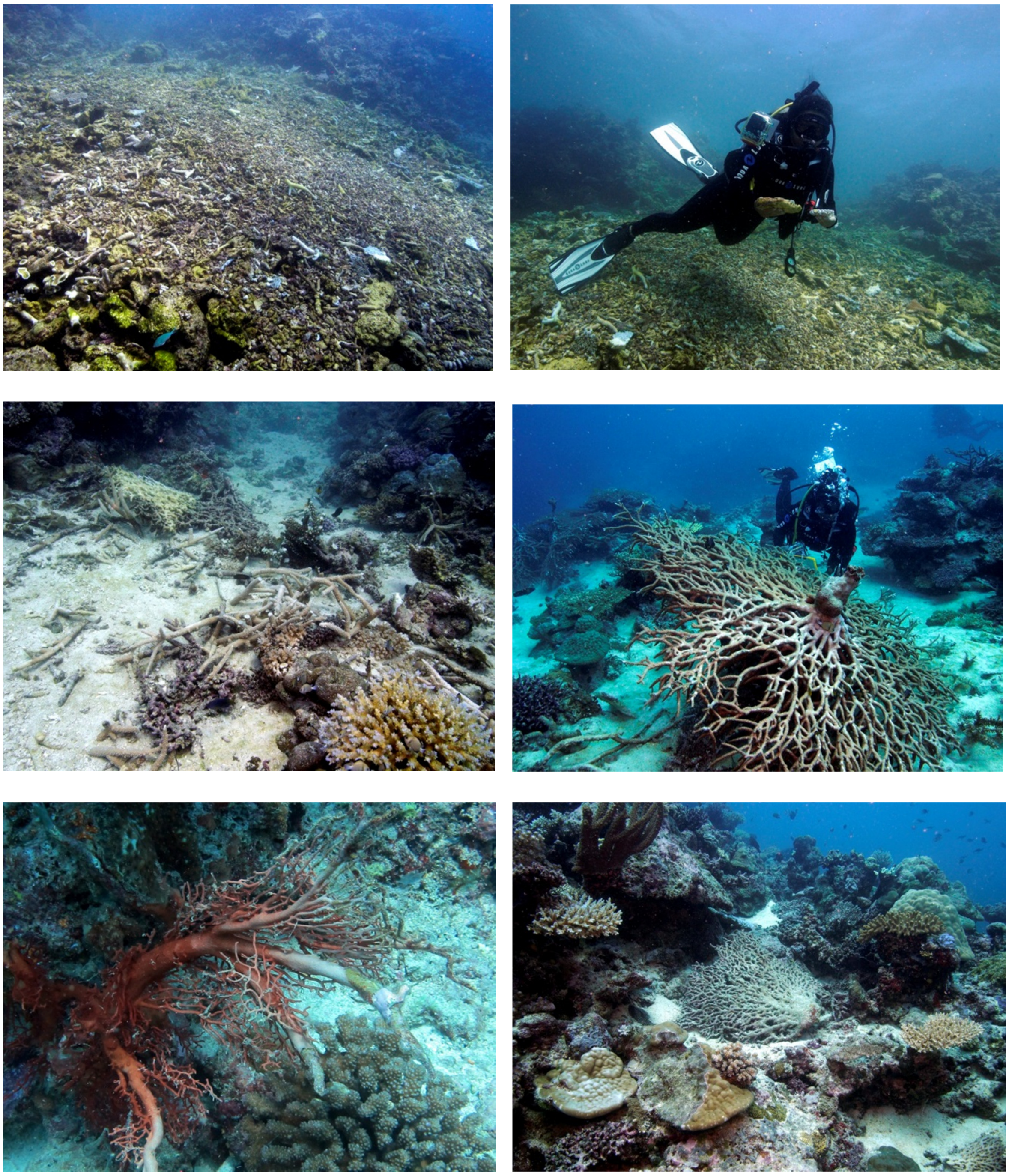


Plate 1: Damage to Namena Marine Reserve caused by Tropical Cyclone Winston. ©Jack & Sue Drafahl

Plate 2. Vatu-i-Ra Island before and after cyclone Winston (©BirdLife International / Sangeeta Mangubhai/WCS) (top). Namena Island before (middle, ©Stuart Chape) and after cyclone Winston (bottom, ©Sangeeta Mangubhai/WCS).

