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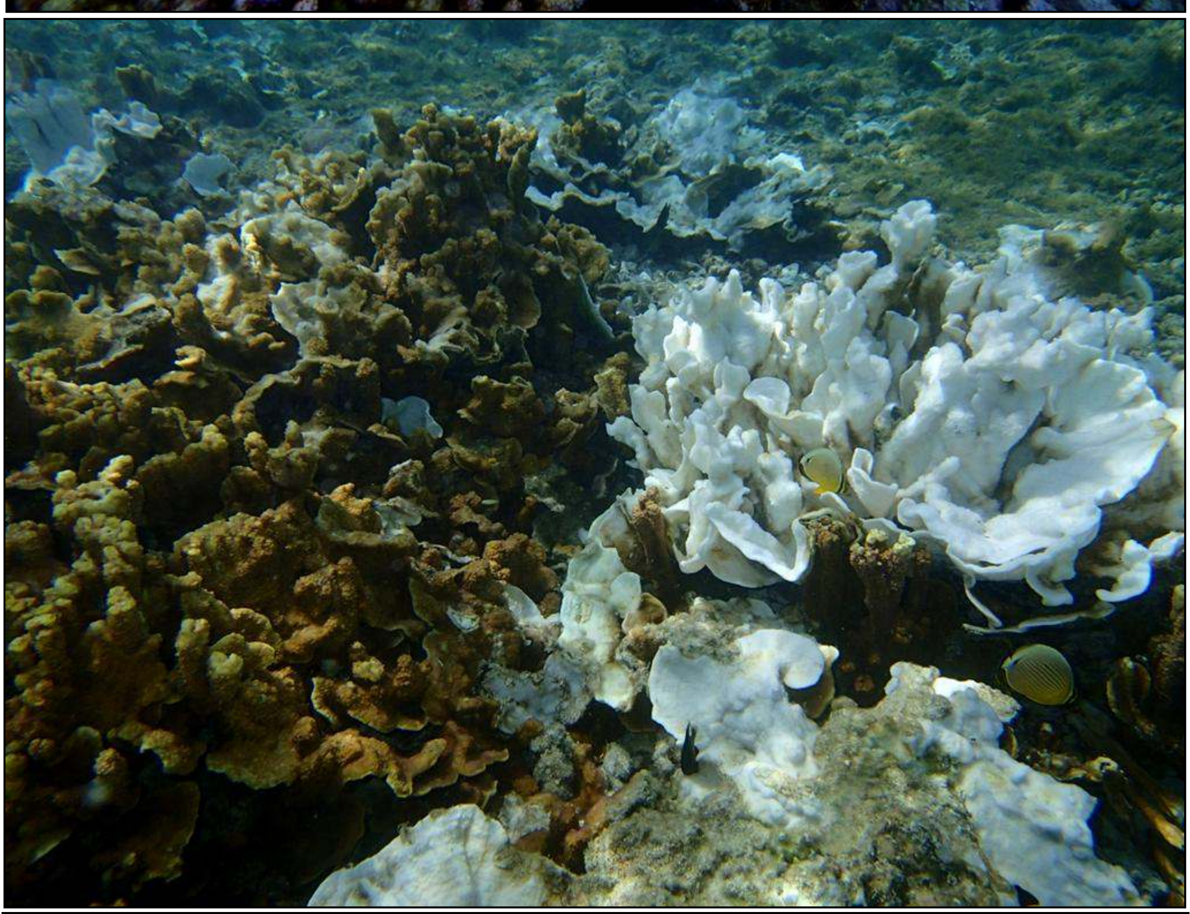
Impacts of the 2015/2016 El Niño event in the Northern Cook Islands



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Cover photo: A bleached *Pocillopora eyedouxi* on the fore reef of Pukapuka. Photo taken by Teina Rongo in 2016.

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EXECUTIVE SUMMARY

The 2015/16 El Niño event was the strongest recorded since the 1982/83 and 1997/98 events. This recent event brought unusually warm water to the equatorial Pacific, wreaking havoc on coral reef ecosystems in its path. From November 2015 to June 2016, much of the northern Cook Islands were experiencing ocean temperatures well above 30°C. In July 2016, the impacts of this event were examined on the atoll islands of Penrhyn, Rakahanga, Manihiki, and Pukapuka in the northern Cook Islands by Climate Change Cook Islands of the Office of the Prime Minister. Impacts were most visible in the marine environment with bleaching decimating over 60% of corals. Much of the bleaching was noted on fore reef habitats followed by deeper lagoon habitats while shallow reef flat habitats appeared the least affected. Of interest was the longitudinal effect of thermal stress noted in the northern group. In particular, impacts were highest on the easternmost island of Penrhyn, and least on the westernmost island of Pukapuka, a trend that may explain the susceptibility of Penrhyn to ciguatera poisoning (the only island in the north where ciguatera poisoning has been reported) and other problems such as oyster disease in the past when compared with the rest of the northern islands. This assessment noted that coral from the genus *Pocillopora,* the most common genera on the fore reefs in the northern group, were the most affected by thermal stress. Other changes noted during this event include the loss of seabirds and the decline of some important pelagic species (i.e., flying fish and tuna). While El Niño brings more rainfall to the northern group and a surplus supply of water for residents, heavy rainfall in Pukapuka created stagnant conditions in wetland plantations, which was problematic to the growth of *taro*, a staple food source in the diet of Pukapukans. With the anticipated swing of the El Niño Southern Oscillation into the cool phase of La Niña, problems such as marine disease, algal blooms, and anoxic shoaling may be expected in the lagoons of Manihiki and possibly Penrhyn, considering that such pattern has been observed in this region in the past. In addition, the anticipated La Niña event will likely bring drought conditions to the northern islands and water conservation will be critical. The impacts noted from this 2015/2016 El Niño event emphasize the need for more research in the northern islands to understand how various ecosystems respond to climate variability. In particular, we need to understand the synergy of impacts (if any) of an El Niño event and the La Niña event that follows. Certainly, the impacts noted in this 2015/2016 event hint at what we can expect in our region under a scenario of a warmer planet given the International Panel on Climate Change projections.

1. INTRODUCTION

El Niño Southern Oscillation (ENSO) is a climate phenomenon that brings unusually warm water to the equatorial Pacific, stressing and often decimating coral reefs in its path through coral bleaching. Coral bleaching is a stress response by a diversity of coral genera, often associated with a period of prolonged elevated ocean temperatures (Glynn, 1993; Goreau & Hayes, 1994; Brown, 1997; Hoegh-Guldberg, 1999). Consequently, this causes the symbiotic zooxanthellae (a photosynthetic dinoflagellate from the genus *Symbiodinium*) within the coral host tissue to be expelled, leaving the coral looking 'bleached'. In the past, records of coral bleaching in the Cook Islands (Figure 1) were mainly from the southern group (Table 1). In particular, the 1991/1992 and 1993/1994 bleaching event (associated with a mild El Niño event) were recorded in Aitutaki and Rarotonga respectively (Goreau & Hayes, 1995; Rongo *et al*., 2013). On the contrary, reports of coral bleaching in the northern group are limited to anecdotal accounts (see Table 1; Table 2 for La Niña and El Niño events since 1964). In the southern Cook Islands, coral bleaching has been reported during extreme low tides events associated with El Niño years where coral colonies on reef flats were exposed for several hours (Rongo *et al*., 2009; Rongo and van Woesik, 2013). In addition, El Niño events are also associated with increased high irradiance stress due to higher frequency of clear skies in the southern group. Consequently, such conditions have resulted in extensive bleaching in the lagoons of Aitutaki and Rarotonga. For example, a mass bleaching event was noted in the lagoon of Aitutaki in 2014 (Teina Rongo, pers. comm).

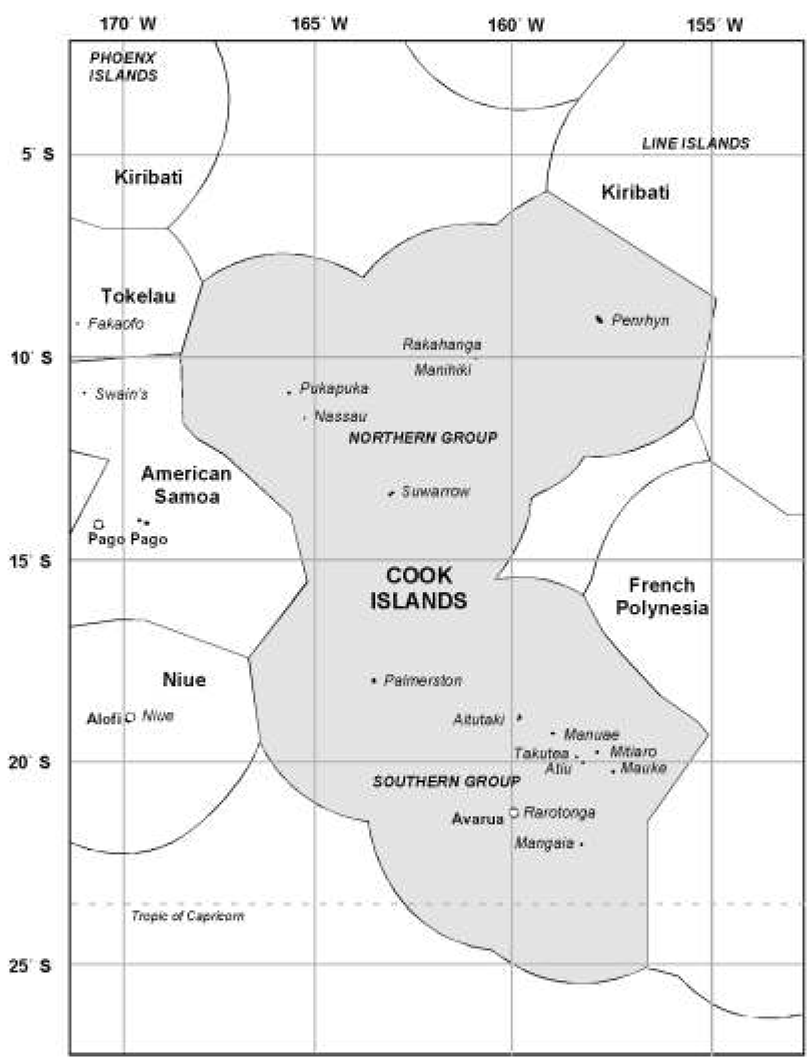

Figure 1. Map of the Cook Islands taken from http://fisherymanagement.wikia.com/wiki/Cook_Islands.

