Holistic Approach to Reef Protection (HARP) Phase II: Assessment of Bleaching

Dhigu (South Malé Atoll) and Kihavah (Baa Atoll), Maldives

Field Report

April 2016

Andrew Bruckner
Georgia Coward
Stefan Andrews

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Executive Summary

From April 7- May 3 2016, three HARP marine biologists completed 1) benthic, fish and photo-transect assessments of 10 permanent sites, 2) established additional photo-transects on 7 of the 10 sites, 3) collected coral samples from tagged colonies, 4) conducted a crown of thorns starfish removal on one infested reef near Dhigu, 5) undertook a pilot coral mariculture experiment, 6) tagged over 150 colonies of two species to monitor survival from bleaching, 7) conducted seven educational seminars and lectures for staff, guests and a high school group, and 8) met with the Maldives Minister of Education to begin discussions on an educational program and curriculum for local Secondary School students.

The scientists monitored the progression of coral bleaching and associated increases in water temperatures over the duration of the mission. Bleaching first began in early April, with most colonies turning pale or acquiring vivid fluorescent pigmentation and only the most sensitive species showing full (white) bleaching. By the end of the mission, severe bleaching had occurred on all reefs, including fore reef, channel reef and lagoonal patch reef communities and 70-90% of the colonies were completely white. A portion (approximately 10%) of colonies of the same species that bleached appeared to remain fully pigmented and 10% of the colonies turned a fluorescent pink, purple, blue, yellow or green. Bleaching was most severe in very shallow water (0-3 m depth), with >90% of the colonies of all taxa (massive, plating and branching corals) turning completely white. Bleaching occurred to depths greater than 30 m.

Partial colony mortality was first noted among *Pocillopora* colonies in early April, with the death and algal colonization of branch tips. By the end of April, many of the table corals (*Acropora cytherea*) and staghorn corals also began dying and entire Pocillopora colonies died. Golden-brown colored filamentous algae rapidly colonized the dead coral skeletons. Other species showed some partial mortality, although this only affected a small proportion of colonies. The one dominant massive boulder coral (Porites) showed variable bleaching, with only a small percentage of colonies turning completely white (20-30%) and many more becoming pale or colored blue, pink, yellow of green (40-50%). Very few (<5%) of these had died by the end of the mission. The shallow population of staghorn coral surrounding the Water Villas sustained very high mortality, with 8-0% of the colonies bleaching in early April and dying by April 29, 2016, with skeletons becoming quickly covered in algae.

Water temperatures climber to higher than 30°C by early March and 31°C by early April and remained between 30.5 – 31.8°C until at least May 3, 2016. A brief respite occurred following heavy rainfall on April 22, 2016, but calm doldrum-like conditions, full sunshine and warm water temperatures returned within two days and persisted until the onset of the summer monsoon on May 5, when skies became more cloudy, periodic

rainfall, stronger winds and choppy seas. Unnaturally high water temperatures occurred from the surface to 30 + m for all of March and April.

Coral fish communities showed some interesting trends, especially in Kihava. In addition to the documentation of new species, a prominent settlement of juvenile fishes was noted in most sites, especially among planktivores. Unusually large schools, consisting of thousands of fish <5 cm in diameter were observed on most sloping reef environments.

The existing "Adopt a Coral Frame" program was negatively affected by the unusually warm water conditions, with all of the corals becoming completely bleached by mid April and nearly half dying. Several new frames were established during the period of peak high water temperatures, and very few of the newly attached coral fragments were still alive by the end of April.

A successful crown of thorns starfish (COTS) removal effort was undertaken on the one remaining reef near Dhigu that was still infested with COTS. Over 430 starfish were removed over two days. This was important as these COTS were feeding on the few remaining (bleached) corals on this reef, and once they consumed these corals they were likely to move to an unaffected reef.

A total of 50 groups of branching corals of two species (over 150 colonies) were tagged to evaluate their survival. These included corals that did not bleach ("super corals"), fully bleached colonies, and colonies that produced fluorescent photo-protective pigments. We will evaluate survival of the different colonies and plan to use the "super corals" in our coral gardening efforts.

A coral gardening experiment was undertaken at Gulifushi with involvement by guests. Four frames were established with corals of two species, using colonies that were bleached, fluorescent yellow, fluorescent blue and light brown. Survivorship of the different colonies will be monitored to determine whether the "super corals" exhibit greater survival and growth.

A series of presentations were conducted for guests, staff and high school students to educate them on the HARP program, our activities during this mission, and the coral bleaching event in general. Demonstrations of our coral sampling and coral mariculture were also presented, and guests participated in guided snorkels to become more educated on climate change, el Nino and coral bleaching. Two families and a group of reporters also participated in our coral mariculture program, attaching coral clippings to the coral frames. Numerous staff also participated in the COTS clean-up effort.

Acknowledgements

The HARP Program would not be possible without the partnership and support from Anantara Dhigu, Veli and Naladhu and Anantara Kihavah Resorts. We must thank the General Managers, Coetzer Deysel and Jean-Marc Ma-Poon, who are extremely enthusiastic and supportive of the Program and fully understand the need to conserve these vibrant and vital ecosystems. Liz Smailes and Ayesha Barker have both been invaluable to the Program, driving it and their positivity has helped get the HARP Program off the ground! We are grateful for all of the organizational and logistical assistance from Liezl Lising during our Kihavah visit. We would like to thanks Mr John Roberts, the Director of Conservation, for visiting and working alongside us during the trip- we loved sharing this Program with him. Also, the team at Aquafanatics and Elements for providing us with diving equipment and knowledge, and a special thank you to Joseph Lassus who dived and worked with us at Kihavah. Education is a key component of the HARP Program, and we would like to thank Mr Mohamed Yamany for organizing the seminars with staff and local school students. The *Eat, Paint, Learn* evening would not have been possible without Julie Simpson, Kihavah's in-house artist. Finally, a huge thank you to our colleague, Stefan Andrews, for his dedication, enthusiasm and hard-work filming and photographing the entire visit and for spending hours producing videos.