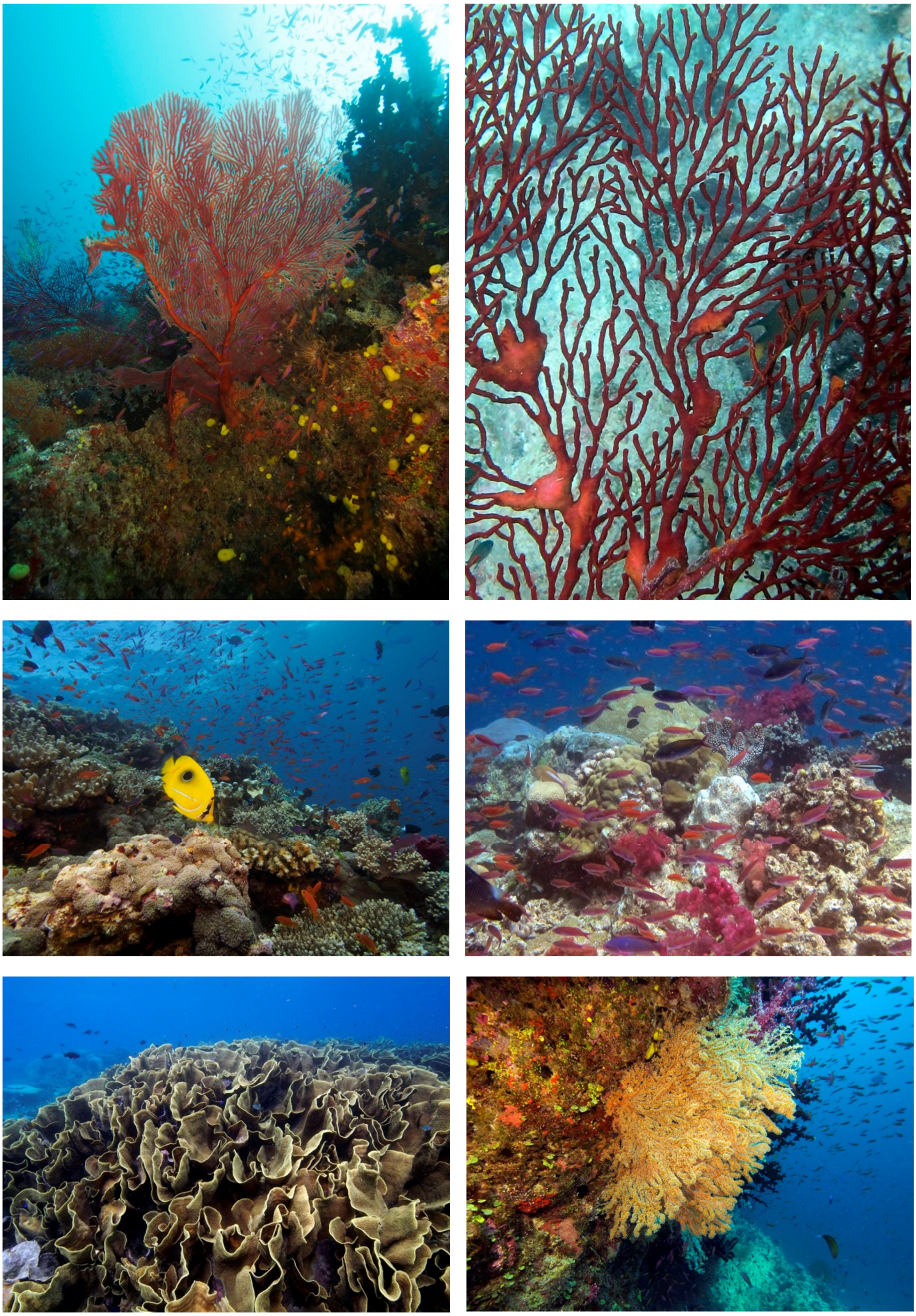


Plate 3: Coral reefs surveyed that had little damage from Tropical Cyclone Winston. ©Jack & Sue Drafahl (left, bottom right), ©Sangeeta Mangubhai/WCS (top right, middle right)