Table 1. Coral bleaching and other marine impacts associated with the El Niño Southern Oscillation noted in the Cook Islands.

YEAR	ISLAND	ENSO PHASE	IMPACTS NOTED
1982/83	Rarotonga, Penrhyn, possibly other southern and northern group islands	Very strong El Niño	Bleaching from extreme low tide; other southern and northern islands may have been affected as well, but not recorded. In Penrhyn, micro-atolls (*kava*) were exposed for weeks and massive die-off of corals, clams and oysters were noted (Manata Akatapuria, pers. comm.).
1991/92	Aitutaki, Rarotonga	Moderate El Niño	Bleaching noted on the fore reef of Aitutaki and Rarotonga (Teina Rongo, pers. obs.).
1994/95	Aitutaki, Rarotonga, Manihiki	Weak El Niño	Maximum temperature was 30.1°C in Manihiki; extensive bleaching on Aitutaki and Rarotonga fore reef habitats (Goreau & Hayes, 1995).
1997/98	Rarotonga, Penrhyn, Manikihi, Rakahanga	Very strong El Niño	Coral bleaching noted in the lagoon and reef flat habitats of Rarotonga and Penrhyn. Cyclone Martin likely degraded the reefs of Manihiki & Rakahanga.
1999/00	Manihiki	Moderate La Niña	Mass mortality of oysters in Manihiki; the cause of this massive die-off has been attributed to disease (SPC, 2002).
2001	Manihiki, Penrhyn	Moderate La Niña	Mass mortality of oysters in Manihiki; the cause of this massive die-off has been attributed to disease (SPC, 2002).
2003	Rarotonga	Moderate	Coral bleaching in the lagoon from warm and stagnant conditions. The "Titikaveka Irritant Syndrome" also occurred during this time (Rongo & van Woesik, 2013).
2006	Rarotonga	Weak El Niño	Coral bleaching noted in lagoon and reef flat habitats in Ngatangiia from extreme low tides (Rongo *et al.*, 2006).
2009	Rarotonga	Moderate El Niño	Coral bleaching noted in the lagoon and reef flat habitats (Rongo *et al.*, 2009).
2011	Manihiki	Weak to moderate La Niña	Mass mortality of oysters and other invertebrates were noted at depths < 25m because of anoxic conditions (CI News, 2012).
2014	Aitutaki, Rarotonga, possibly other southern group islands	Neutral ENSO	Extensive bleaching noted in the lagoon and reef flat habitats from extreme low tides (Rongo *et al*., 2015).
2015/16	Penrhyn, Manihiki, Rakahanga, Pukapuka, Nassau, Palmerston	Very Strong El Niño	Extensive bleaching noted on the fore reef and lagoon habitats. The impact was more severe in Penrhyn to the east and less in Pukapuka to the west. Ocean temperatures reached 35°C (Teuru Passfield, pers. comm). Bleaching on Palmerston may have been minor (Arthur Neale, pers. comm.)

Table 2. El Niño and La Niña events since 1964 (modified from http://ggweather.com/enso/oni.htm)

El Niño				**La Niña**		
Weak	**Moderate**	**Strong**	**Very Strong**	**Weak**	**Moderate**	**Strong**
1968-69	1986-87	1965-66	1982-83	1964-65	1970-71	1973-74
1969-70	1987-88	1972-73	1997-98	1967-68	1998-99	1975-76
1976-77	1991-92		2015-16	1971-72	1999-00	1988-89
1977-78	2002-03			1974-75	2007-08	
1979-80	2009-10			1983-84	2010-11	
1994-95				1984-85		
2004-05				1995-96		
2006-07				2000-01		
				2011-12		

With improved communication with the northern Cook Islands and online tools available to anticipate potential ENSO impacts (Figure 2), reports of extensive bleaching in the northern group from the recent El Niño event of 2015/2016 were noted. This El Niño event saw coral reefs across the Pacific equatorial region experiencing blistering high sea surface temperatures surpassing those reported during the 1982/1983 and 1997/1998 strong El Niño events. In late June 2016, Dr. Teina Rongo from Climate Change Cook Islands (CCCI) of the Office of the Prime Minister visited the northern group to carry out a brief assessment on the extent of coral bleaching and other impacts associated with this El Niño event.

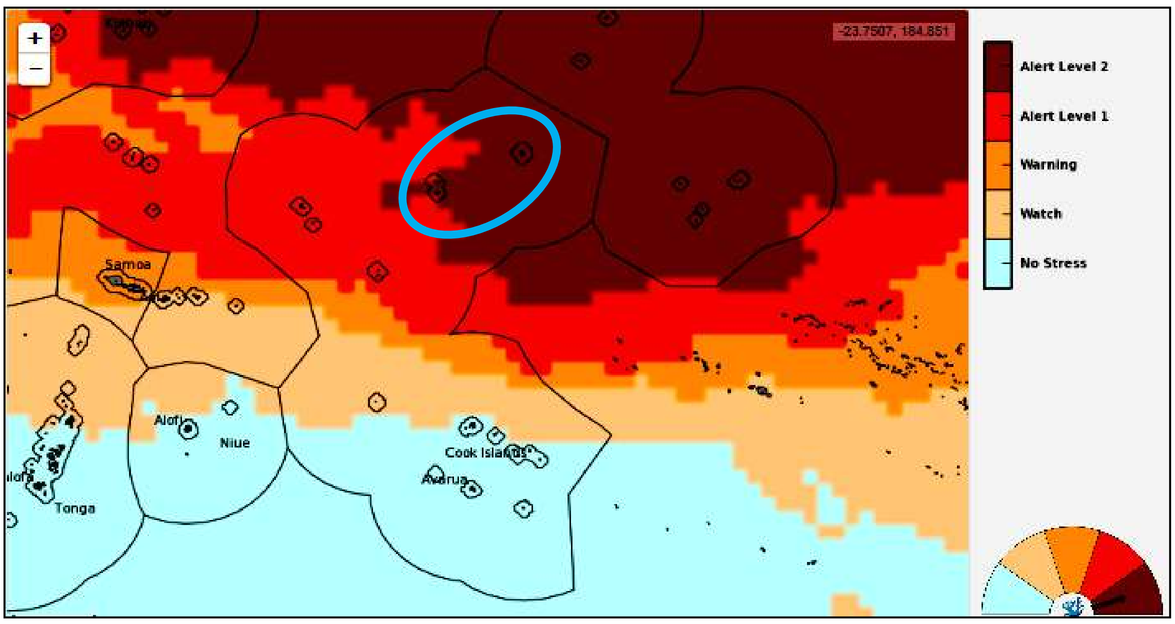

Figure 2. Four-week coral bleaching outlook map of the central Pacific region taken in January 2016 (http://cosppac.bom.gov.au/products-and-services/ocean-portal/). The Cook Islands EEZ outlined with the blue elliptical shape delineating northern group islands Penrhyn, Manihiki and Rakahanga in Alert Level 2 for coral bleaching. Pukapuka, Nassau, and Suwarrow (islands southwest of the delineation) were within Alert Level 1.

2. MATERIALS AND METHODS

From 27 June to 9 July 2016, as ocean temperatures began to cool with ENSO shifting towards ENSO-neutral conditions (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.pdf), the impacts of the recent 2015/2016 El Niño event were examined on the islands of Penrhyn, Rakahanga, Manihiki, and Pukapuka in the northern Cook Islands. Given that this visit to the northern group came a few months after the peak of this event compounded with the short amount of time spent on each island, a more detailed investigation could not be carried out. In addition, only a few sites could be visited both in the lagoon and on the fore reef of each island.

The assessment was done via snorkelling with an underwater camera to document the impacts on the reef. While much of the focus was within the marine environment, interviews with residents on each island were also conducted to understand other impacts of this El Niño event. Because no proper quantitative survey was carried out to record the severity of bleaching, caution must be taken when using the estimates provided in this report.

3. RESULTS

3.1. *PENRHYN*

Two fore reef sites and five lagoon sites were briefly examined on Penrhyn to determine the extent of coral bleaching. The assessment was carried out with the assistance of Thomas Taime, CCCI's focal point for Penrhyn, and Dr Michael White, a marine researcher living on Penrhyn. Fore reef Site 1 was located on the left side of the main passage heading out, and Site 2 further south; both sites were on the west side of the island (Figure 3). Coral bleaching at both fore reef sites were estimated to be well above 60%, with mortality occurring predominantly among the Pocilloporids (i.e., *Pocillopora meandrina and P. verrucosa*) that were overgrown by a dark layer of turf algae (Figure 4). Partially bleached corals appeared to be recovering, especially among the plate type *Montipora* species (possibly *tuberculosa)* that were one of the most common coral species on the fore reef (see Figure 4). While some large colonies of *Porites* species also died from bleaching, partial mortality was recorded on many colonies (Figure 5). *Acropora* species were rare at the two fore reef sites examined. Coral diversity was lower at Site 2 with mortality from bleaching occurring predominantly among *Pocilloporids*. Overall, these reefs seemed set to recover considering the healthy numbers and diversity of herbivores observed grazing on the reefs.