Water temperatures

Water temperatures were at normal levels in January 2016 when the permanent sites were established (28-29° C). Beginning in March temperatures climbed to 30° C and remained above 30° C for the entire month of March, reaching 31° C and higher during April and May. Normal sea water temperatures during this period are approximately 29° C. Sea surface temperatures, monitored by satellite (Fig. 1) illustrate the temperatures on January 4, 2016 (top) and the large body of unusually warm water extending from Indonesia to Africa on April 25, 2016 (bottom).

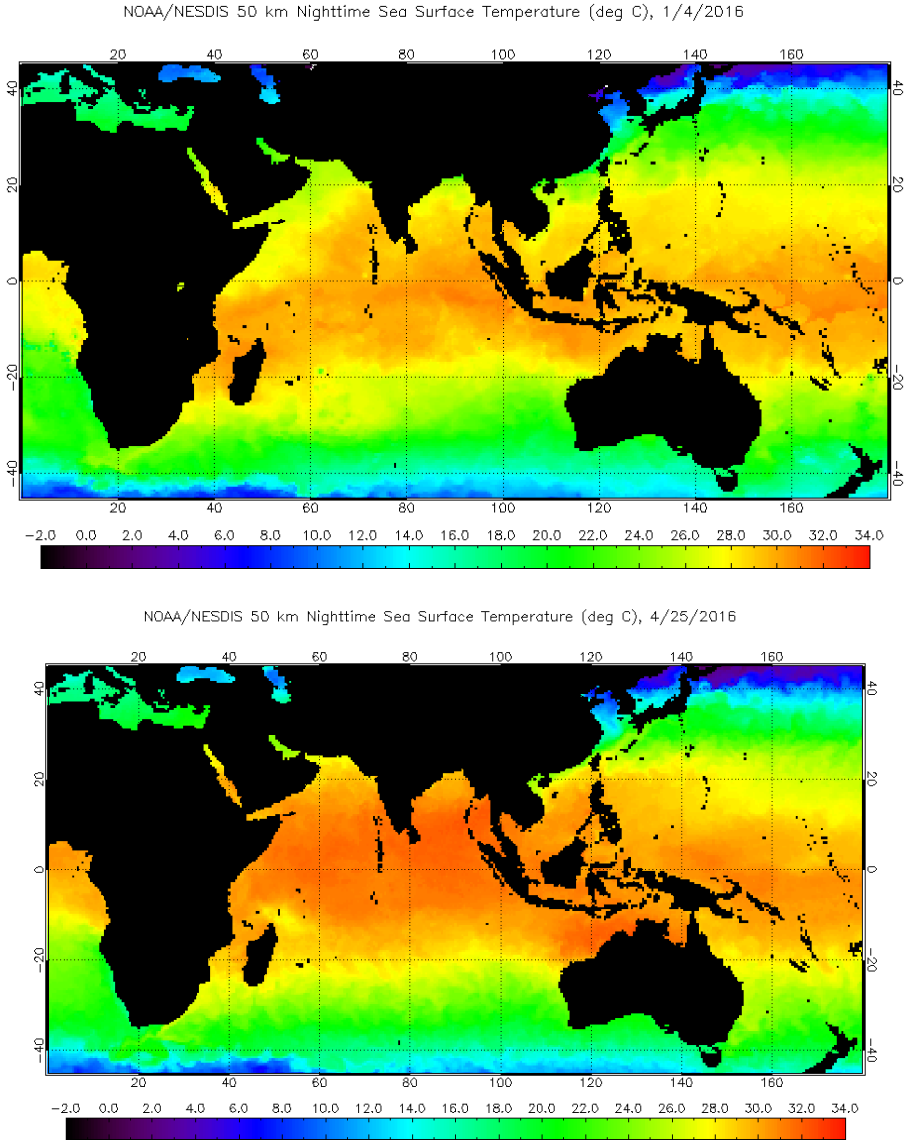


Fig. 1. Sea surface temperatures in the Indian Ocean on 1/4/16 (top) and 4/25/16 (bottom). In January, surface waters were 28-29˚C. During April waters were consistently at 31˚C or higher. Normal temperature for this period is 29-30˚C. Figures are from NOAA Coral Watch.

In January, water temperatures were at normal levels. As of May 12, 2016, the surface water temperatures had accumulated the equivalent of 12 degree heating weeks (fig.2; bottom). Degree heating weeks is a measure of the combined total number of weeks and degrees Celsius that water temperatures exceeded the normal mean temperature for this period. 1 degree heating week is enough to start to induce bleaching.