Plate 4: Healthy fish populations at sites popular with SCUBA divers. ©Janet McClelland (top, middle), ©Sangeeta Mangubhai (bottom)

Bleaching in the Vatu-i-Ra Seascape

In the weeks leading up to the Cyclone Winston, Fiji was experiencing drought conditions and elevated sea surface temperatures (SSTs), as a result of the El Niño Southern Oscillation cycle (Figs. 4-6). There had been reports of coral bleaching from dive operators and local scientists, and the local newspaper, the Fiji Times, ran a number of stories about fish kills along the Coral Coast. *In situ* temperatures on inner reef flats along the Coral Coast reached a high of 35°C. Following the cyclone, *in situ* SSTs in Fiji dropped by 1-2°C, and satellite imagery showed hot spots (Fig. 5) and temperature anomalies (Fig. 6) dissipating. Satellite images showed SSTs were still slightly elevated at the time of surveys, at 5-6 degree heating weeks (Fig. 4).

Rapid assessments in the Vatu-i-Ra Seascape in March 2016 indicated that the average percentage of bleached corals was highest at Gau (20.2±8.6%) and reefs in the Eastern Bligh Waters (7.0±4.8%), and lowest at Wakaya Island (3.4±0.6) and Namena Marine Reserve (0%) (Table 5). Only three sites (i.e. Jungle Jig, Nigali Passage and Cat's Meow) had >14% bleached colonies, while all other sites had <8% bleached corals. Jungle Jig had the highest bleaching index and site susceptibility to coral bleaching of all sites (Table 5), though it should be noted this was the only outer barrier reef that was surveyed. The sites with the lowest susceptibility to bleaching were Cat's Meow, E6 and Namena Channel (<15).

The greatest diversity of bleached genera was documented at Eastern Bligh Waters and Vatu-i-Ra, though this may reflect the greater number of sites visited and therefore more time spent underwater documenting the bleaching (Table 6). Coral bleaching was documented in 26 coral genera, with bleaching highest on the tops of bommies in 3-8 m of water. Bleached colonies of *Acropora, Pocillopora, Pavona* and *Porites* species were recorded in each of the six areas surveyed (Table 6).