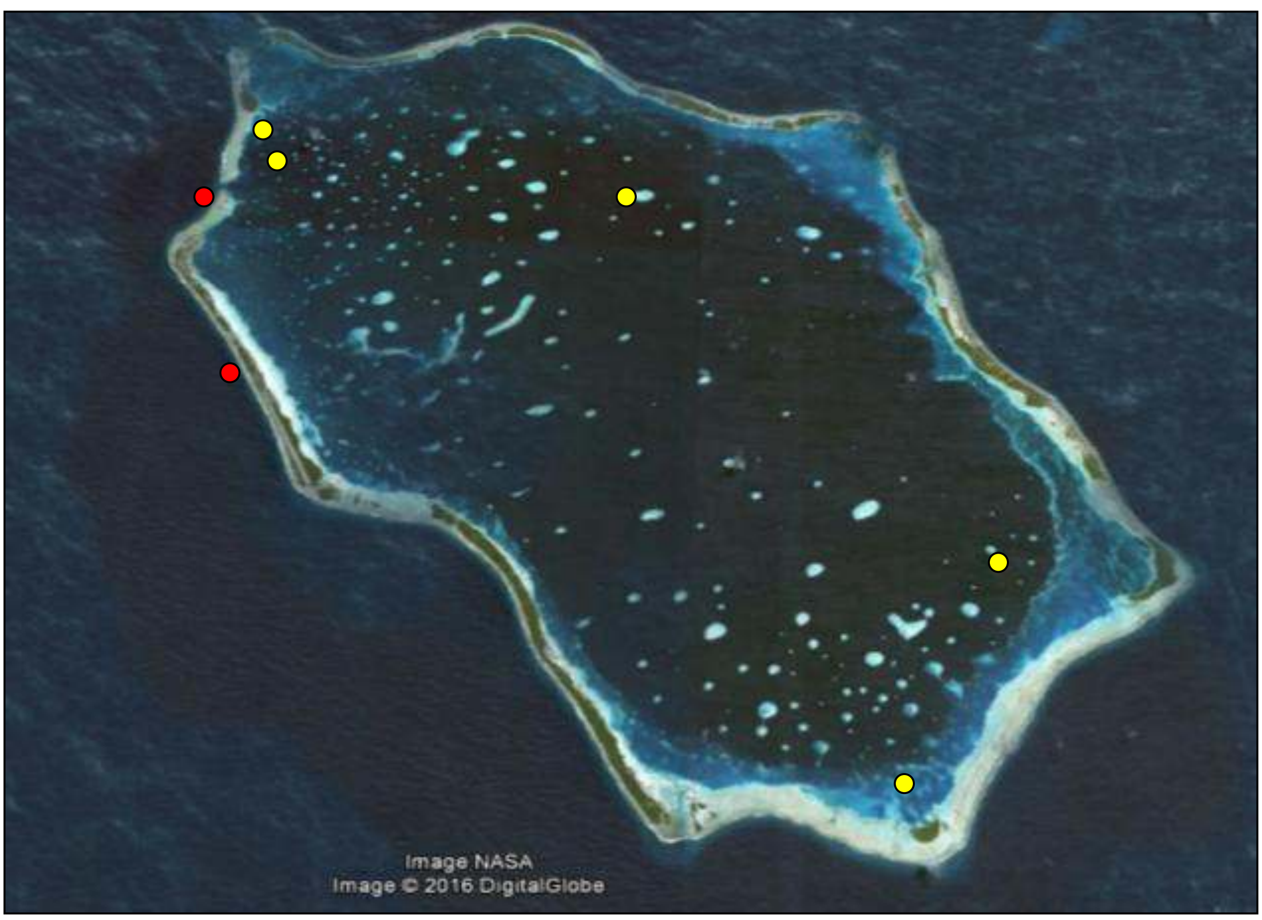

Figure 3. Google Earth map of Penrhyn with the general areas visited on the fore reef (red dots) and in the lagoon (yellow dots) indicated.

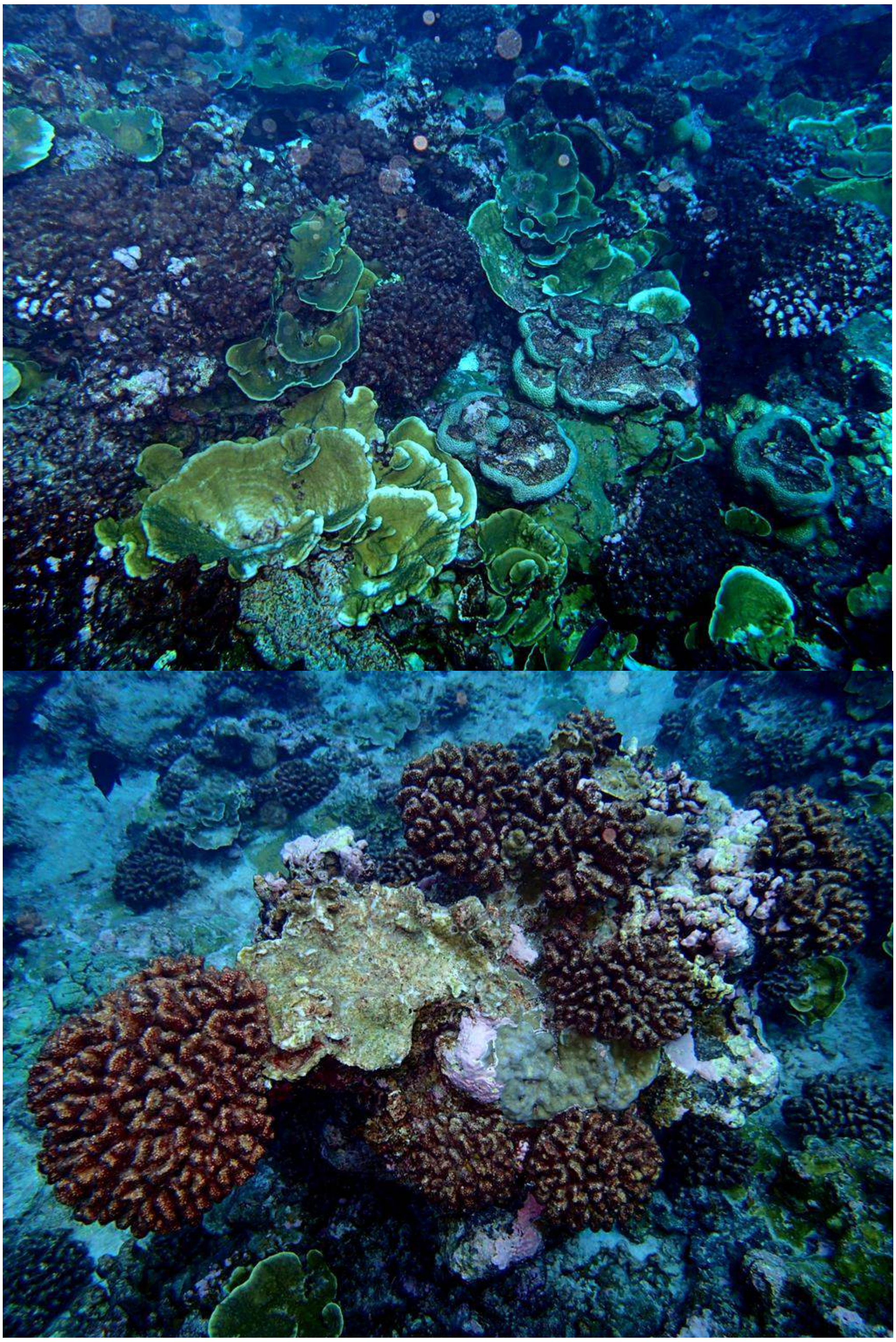

Figure 4. *Top*: partially bleached colonies of a *Montipora* species (lettuce type corals) that are likely recovering. Dark patches disbursed among the *Montipora* are dead colonies of *Pocillopora* overgrown by turf algae. *Bottom*: dead colonies of a *Pocillopora* species from the recent 2015/2016 coral bleaching event.