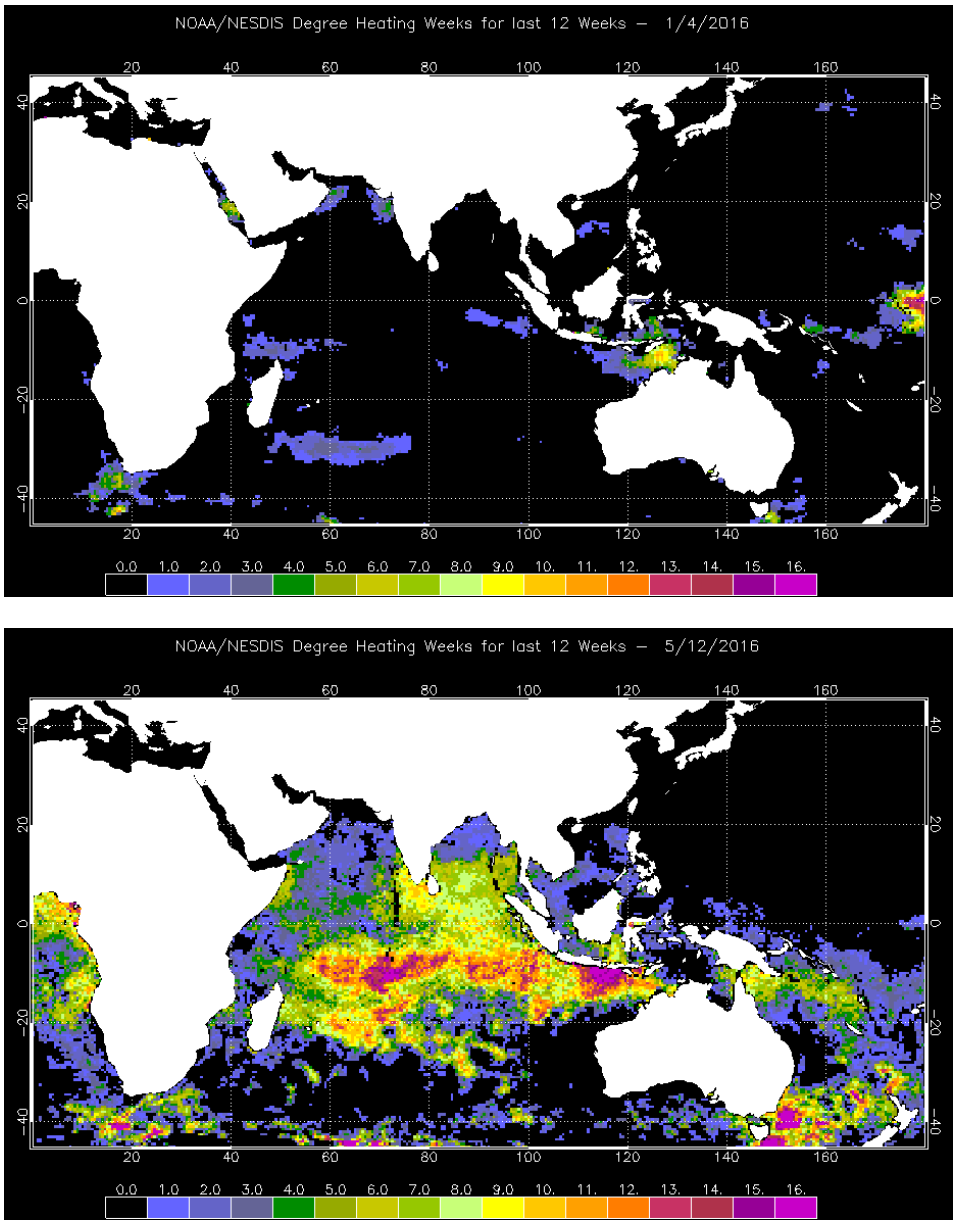


Fig. 2. Degree heating weeks for 1/4/16 (top) and 5/12/16 (bottom). Temperatures were normal in January. By May, the Maldives have experienced 12 degree heating weeks, which indicates the temperature has been 1˚C above normal for 12 weeks or 2˚C above normal for 6 weeks. Figures are from NOAA Coral Watch.

Our *Hobo* temperature meters, placed on the reef at 7-8 m depth within each of our permanent study sites, illustrate the changes in water temperatures between January-May, 2016. Raaebundi (lagoonal patch reef), South Malé Atoll (Fig. 3; top) illustrates relatively stable water temperatures until March 5, followed by a progressive increase, with over one month of reef temperatures that were between 30.5-31° C. A similar trend was noted on Baa Atoll (lower). It is interesting to note the sudden decline in temperature on April 22, 2016 following a severe storm with heavy rainfall. Water temperatures during the five days following this storm continued a slow decline.