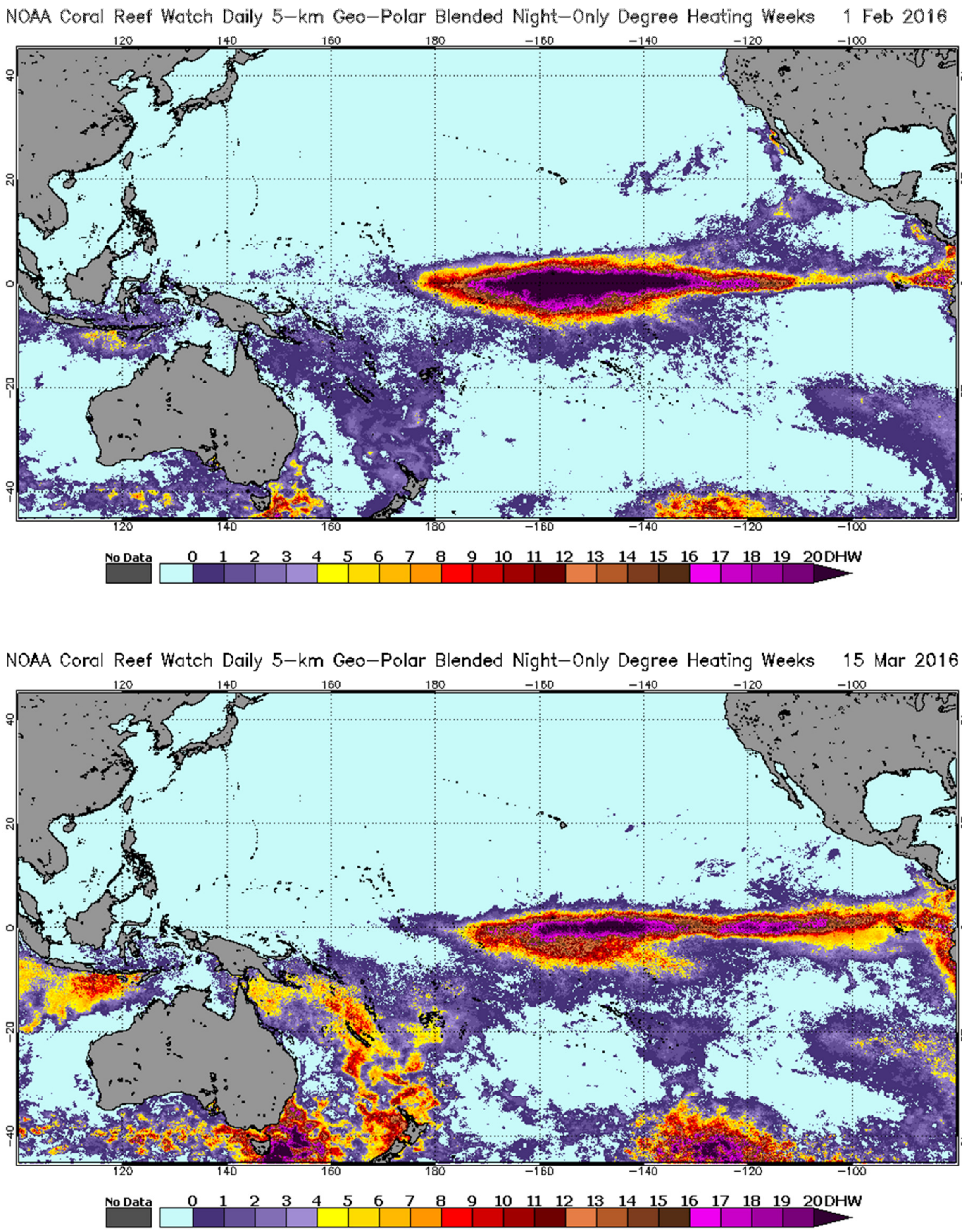


Figure 4. Degree heating weeks before (1 February 2016) and after (15 March 2016) cyclone Winston, at 5 km pixel resolution. Source: NOAA Coral Reef Watch