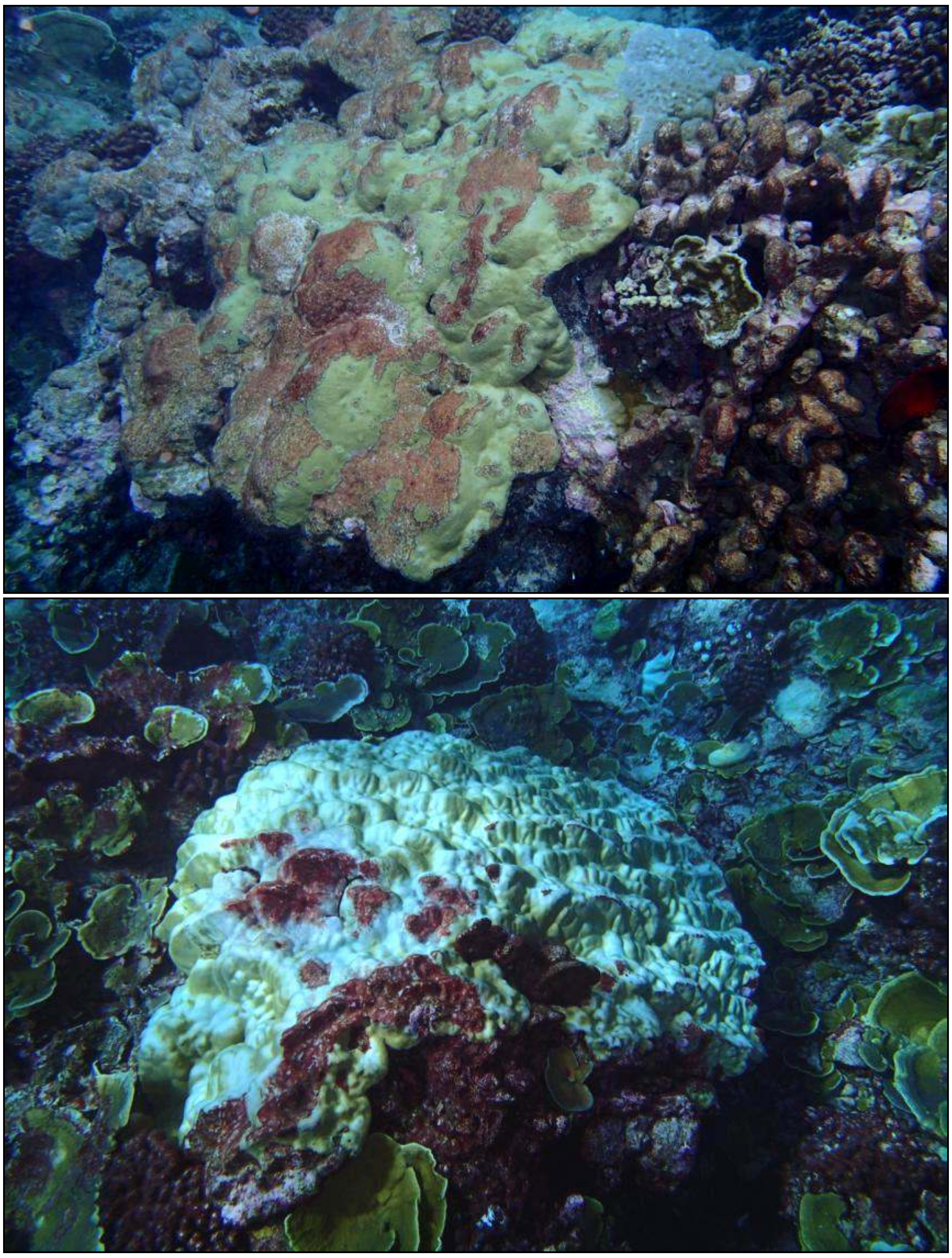

Figure 5. *Top*: dead areas on a partially bleached colony of *Porites* spp. were overgrown by a brown turf alga. *Bottom*: colony of a still-bleached *Porites*.

Dr. Michael White, a marine researcher who has been residing in Penrhyn for at least four years, accompanied the author to sites within the lagoon on the south side that he has been monitoring for some time. Lagoon sites were located near the *motu* (islet), and were predominantly back reef type communities with depths around 2 m from reef top to lagoon bottom. Corals at these sites were bleached, especially among Acroporids (mostly *Acropora* species and a few colonies of *Monitipora* species), with the majority of dead colonies on the reef top. Soft corals seem to have been affected as well, but remnants seemed to be recovering (Figure 6).

Figure 6. A recovering soft coral (*Lobophytum pauciflorum*) on a back reef habitat of Penrhyn. Coral colony at the top is *Favia rotumana,* which is one of the faviids that did not seem affected by bleaching during this assessment.

Corals that seemed less affected from bleaching were the Faviids (e.g., *Favia rotumana* [see Figure 6], *Favites* species, *Acanthastrea echinata,* and *Echinopora* species); only within this family was full recovery observed, with remnant bleached patches left. *Favia stelligera* showed partial bleaching, but areas that had bleached and died were overgrown by turf algae. Several large dead *Porites* species from the inner lagoon at depths of more than two meters experienced complete mortality from bleaching and were overgrown by turf algae as well (Figure 7). These inner lagoon habitats generally experience poor water quality and coral cover is usually low. Overall, back reef communities seemed to fair well; water visibility was excellent and conditions seemed set for recovery to occur.

Although growth of cyanobacteria was observed on shells of empty *pa`ua* (*Tridacna maxima*) that may have died from thermal stress during this El Niño event, this was noted in small patches on reef tops (Figure 8). In addition, long strands of *Caulerpa urvilleana* were observed growing alongside patch reefs in the lagoon (see Figure 8). While this species was noted on a previous trip in 2014 growing in small patches, it was difficult to determine if their cover has increased significantly as there was no prior baseline information recorded and no quantitative survey conducted during this trip. However, this species has been reported in the lagoons of atolls in French Polynesia as an important alga for trapping sediment and reducing resuspension (http://www.atolls-polynesie.ird.fr/ecorecat/ukalgues.htm).

Figure 7. *Top*: colony of *Hydnophora exesa* with a dead patch killed off by bleaching overgrown by a red alga. *Bottom*: dead colony of *Porites* covered with turf algae at a sheltered inner lagoon habitat.

Figure 8. *Top*: Cyanobacteria species growing over an area previously occupied by *pa`ua* (*Tridacna maxima*) that was possibly killed by thermal stress. *Bottom*: *Caulerpa urvilleana*, a common algae growing on the sides of patch reefs.

According to Dr. White, the number of long-range sea birds such as boobies (i.e., *Sula sula*) and frigatebirds (e.g., *Fregata magnificens*; Figure 9) observed on Penrhyn declined during this recent El Niño event. However, during this visit,, they seemed to have returned. A possible explanation is the over six months of extremely warm water around Penrhyn may have inadvertently affected pelagic fish species (food source for seabirds), and likely pushed seabirds to forage further from their nests. Regarding *maroro* (flying fish; see Figure 9), according to local fishermen, their catch used to be in the hundreds during one trip; this year, catch numbers had declined to well below 50 per trip.

Figure 9. *Left*: *Tapuku* (red-footed booby; *Sula sula*) from Penrhyn was one of the sea birds noted to have disappeared during the recent El Niño event (photo taken from http://cookislands.bishopmuseum.org). *Right*: *maroro* (flyingfish), an important pelagic food fish in the northern group noted by local fishermen to have declined in numbers during this El Niño event (photo by Teina Rongo).

3.2. *RAKAHANGA*

On 2 July 2016, two fore reef sites and two lagoon sites were visited on Rakahanga (Figure 10). Considering the scarcity of coral colonies in the lagoon, it was difficult to determine the severity of coral bleaching there. However, the few corals observed were either completely bleached or partially bleached; the most common were small colonies of *Platygyra pini* and *Montipora* species. Interestingly, small sub-massive colonies of *Porites* did not bleach. On the outer reef, quick spot dives were conducted on either side of the harbour passage. From a previous visit in 2014, coral communities were observed to be healthy, and it was evident that the recent bleaching event likely killed an estimated 80% or more of the corals on the fore reef. This was predominantly among *Pocillopora verrucosa* and *P. meandrina*, the two most dominant species on the fore reef slopes of Rakahanga (Figure 11). Most of these colonies were around 20 – 40 cm in diameter. Coral mortality on the shallower reef slopes (<10 m; where corals were abundant) was high while those at deeper slopes (>10 m; where corals were depauperate) was low, and there were some colonies still bleached during the visit.

Figure 10. Google Earth map of Rakahanga with the general areas visited on the fore reef (red dots) and in the lagoon (yellow dots) indicated.

Figure 11. Fore reef of Rakahanga dominated by the genera *Pocillopora* (two examples of live colonies outlined in yellow); photo taken by Teina Rongo in 2014. White areas in this photo are predominantly coralline algae. All Pocilloporids were bleached during this 2016 visit.

3.3. *MANIHIKI*

Similar to Rakahanga, coral bleaching on Manihiki (Figure 12) was more prevalent in the Pocilloporid family (e.g., *Pocillopora verrucosa, P. Meandrina, and P. eyedouxi*). Most corals killed by bleaching were at depths less than 10 m, which were overgrown by turf algae during the visit; partially bleached corals were largely observed at deeper sites (>10 m). Although coral colonies on reef flat habitats seem unaffected by bleaching during the visit, it was difficult to determine whether they did bleach and have recovered before the visit or did not bleach at all (Figure 13). Coral growth forms on the reef flat tend to be encrusting as opposed to the massive types in the lagoon and fore reef habitats. In the lagoon, several *Porites* corals were observed to have an interesting pattern of partial bleaching, with bleaching only occurring on the lower portion of the colony (Figure 14). *Plerogyra sinuosa* (Figure 15), a rare coral in the Cook Islands only recorded in the lagoon of Manihiki to date, were among the many corals that showed partial bleaching.

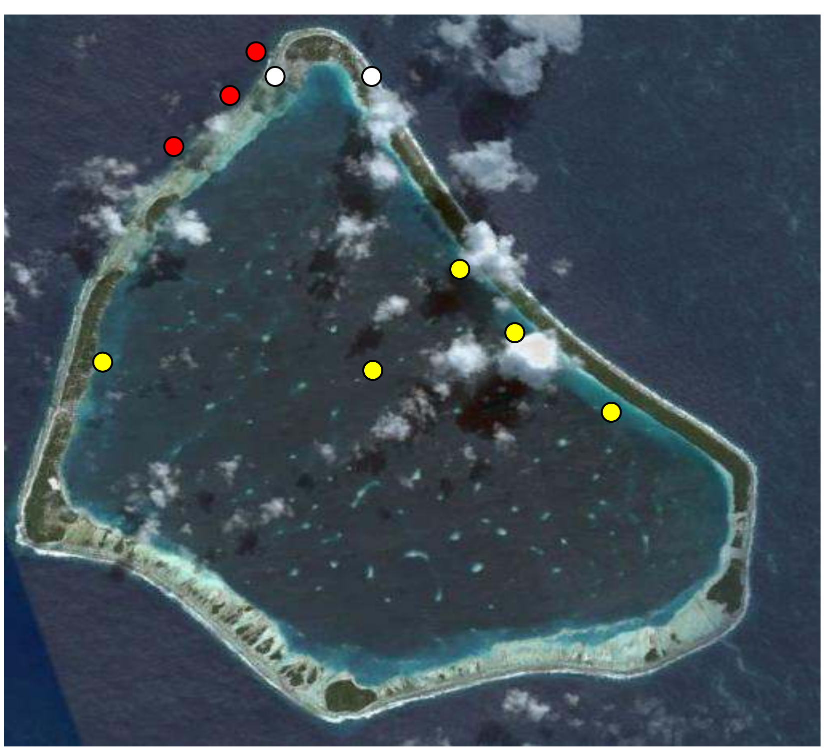

Figure 12. Google Earth map of Manihiki indicating the general areas visited inside the lagoon (yellow), reef flat (white), and on the fore reef (red).