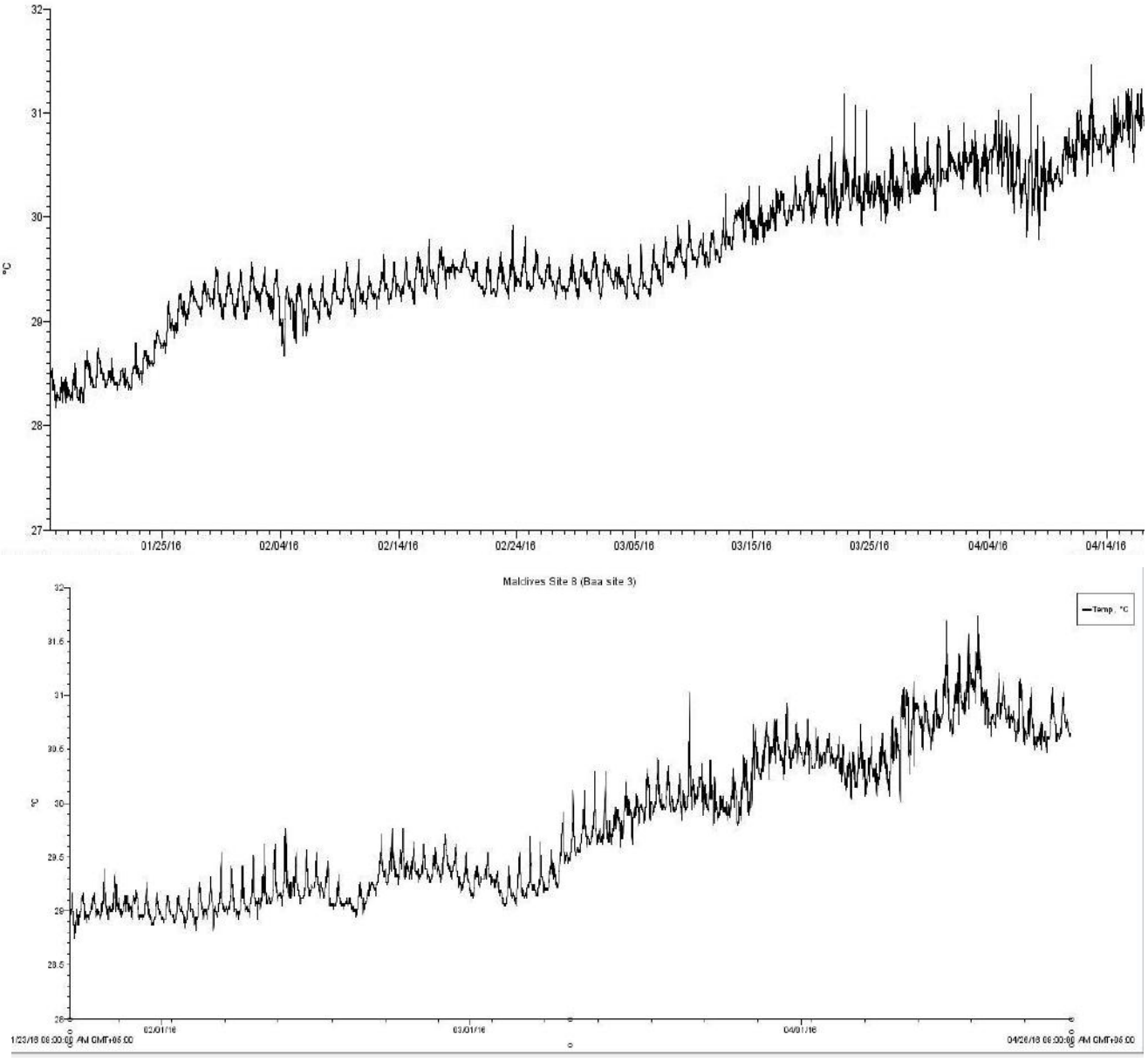


Fig. 3. Reef temperatures on South Malé Atoll and Baa Atoll at 8 m depth. Raaebundi (top) from 1/15/16 to 4/17/16.. Baa Atoll from 1/29/16 to 4/27/16.

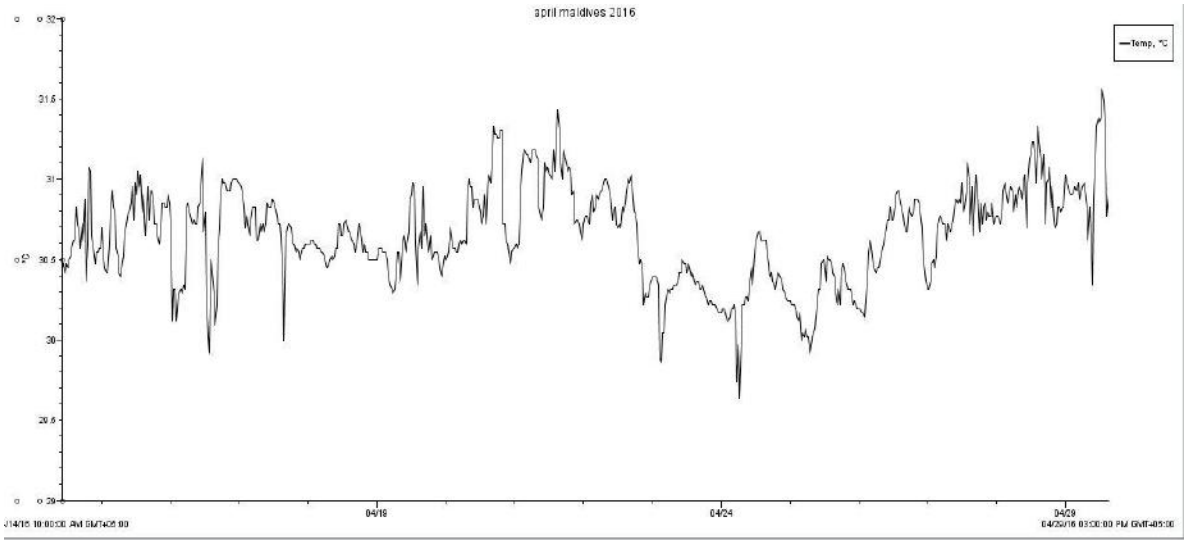


Fig. 4. Reef temperature on Veli Channel reef from 4/14/2016 to 4/20/2016.