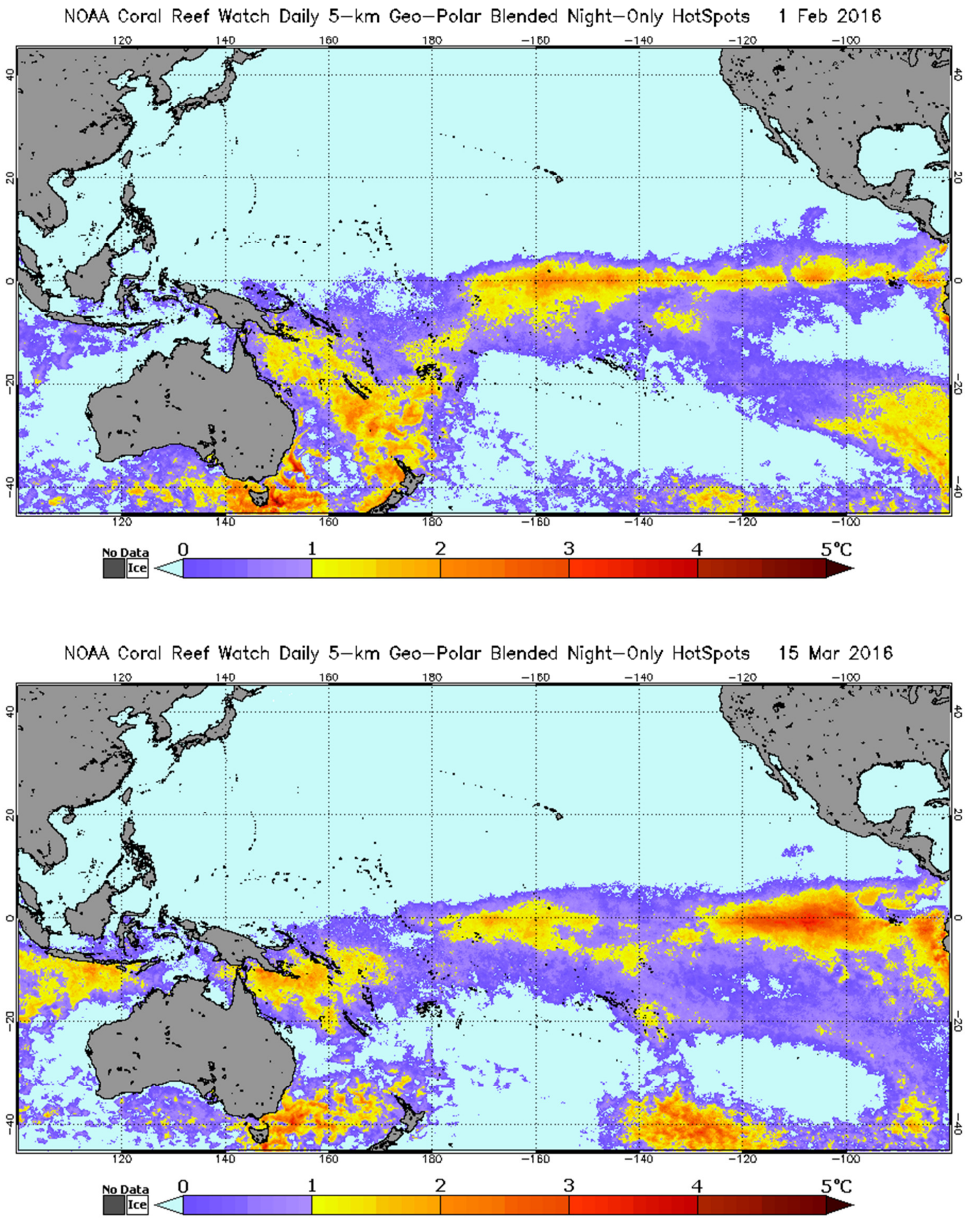


Figure 5. Hotspots before (1 February 2016) and after (15 March 2016) cyclone Winston, at 5 km pixel resolution. Source: NOAA Coral Reef Watch