Figure 13. Encrusting colonies of a *Porites* species located on the reef flat that were unaffected by bleaching. These reef flat/reef crest communities often experience extreme climate conditions. Photo taken by Teina Rongo on the windward side of the island along the Manihiki runway at a depth of < 1 m.

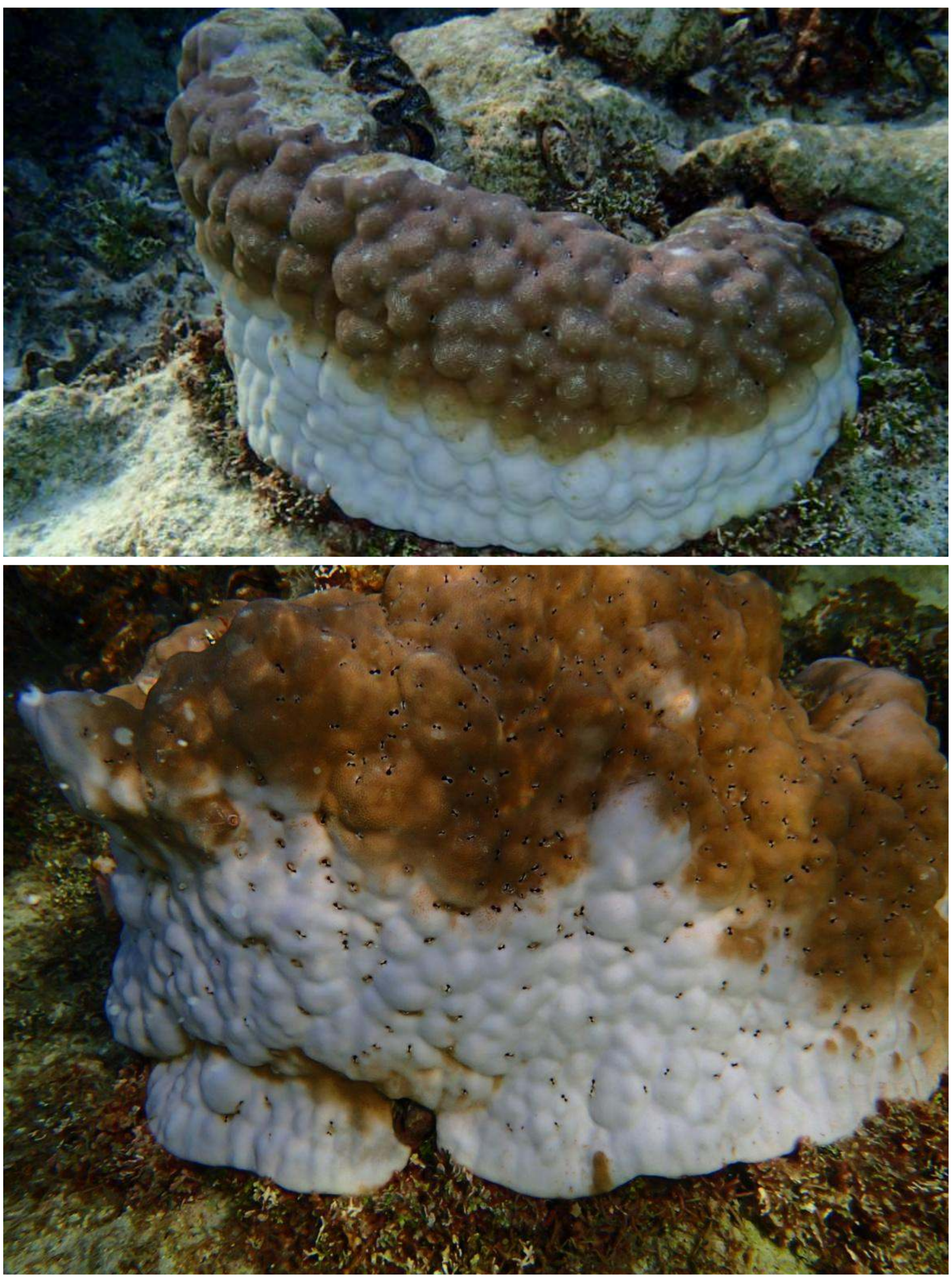

Figure 14. Top and bottom are two massive colonies of *Porites lutea* from the Manihiki lagoon showing partial bleaching; the upper section of both colonies seem less affected by bleaching, while the lower section was bleached. A similar pattern was seen on other *Porites* colonies elsewhere in the lagoon. Photo taken by Teina Rongo on a coral micro-atoll in the middle of Manihiki lagoon at a depth of < 2 m.

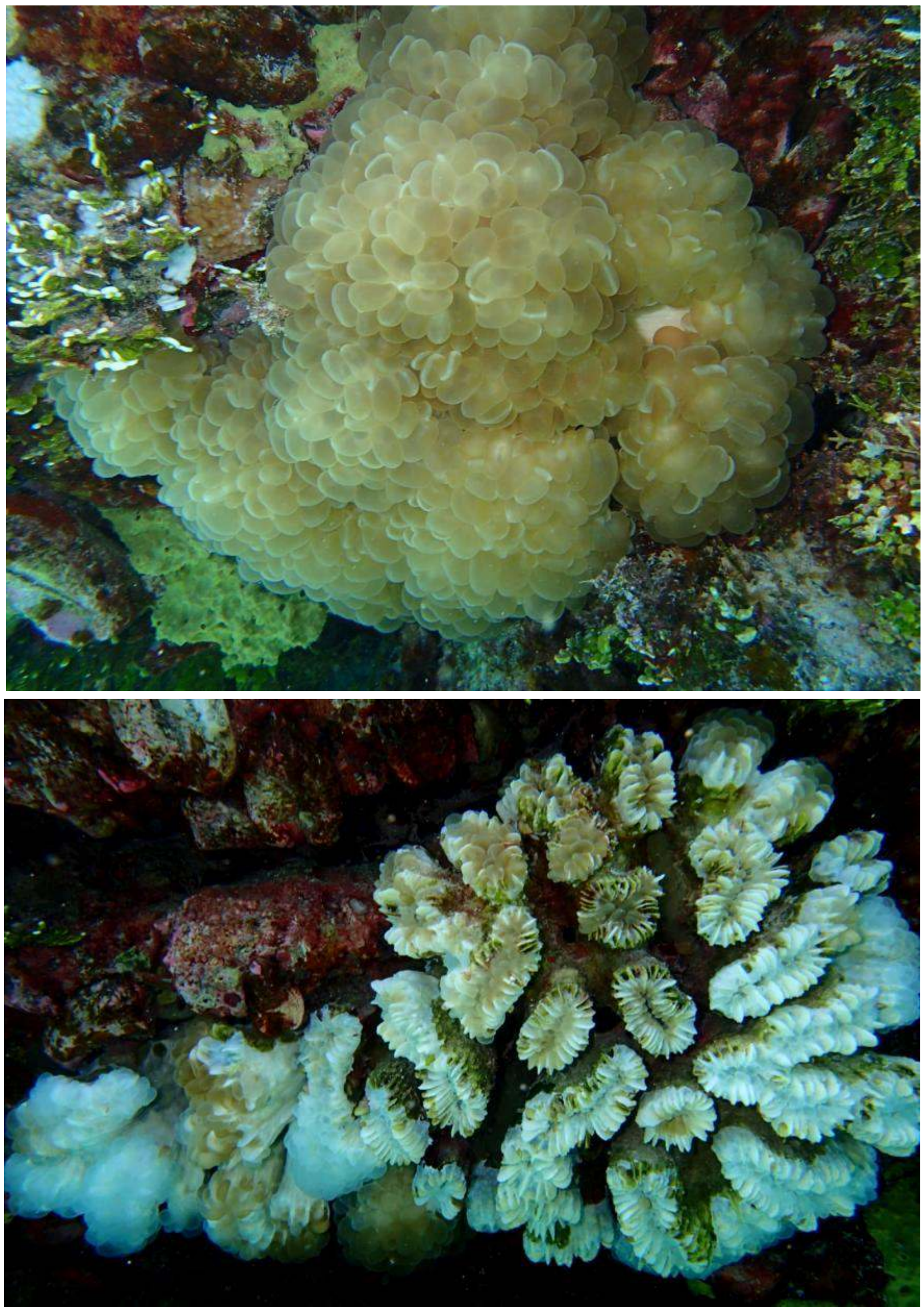

Figure 15. *Top*: bubble coral (*Plerogyra sinuosa*), a rare species in the Cook Islands only recorded in the lagoon of Manihiki to date, with coral polyps extended. *Bottom*: partially bleached *P.sinuosa* with corallites exposed. Photo taken by Teina Rongo from a *kava* (micro-atoll) in the middle of Manihiki lagoon at a depth of 3 m.