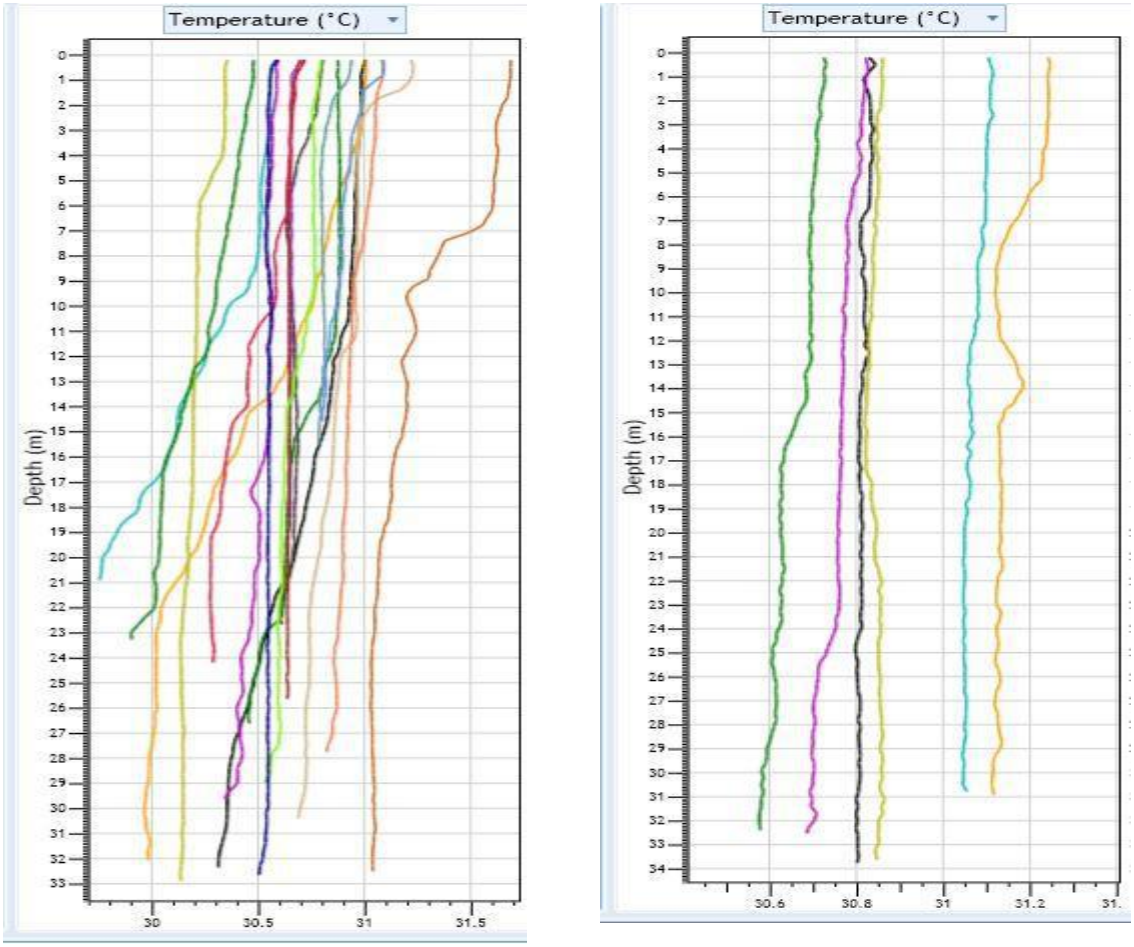
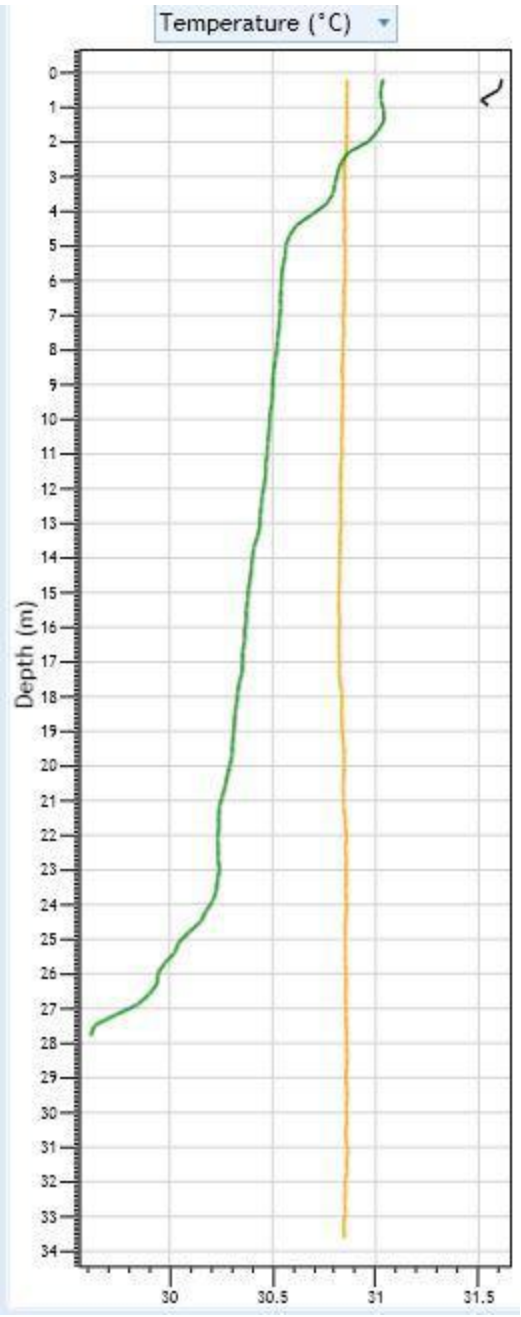


Fig. 5. Temperature profiles at permanent sites near Dhigu (left) and Kihavah (right). Dhigu temperatures are from 4/12/16-4/21/16. Kihavah temperatures are 4/24/16-4/27/16.



While a similar drop in temperature was noted following the storm on 4/22/16, temperatures climbed to values higher than that recorded prior to the storm between April 24-May, 5, 2016, exceeding 31° C in most locations, as seen at Veli Channel reef (Fig. 4). This was associated with another 10 day period of very calm seas.

In addition to the warm surface waters, the unusually warm water extended down to greater than 30 m depth within nearly all of our permanent sites. The only exception was at a fore reef location in South Malé in early April (Fig. 5 left; yellow and green profiles), where temperatures declined a little more than 1 C from just over 30° C to around 29° C at 25 m depth.

Fig. 6. Comparison of the temperature profile from the surface to 28+ meters depth at one site (Raaebundi) during April, 2016 (yellow line) and on May 4, 2016 (green line) after the onset of the summer monsoon.

Fig. 6 shows a profile for a lagoonal patch reef in South Malé atoll (Raaebundi) on April 12, 2016 (yellow) and again on May 5, 2016 (green). The green profile shows the change in water temperature as the monsoon begins. While the surface water is still very high, deeper, cool water is found below 25° C. Provided that winds and rough seas persist, this cool deep water should begin to mix with the surface water, relieving the stressful water temperatures.

Extent of coral bleaching

Coral bleaching was first reported in the southern atolls and it slowly expanded northward, first affecting central Maldives in early April. By late April, extensive bleaching was visible on most reefs and it was readily observable from the air (Fig. 7). Mild bleaching was first noted on reefs near Dhigu, South Male Atoll during our April 7 surveys. *Pocillopora meandrina* was the first species to bleach, followed by the acroporids, and eventually most massive and plating species. The fore reef showed 40-50% bleaching by April 15, increasing to >90% by May 4, 2016 (Fig. 8). Lagoonal reefs showed moderate bleaching on the slopes, with less bleaching in shallow water until after April 25, when all of the table acroporids and most other species bleached (Fig. 9). Channel reef showed the lowest prevalence of bleaching, with much more severe bleaching in shallow (1-2 m depth water), and less at 5-8 m depth (Fig. 10; top). By early May, bleaching was noted in all locations to 30+ meters depth with 50-70% of the corals turning white or very light yellow, about 10-20% fluorescent yellow, green, blue, pink or purple and 10% unbleached.