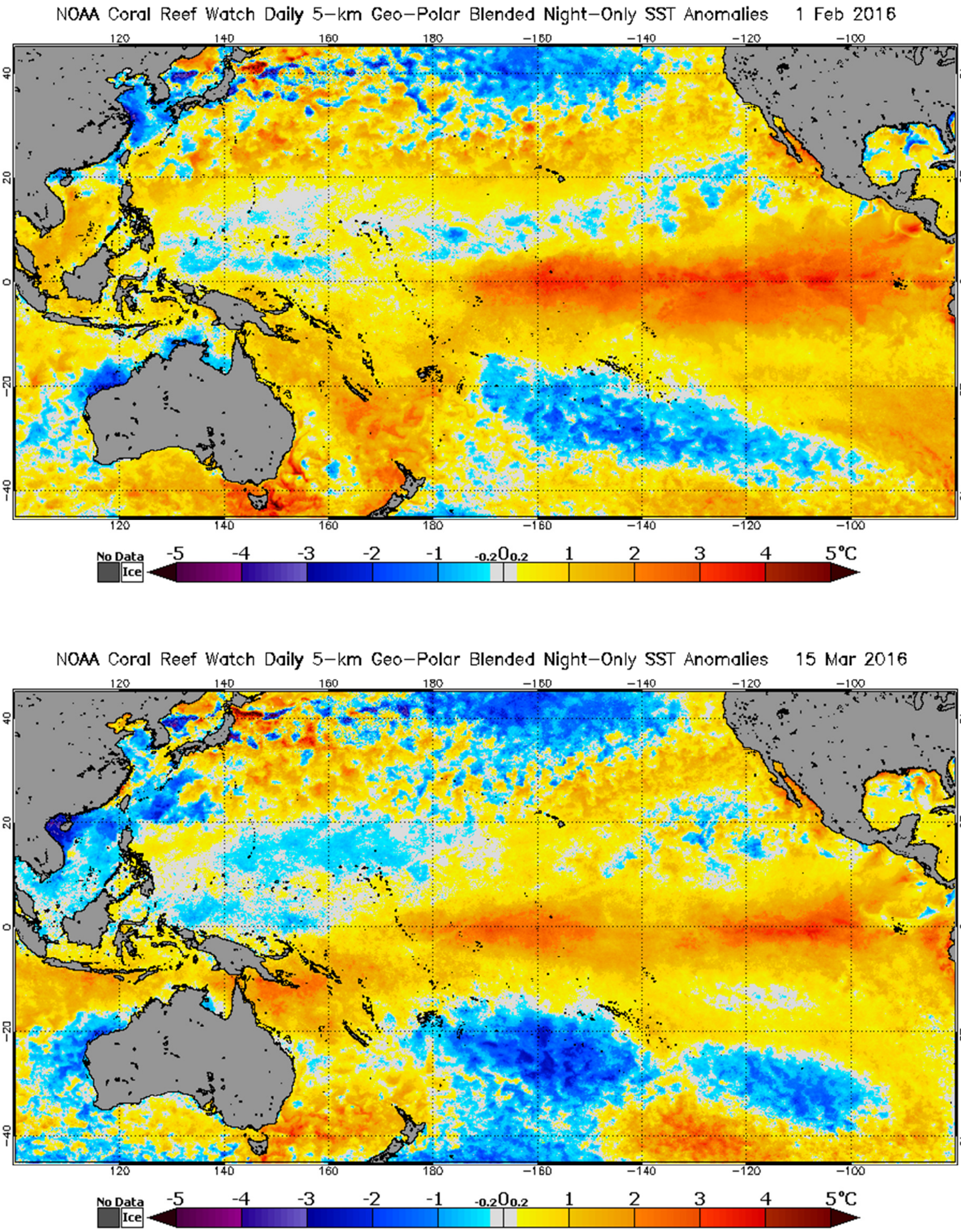


Figure 6. Sea surface temperature (SST) anomalies before (1 February 2016) and after (15 March 2016) cyclone Winston, at 5 km pixel resolution. Source: NOAA Coral Reef Watch

Table 5. Degree of coral bleaching documented on different reefs at 12-15 m depth. For the four main areas surveyed (bold), averages ± standard deviation, have been calculated across the sites. * See methods in McClanahan et al. (2014).

Areas/Sites	#	#	Coral	%bleach	Bleaching	Site
Gau	**168**	**17.5**	**0.77**	**20.2±8.6**	**6.71**	**21.6**
Jungle Jig	244	20	0.76	26.23	9.43	20.6
Nigali Passage	92	15	0.78	14.13	3.99	22.7
E. Bligh Waters	**127.2**	**21.4**	**0.85**	**7.0±4.8**	**3.23**	**15.0**
Cat's Meow	141	22	0.80	14.89	9.22	14.0
E6	118	19	0.78	3.39	1.27	13.0
Humann Nature	120	17	0.89	7.50	3.06	16.2
Ravai's Wives	117	27	0.90	3.42	1.28	15.3
Undeniable	140	22	0.89	5.71	1.31	16.4
Wakaya	**260**	**23.7**	**0.87**	**3.4±0.6**	**1.02**	**17.1**
Hole in Wall	261	24	0.89	3.83	1.09	16.1
Lion's Den	325	26	0.89	2.77	0.51	18.0
Vatu Vai	194	21	0.85	3.61	1.46	17.1
Vau-i-Ra	116	18	0.86	1.72	0.29	16.9
Mellow Yellow	116	18	0.86	1.72	0.29	16.9
Namena	**53.5**	**9.5**	**0.77**	**0**	**0**	**15.0**
2 Thumbs Up	53	13	0.84	0	0	16.3
Namena Channel	54	6	0.69	0	0	13.7

Table 6. Coral genera that bleached on coral reefs in the Vatu-i-Ra Seascape. The number of sites visited is indicated in parentheses.