Montipora (*kaiva*) is one of the most dominant species of coral found on the back reef along the eastern side of Manihiki. Although large areas of *kaiva* were bleached (Figure 16), they appeared to be recovering in some areas. Bleaching in *pa`ua* (Figure 17) was still evident on a few at sites visited in the lagoon, but they may be recovering. Because of the limited time available, the impact of bleaching on *pa`ua* was not quantified. What was evident in Manihiki was that recruitment of *pa`ua* is limited on the reefs; only the adults were found on the reef substrate. Interestingly, *pa`ua* recruits were observed on the buoys of oyster lines (Figure 18). Factors such as sedimentation may be influencing the recruitment of *pa`ua* and likely other sessile invertebrates on reefs in Manihiki (Rongo and Dyer, 2014).

Figure 16. *Top*: *Kaiva* corals (*Montipora* spp.) bleached alongside an unbleached colony. *Bottom*: close up of a bleached *kaiva* with the coral polyps visible in purple. Photo taken by Teina Rongo on the back reef on the eastern end of Tukao, in the passage entering the Tukao Harbour at a depth < 2 m.

Figure 17. A partially bleached *pa`ua* (*Tridacna maxima*) that may be recovering, regaining coloration from the periphery. Photo taken by Teina Rongo from the inner lagoon habitat on a *kava* at depth of 1m.

Figure 18. Numerous recruits of *pa`ua* (*Tridacna maxima*) on a buoy. Photo taken by Teina Rongo from a black pearl farm line at a depth of 7 m.

3.4. *PUKAPUKA*

Seven locations were examined on Pukapuka; two on the fore reef and five in the lagoon (Figure 19). While extensive bleaching was noted on Pukapuka, the severity was not to the extent observed on the other islands. In particular, not all *Pocillopora* species were killed by bleaching; some were unaffected and some showed partial and complete bleaching, but chances of recovery seemed high. Corals that were bleached included the following: *Porites* spp., *Leptastrea purpurea, Montipora floweri*, and *Stylophora pistillata* (Figure 20). Interestingly, two species of coral noted in the Pukapuka lagoon have not been reported elsewhere in the Cook Islands (e.g., *Stylophora pistillata* and *Pavona decussata*, with the latter unaffected by coral bleaching). Considering that Pukapuka is the westernmost island in the Cook Islands and the above-mentioned corals are common in the western Pacific, this information may be important to understand the distribution of marine species across the region.

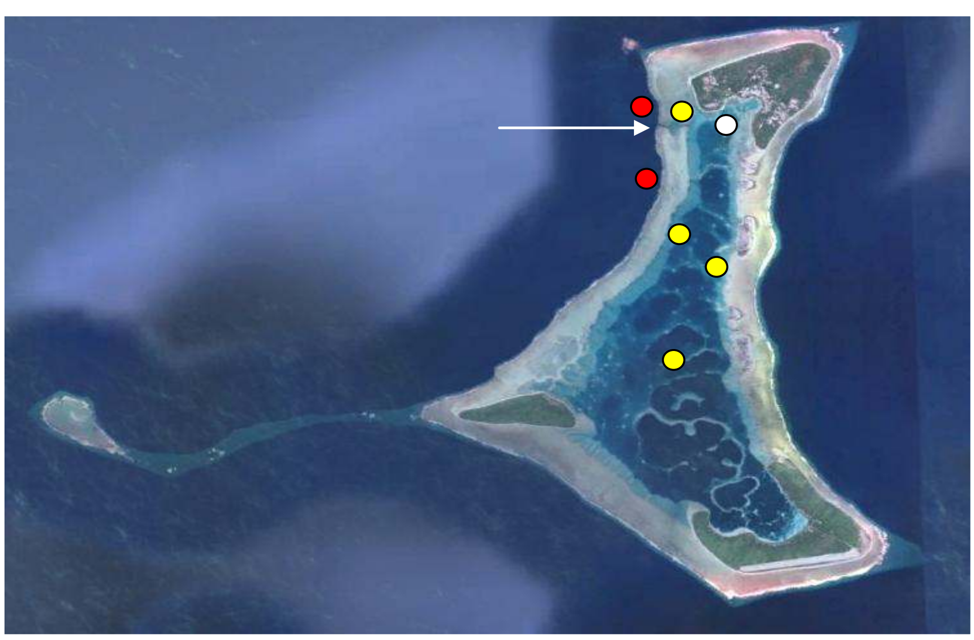

Figure 19. Google Earth map of Pukapuka with the general area of sites visited in the lagoon (yellow dots) and fore reef (red dots) indicated. White dot indicates lagoon site in front of the main settlement on Pukapuka where unique coral assemblages were noted. Arrow indicates passage to the main harbour.

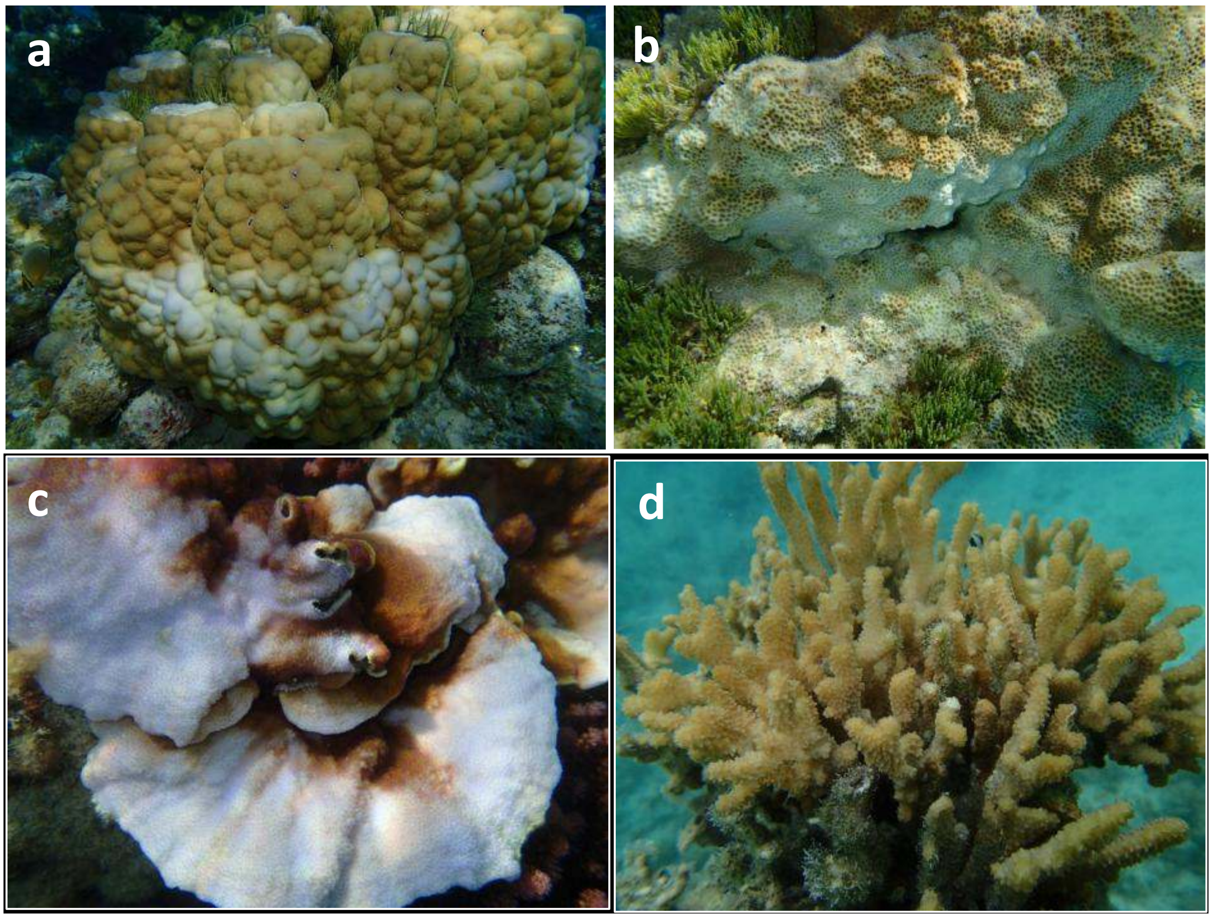

Figure 20. Partially bleached coral observed on Pukapuka: a) *Porites* spp., b) *Leptastrea transversa*, c) *Montipora floweri* (common in the harbour passage; indicated by arrow in Figure 19), d) *Stylophora pistillata* (this coral is not reported anywhere else in the Cook Islands). Photos taken by Teina Rongo.

Lagoon coral communities seemed more resistant to bleaching. Large coral communities found in front of the harbour area (see white dot in Figure 19) were healthy colonies of *Pocillopora damicornis*. *Pocillopora damicornis* tend to have high tolerance to thermal stress and are known to be weedy in sheltered lagoon habitats. In addition, *Pavona decussata* (a coral species not reported elsewhere in the Cook Islands), was also abundant at this same site and seemed unaffected by bleaching; perhaps this species has similar thermal tolerance as *P. damicornis*.

On Pukapuka's fore reef, bleaching was less extensive when compared with observations from Penrhyn, Rakahanga, and Manihiki (Figure 21). While some species of *Pocillopora* were killed by bleaching, those that were still bleached during the visit were likely to recover. In addition, many colonies of *Pocillopora* at the two fore reef sites visited did not bleach (Figure 22).