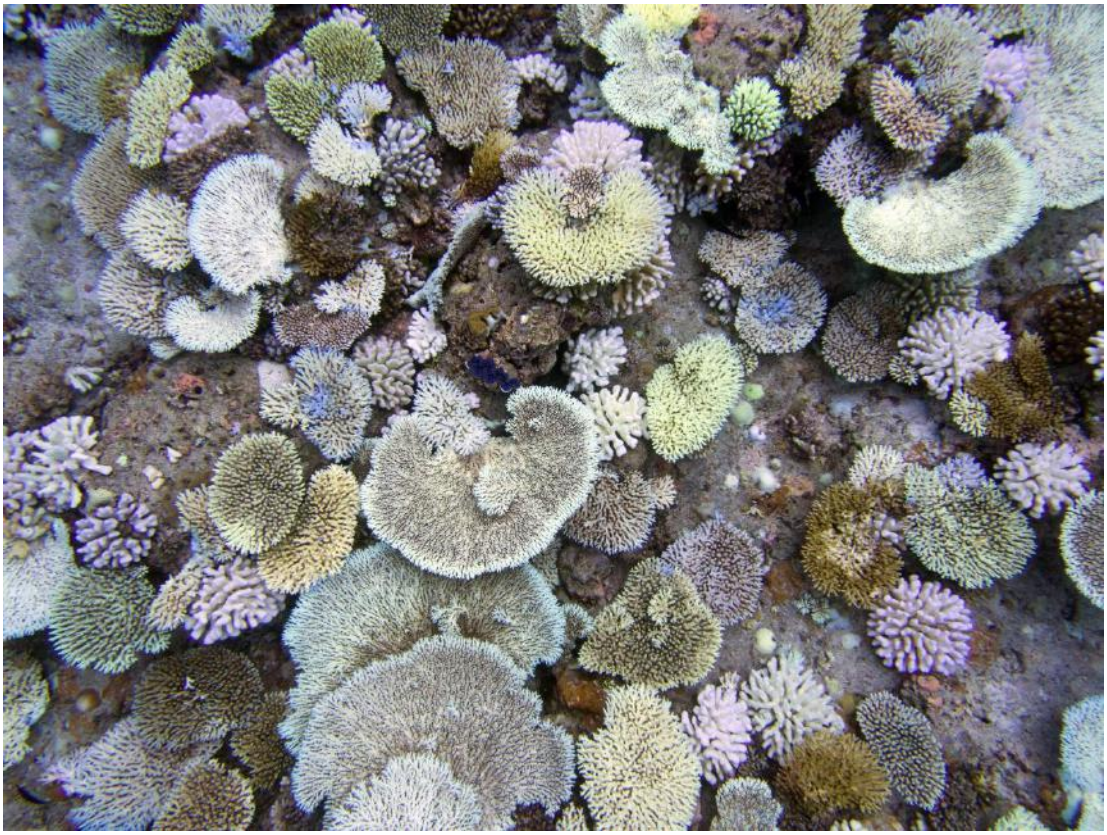
Fig. 7. Lagoonal patch reef in North Malé showing the widespread extent and severity of bleaching throughout the Maldives. All of the white circles are bleached table corals and the golden brown circles are colonies that recently died from the bleaching.

Fig. 8. *Pocillopora* was one of the first coral taxa to bleach, with up to 90% of the colonies fully bleached by early May. There were, however, some colonies of the same species that did not bleach. Photo taken on Maafushi fore reef.

Acropoid corals were among the most severely affected; especially those in very shallow water (Fig. 11). Large stands of staghorn coral on the reef slopes became fully bleached, with some colonies turning a fluorescent blue or aquamarine color (Fig. 12).

Bleaching was also severe at Baa atoll, near Kihavah, although many of the outer fore reef locations were less bleached than the lagoonal reefs (Fig. 13). Most of the outer reefs are dominated by massive *Porites* colonies, which more frequently became pale (40-50%), or blue (20-30%), with many fewer colonies (10-20%) that turned completely white (Fig. 13). In contrast, lagoonal populations of *Acropora* (>90%), especially the large table corals were severely bleached. Large stands of foliaceous and plating corals in the genus *Echinopora* were also severely bleached on lagoonal reefs (Fig. 14).

Most other corals also bleached, or became light/lemon yellow or dramatic fluorescent hues (Fig. 15). Notably, many of these corals showed patchy bleaching, with portions of the colony that were shaded showing much less severe bleaching (Fig. 16).



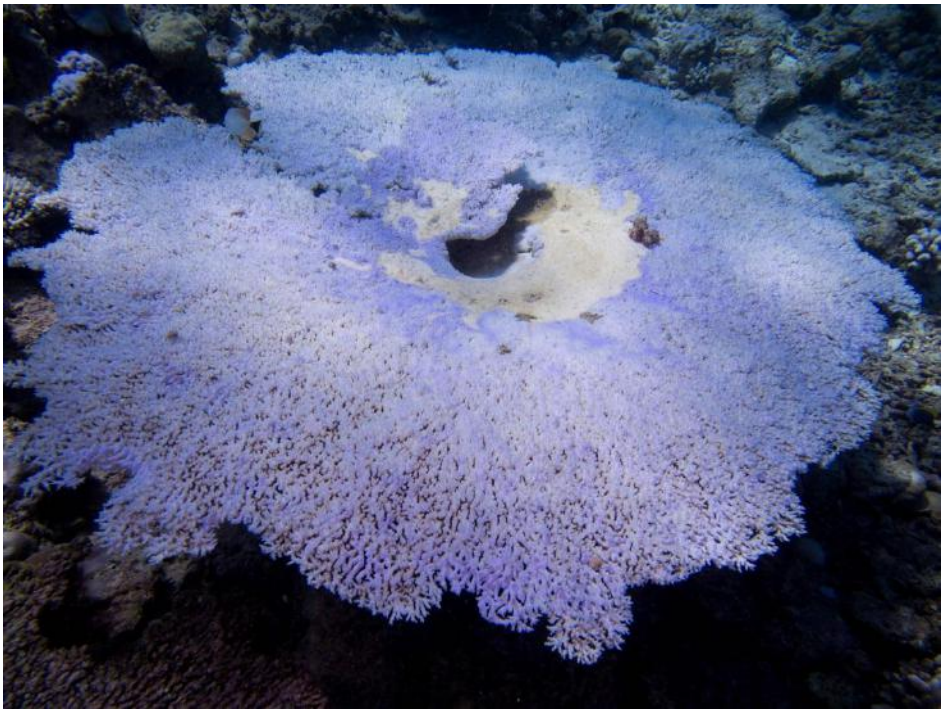


Fig. 9. By early May, reefs dominated by small table acroporids were completely bleached and colonies began to die. All of the corals that are golden brown are now dead and covered with filamentous algae. Photo taken on the fringing reef off Marina Island. Many of the table acroporids turned a light blue or lemon yellow. Generally, they began dieing in the oldest portions of the colony with tissue loss expanding towards the colony perimeter.