Genera	Vatu-i-Ra (6)	Bligh Waters (6)	Namena (6)	Wakaya (3)	Batiki (1)	Gau (3)
Acropora	X	X	X	X	X	X
Astreopora		X	X	X		X
Diploastrea	X	X				X
Favia	X					
Favites	X	X				
Fungia						X
Galaxea	X	X		X		X
Gardineroseris		X				X
Goniastrea	X	X				X
Hydnophora	X	X				
Pavona	X	X	X	X	X	X
Leptoria	X				X	
Leptastrea		X				
Leptoseris		X				
Merulina	X					X
Montastrea	X	X			X	
Montipora	X	X			X	
Pavona	X	X	X			X
Platygyra	X	X				
Pocillopora	X	X	X	X	X	X
Porites	X	X	X	X	X	X
Psammocora		X				X
Stylophora	X	X				
Symphyllia	X					
TOTAL	**18**	**19**	**6**	**6**	**6**	**13**

Plate 5. Coral bleaching in the Vatu-i-Ra Seascape in March 2015, 3-4 weeks after cyclone Winston. ©Sangeeta Mangubhai/WCS, ©Jack & Sue Drafahl

DISCUSSION

Tropical Cyclone Winston not only altered landscapes and communities along its main pathway, but strong winds, waves and swell caused significant damage to coral reefs up to 20-30 m below the surface in the Vatu-i-Ra Seascape. Damage to coral reefs was highest in the north where the eye of the cyclone passed, and lowest in the south. There was no clear pattern to the damage, with both windward and leeward reefs equally impacted. Similar to the Great Barrier Reef, there was extensive damage to corals (especially branching and table growth forms), coral abrasion, dislodgement of large coral colonies and structural damage to the reef framework, with the level of destruction highly variable and patchy between reefs (Fabricius et al. 2008, Beeden et al. 2015).

While no data were collected on reef fish, there will likely be changes to fish species composition and biomass, especially in areas that sustained high coral and reef structural damage, like the Namena Marine Reserve. A reduction in corals and the reef structure will reduce the available habitat, which may make some species more vulnerable to predators (P. Marshall, pers. comm.). Significant decreases in density, biomass and diversity of reef fish assemblages were recorded in New Caledonia up to 3 years after Cyclone Erica (Guillemot et al. 2010), and are expected on Fiji's reefs. This will impact fisheries in the Vatu-i-Ra Seascape, which have been valued at FJ$24,097,900 (Kastl and Gow 2014).

The tourism industry in the seascape generates a gross revenue of FJ $47,240,700 annually (Kastl and Gow 2014). While the tourism industry has lost a number of their preferred sites, they have some ability to dive on new sites, or focus their dive operations on areas that survived the cyclone. However, the protection of undamaged coral reefs should be made a priority to support this important sector and its contribution to Fiji's economy.

Recovery from these types of disturbances, especially cyclones, can take decades, depending on frequency of these events, the scale and intensity of structural damage caused, and compounding anthropogenic stresses (e.g. pollution, overfishing) on coral reefs, that might hinder or slow recovery (Beeden et al. 2015). However, in additional to mechanical and structural damage, Fiji's reefs have the additional stress of coral bleaching. At the time of the surveys, the bleaching was mild and the exception of Gau was <8% on most reefs. While the SSTs have dropped 1-2°C since the cyclone, corals had not returned to normal, a month after the cyclone.

The ability of Fiji's coral reefs to persist and recover from cyclone Winston and bleaching stress, is dependent on a number of factors including the intensity, severity and frequency of the disturbance (Connell 1978, Connell et al. 1997), successful reproduction (Harrison and Wallace 1990), availability of viable larvae (Hughes et al. 2000), oceanic current dynamics influencing larval dispersal (Bull 1986, Oliver and Willis 1987), and settlement and recruitment processes (Babcock and Mundy 1996, Richmond 1997). Even mild bleaching can interrupt annual coral reproduction (Mangubhai 2007).

Given the findings of this rapid assessment, the following recommendations are made:

i. actions should be taken to minimize human-stresses to coral reefs, especially areas that are heavily impacted;
ii. protection of coral reefs that were undamaged, which may play a critical role in the recovery of adjacent impacted reefs;
iii. more comprehensive assessments should be undertaken of coastal coral reefs to document the intensity and scale of damage, to determine the potential impact to local subsistence and commercial fisheries, and inform marine resource management decisions;
iv. the data from the assessments should be reviewed in parallel with fisheries data from government-led Household Income Expenditure Surveys (HIES) and other socioeconomic surveys, to determine the impact of the cyclone on community food security and fisheries livelihoods; and
v. monitoring programs be extended to measure the recovery of coral reefs over the next 2-5 years, and ensure they are linked to management actions.

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