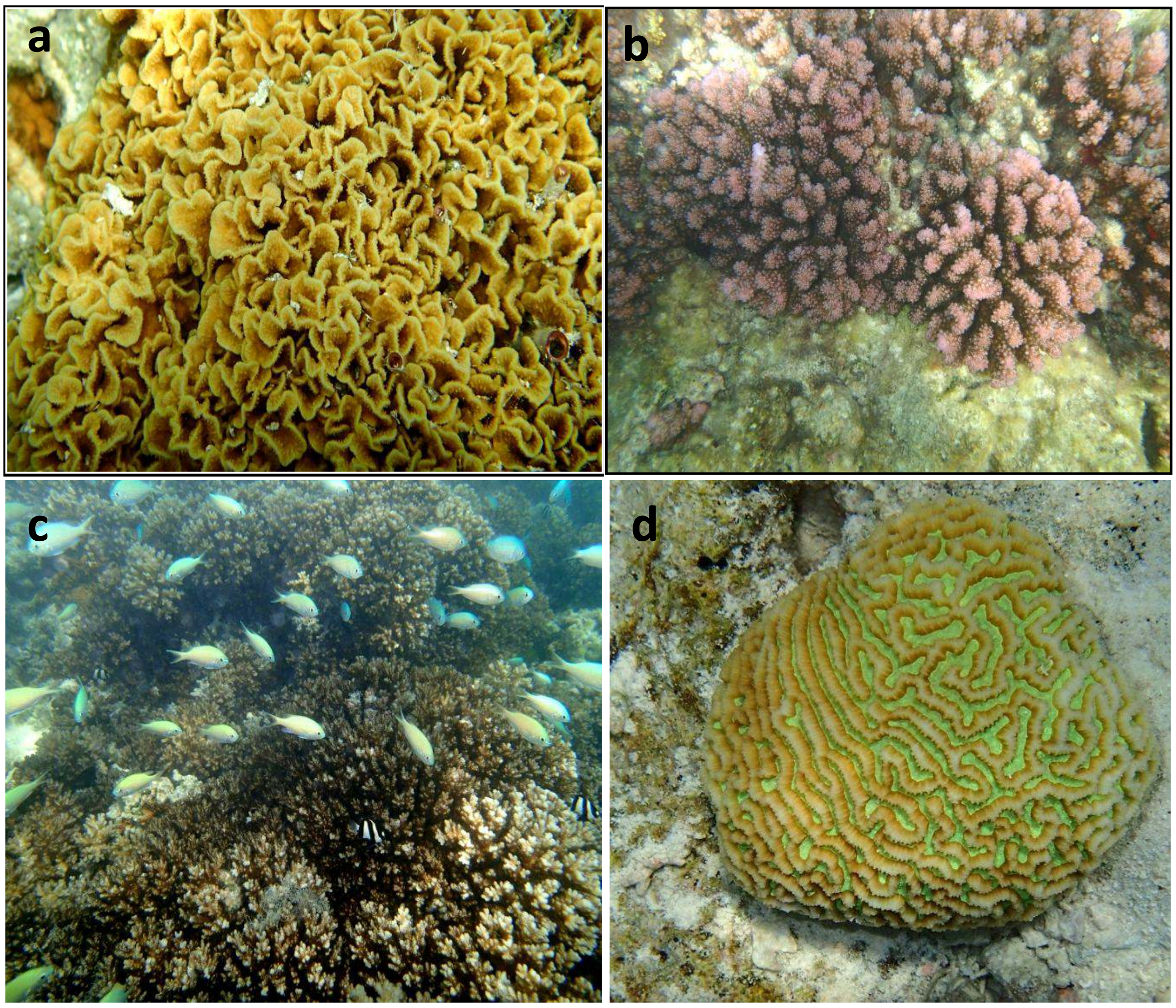

Figure 21. Coral colonies observed to have survived thermal stress associated with the 2015/2016 El Niño event: a) *Pavona decussata*, within the Cook Islands has only been reported in Pukapuka to date and a common species in some areas in the lagoon, b) *Pocillopora verrucosa*, a very common coral in the Pukapuka main passage that did not show signs of bleaching, c) *Pocillopora damicornis*, a common coral near the harbour area, were unaffected by bleaching, and d) *Platygyra daedalea*l, a small submassive coral that did not bleach. Photos taken by Teina Rongo.

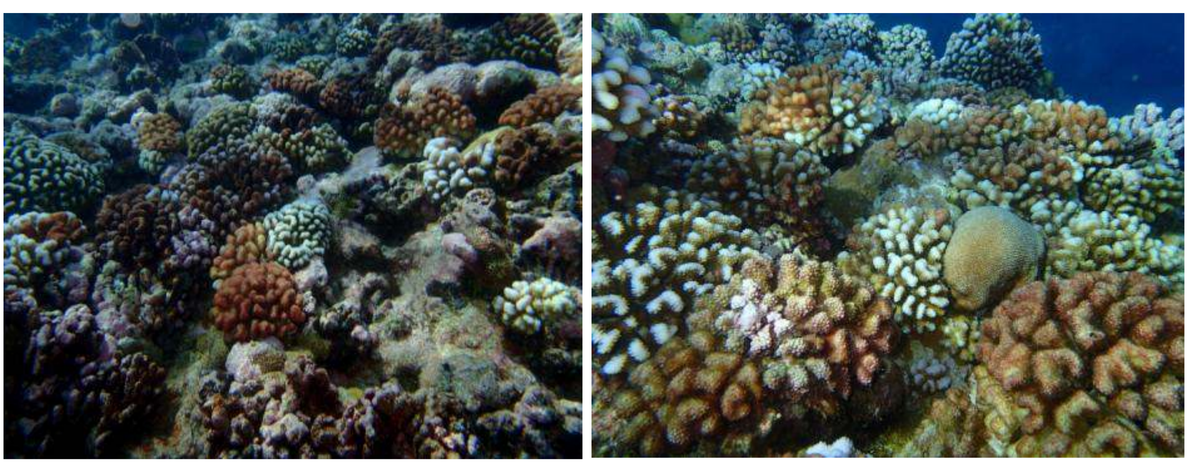

Figure 22. Differential bleaching on the fore reef slopes of Pukapuka. While some coral species have died from bleaching, others were partially bleached with a likely chance of recovering. Unlike the fore reef slopes of Penrhyn, Manihiki, and Rakahanga where mortality of *Pocillopora* corals were high, there were numerous *Pocillopora* species noted on Pukapuka that did not bleach or were only partially bleached. Photos taken by Teina Rongo in 2016.

Although heavy rainfall associated with the recent El Niño event brought excess water to the residents of Pukapuka, this has created problems to *taro* plantations (Figure 23). Stagnant conditions during flood events can cause *taro* roots to spoil. During the visit, the women of Pukapuka, who are traditionally responsible for planting *taro*, were concerned about this prolonged wet period ruining the crop in light of *taro* being a very important staple in the Pukapukan diet.

Figure 23. *Top:* taro plantations inland in Pukapuka. *Bottom:* flooding of swamp areas from heavy rainfall associated with the recent 2015/2016 El Niño event was problematic for *taro* plantations on Pukapuka because stagnant conditions can affect the growth of the *taro.* Photo taken by Teina Rongo.

4. DISCUSSION AND CONCLUSION

The 2015/2016 El Niño event was perhaps the strongest recorded since the 1982/1983 and 1997/1998 events. In the Cook Islands, the impact of this El Niño event was most evident in the marine environment of the northern group with extensive coral bleaching observed on all islands visited. Severity of the bleaching from thermal stress appeared to decrease from East to West (i.e., more severe in Penrhyn, Rakahanga, and Manihiki, and less severe in Pukapuka), particularly on fore reef slopes. The magnitude of this bleaching event in the northern group may be attributed to the following: 1) low annual temperature variability in this region compared with the southern group (e.g., average temperature ranging from 25.3°C to 30.5°C in Penrhyn compared with Rarotonga, which ranges from 19.1°C to 29.5°C; Baldi et al., 2009), 2) proximity to the Inter-Tropical Convergence Zone (ITCZ) (i.e., northern islands are located on the periphery of the ITCZ where significant temperature changes that would affect the northern group may only occur during very strong El Niño events), 3) low frequency of very strong El Niño events (the last El Niño event of this magnitude was noted during the 1997/1998 event, which was 18 years ago), and therefore any adaptive traits in coral populations to cope with thermal stress would not have been maintained, and 4) similarity of species composition and diversity – the same coral species were bleached on all the islands.

Coral bleaching was especially severe on the fore reef slopes of the northern islands examined. The least affected communities were within shallow reef flat habitats. These differences may be associated with the varying degree of temperatures experienced in these habitats. For example, temperatures vary less on fore reef slopes compared with the high variability experienced on reef flat habitats. Thus, reef flat habitats are more resilient to extreme thermal stress events than their fore reef counterparts. This was consistent with observations noted on many of the southern islands (e.g., Aitutaki, Rarotonga, Mangaia, and Mitiaro), where coral communities on reef flat habitats were more resilient to thermal stress associated with extreme low tide and high irradiance (Rongo and Dyer, 2014).

Corals from the genus *Pocillopora* were the most common coral on the fore reefs in the northern group and most affected by thermal stress. With the exception of Pukapuka, mass mortality of corals in the genus *Pocillopora* (i.e., *P. verrucosa, P. meandrina,* and *P. eyedouxi*) from bleaching was observed on the fore reef. *Pocillopora* colonies ranged from 10 – 20 cm in radius, and assuming a growth rate of 1 cm/year, the last major disturbance of this magnitude was less than 20 years ago and within the timing of the 1997/1998 El Niño event. Although Cyclone Martin may have degraded the reefs of Manihiki and Rakahanga in late October/early November 1997, it is likely that surviving corals may have been killed by the subsequent thermal stress associated with the 1997/1998 El Niño event (from December 1997 to April 1998).

While most *Pocillopora* species are brooders with life history characteristics of high recruitment (Richmond & Hunter, 1990), being able to self-fertilize (Brazeau et al, 1998; Carlson, 1999), and the propensity to settle near parental colonies (Harrison and Wallace, 1990) – it is likely that they will remain the most dominant genera on the fore reefs in the northern group. However, given the negative effect of thermal stress on this genera where mass die-off occurs, it is unlikely that any form of resilience to thermal stress will be acquired. Provided that very strong El Niño events remain infrequent and *Pocillopora* maintain their dominance on these reefs, we may continue to see mass die-offs of this genus during very strong El Niño events in the northern group.