Fig. 10. Reefs located in channels resisted bleaching for longer than other reefs such as Veli Channel Reef. On April 20, 2016 most corals were only pale or unbleached (top), however by May 3, a much higher percent of the colonies had bleached and some corals had started to die (bottom).

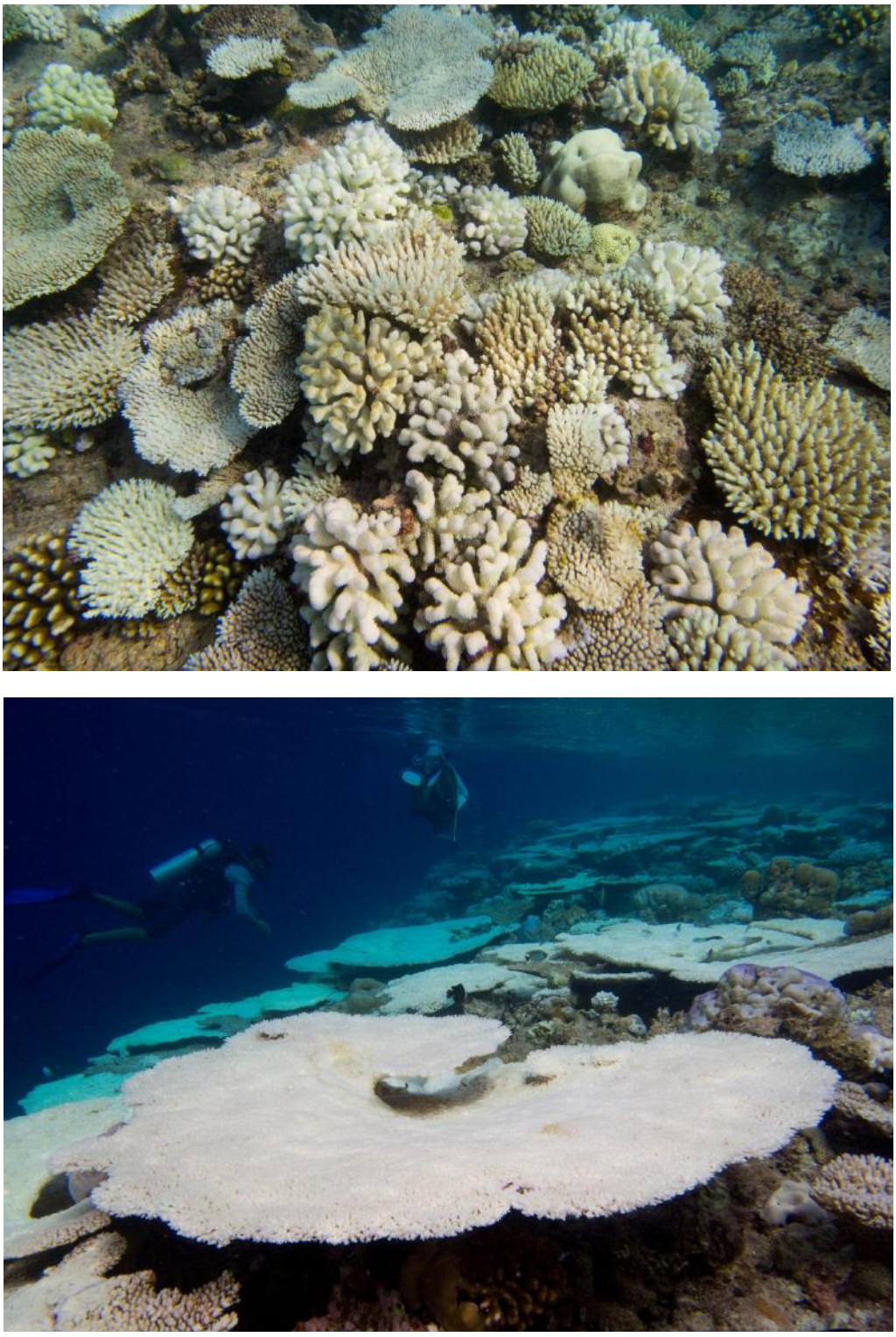


Fig. 11. Shallow reef communities (0-3 m depth) bleached most severely with over 95% of the corals turning completely white (top). Table acroporids (especially *A. cytherea*) were hardest hit, turning white or very light blue and beginning to die by the end of April. Shallow reef crest at Veli (top) and reef flat in Kihavah (bottom).

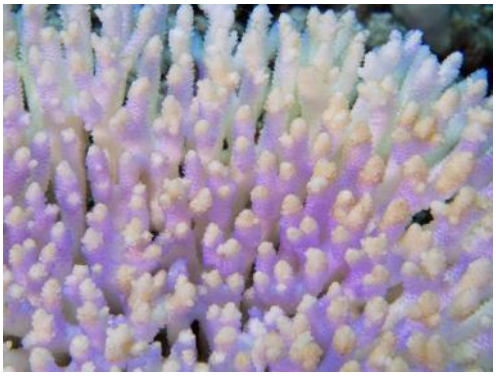


Fig. 12. Reefs with large stands of staghorn coral were very susceptible to bleaching with colonies turning light blue (top left) and eventually completely white (middle and lower left) before beginning to die. Small bleached table acroporid with purple branches (right). The close up of that coral shows that the tips of the branches have died and are covered in algae (lower right).