Partial bleaching within some coral species indicated that colonies host multiple clades of the symbiotic microalgae *Symbiodinium* with different tolerance levels to thermal stress (Rowan, 2004; Berkelmans and van Oppen, 2006). For example, several species of massive *Porites* were observed in Manihiki lagoon with bleaching occurring only at the lower portion of the colonies (see Figure 14), indicating their differential exposure to high irradiance stress. It is likely that the thermally tolerant *Symbiodinium* (i.e., clade D) are dominant on the upper sections of colonies, while the less tolerant *Symbiodinium* (i.e., clade C) are distributed on the lower sections. On the contrary, *Porites* found in shallow reef flat habitats (see Figure 13) did not bleach. Given the encrusting growth form of *Porites* on the reef flat, the distribution of thermal stress to the surface of individual colonies should be even, and the likelihood of the thermally tolerant *Symbiodinium* (clade D) to dominate is high. Perhaps research on clade types found in coral communities among the different reef habitat areas may confirm these observations.

More information was needed to understand the impact of this current El Niño event on the *pa`ua* population. Though seemingly only adult clams were affected by bleaching on the reefs, it was difficult to determine whether new recruits were affected because of their low numbers at present. Rongo and Dyer (2014) have suggested that low recruitment numbers of *pa`ua* on Manihiki and possibly Penrhyn were the result of high sediment movement experienced on the reef substrate. In support, dense *pa`ua* recruits were observed on submerged buoys of oyster lines (see Figure 18) where sedimentation is likely minimal. Interestingly, new recruits on these buoys seemed unaffected by bleaching, which could well be the result of their size. For example, Nakamura and van Woesik (2001) showed that juvenile coral colonies were able to survive thermal stress because they host green fluorescent proteins that protect them from the detrimental effects.

The die-off of *pa`ua* during this recent 2015/2016 thermal stress event was considered a loss of a food source to residents. As thermal stress can be predicted months prior, it was proposed by community leaders on Penrhyn that *pa`ua* should be harvested before any predicted bleaching event. However, under stressful circumstances marine organisms tend to spawn, and harvesting during this time may compromise any chances of recovery of *pa`ua* populations in the long term. In fact, current harvesting of *pa`ua* on the reefs may need to be better managed given the already limited recruitment noted on these islands (Rongo & Dyer, 2014).

Other changes noted during this 2015/2016 El Niño event included the loss of seabirds (on Penrhyn and Pukapuka) and the decline of some important pelagic species (i.e., flying fish and tuna species noted on Penrhyn, Manihiki, and Rakahanga). Ocean temperatures were reported above 30°C during the peak of the bleaching event on Penrhyn (Michael White, pers. comm.). Based on the Australian Government Bureau of Meteorology's regional ocean temperature map (Figure 24), Penrhyn experienced temperatures well above 31°C for six months. Warmer oceans can lead to ocean stratification and may affect the availability of food to pelagic fish species. Consequently, this may have forced both pelagic species and larger seabirds (e.g., frigatebirds and boobies) to migrate further from the islands in search of food in cooler areas. While El Niño events generally bring more rain for the northern group, in Pukapuka however, heavy rainfall created stagnant conditions in the swamp lands because of poor drainage, which subsequently caused problems in *taro* plantations.

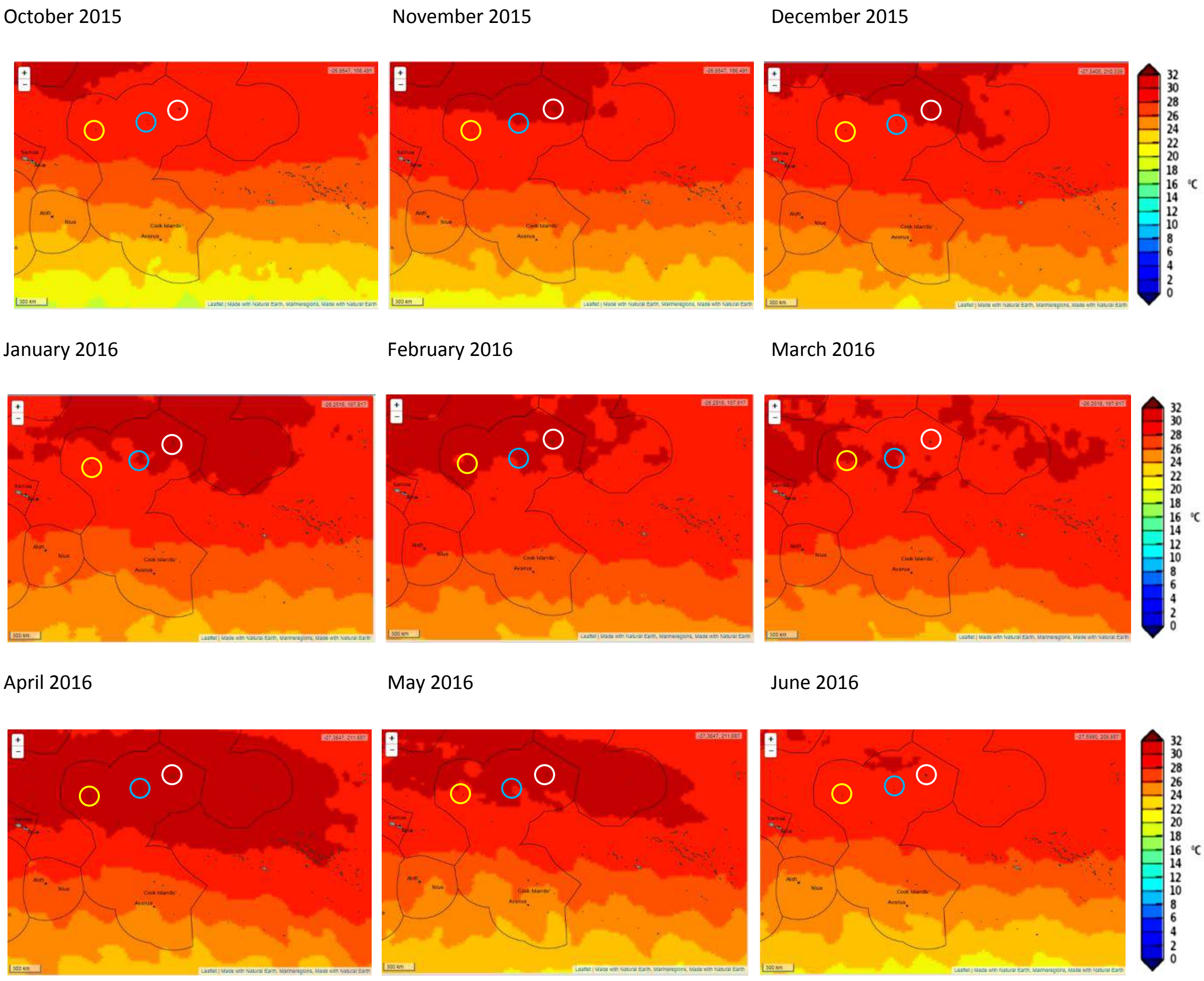

Figure 24. Australian Government's Bureau of Meteorology: monthly mean temperature map for the region from October 2015 to June 2016 (taken from http://cosppac.bom.gov.au/products-and-services/ocean-portal/). The white circle indicates Penrhyn, the most affected island by the 2015/2016 El Niño event, which was bathed in temperatures well above 30°C for six months. Blue circle indicates Manihiki & Rakahanga, and yellow circle indicates Pukapuka. Note that temperatures are returning to normal by June 2016.

The last major El Niño event occurring in 1997/1998 (coral bleaching may have occurred as well) was associated with Cyclone Martin, which degraded the reefs of Manihiki. It is concerning that a degraded reef from extensive bleaching may harbour pathogens, and with the right conditions, may cause disease outbreak among marine species. Interestingly, in 2000 and 2001, mass mortality of oysters on Manihiki and Penrhyn respectively was noted during the La Niña event from 1999 – 2001. Similarly in French Polynesia, mass mortality of oysters occurred in 1985 in the Gambier Islands followed by a number of atolls in the Tuamotu group (SPC, 1985; Chagot *et al*., 1993); these events also occurred during a La Niña period (1983 – 1985) that followed the 1982/1983 very strong El Niño event.

With a degraded reef, limited flushing in the lagoon (Callaghan et al., 2006), and climatic conditions that are normally associated with a La Niña event beginning to emerge in the northern group (i.e., clear skies, high irradiance stress, and calm conditions), it is likely that conditions are favourable for pathogens and algal proliferation, which can lead to disease outbreak and anoxic conditions respectively. In support, mass mortality of oysters noted in Manihiki in 2011 (CI News, 2012) was attributed to the shoaling of a dense layer of an anoxic water mass during a La Niña period (2010 – 2012). During this recent visit in July 2016, it was suggested that the anoxic water mass noted in 2011 is now sitting near the bottom of the lagoon at around 40 – 50 m (Peter Nielsen, pers. comm.). Considering that ENSO is currently swinging into a La Niña phase, it is likely that a similar problem may recur in Manihiki in the coming year or two.

Certainly, the impacts noted from this 2015/2016 El Niño event provides a snapshot of what to expect in our region with the projected warmer planet given the Intergovernmental Panel on Climate Change projections. While a clean-up plan is currently in place for Manihiki lagoon to improve flushing and circulation by removing abandoned oyster lines and accumulated debris since Cyclone Martin in 1997, it is important to consider that the health of the lagoon is currently compromised and any added stress may exacerbate the problem. On the contrary, knowing that problems could potentially occur during the upcoming La Niña event, perhaps the clean up should proceed according to plan. Whatever decision is pursued, the findings of this assessment certainly need to be considered.

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