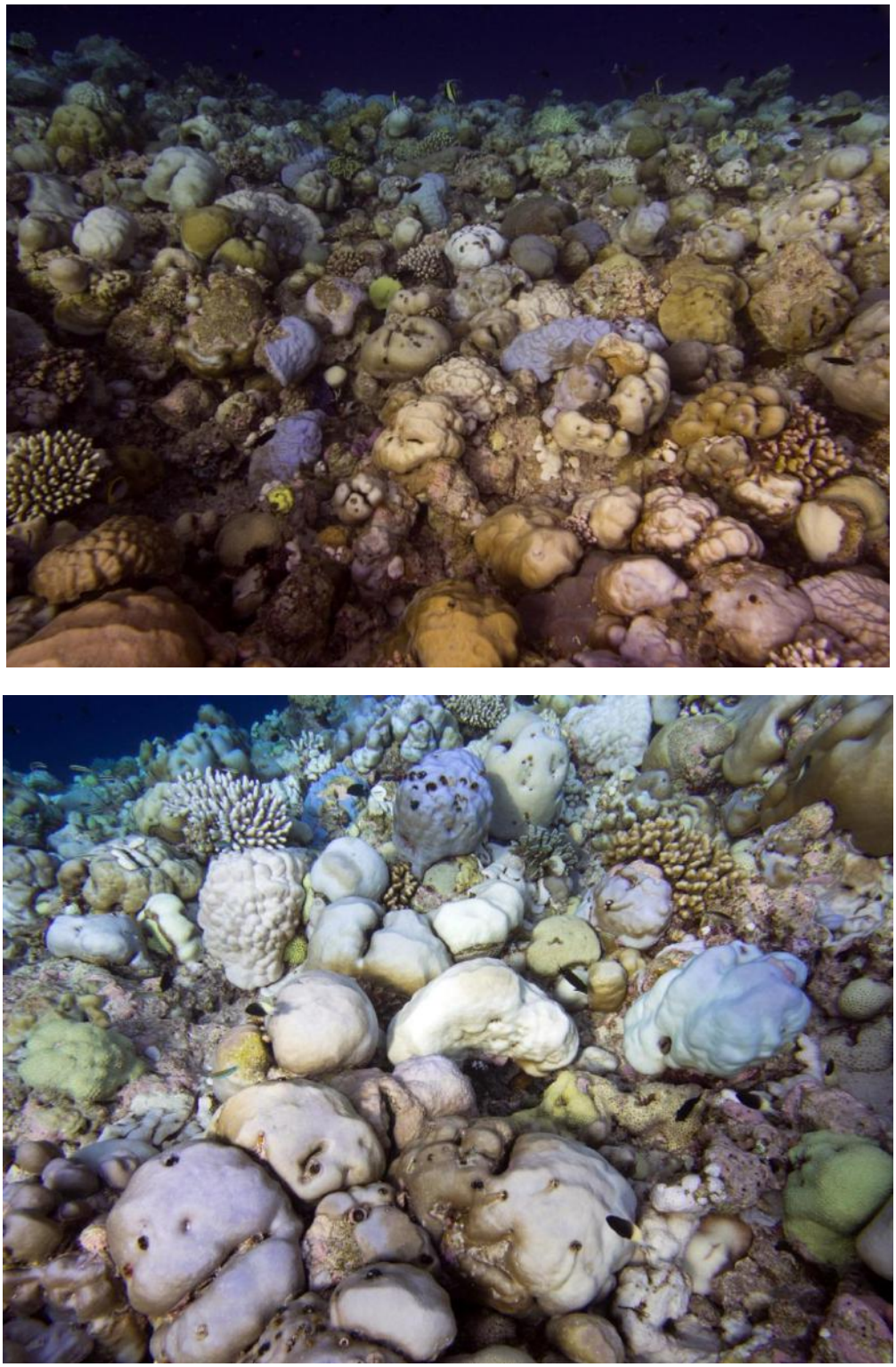


Fig. 13. On Kihavah, outer reef dominated by massive *Porites* (top) showed much less severe bleaching than lagoonal reefs. Colonies on the slope were often pale, light blue or pink (top), while shallow reef flat had many more colonies that were white (bottom)

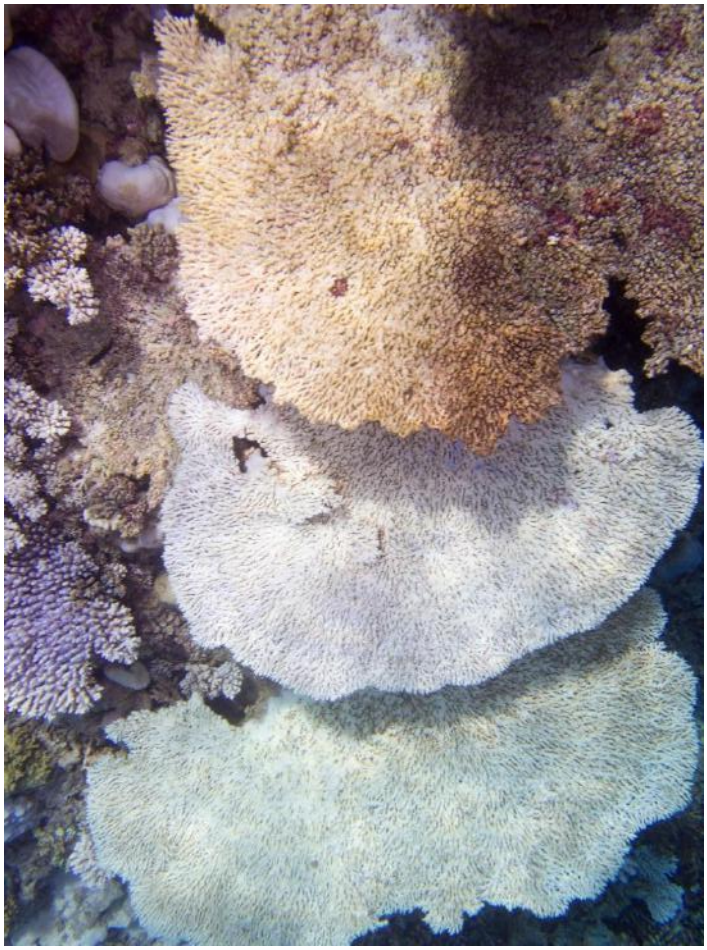


Fig. 14. Lagoonal reefs dominated by branching coral and table corals (top) as well as reefs with stands of foliaceous *Echinopora* (bottom) were severely bleached on Kihavah. In many cases the corals had begun to die. The three table acroporids in the upper image are located at the top of the reef slope. The upper coral has died and it's skeleton has become colonized by algae while the two lower corals are bleached but still alive.

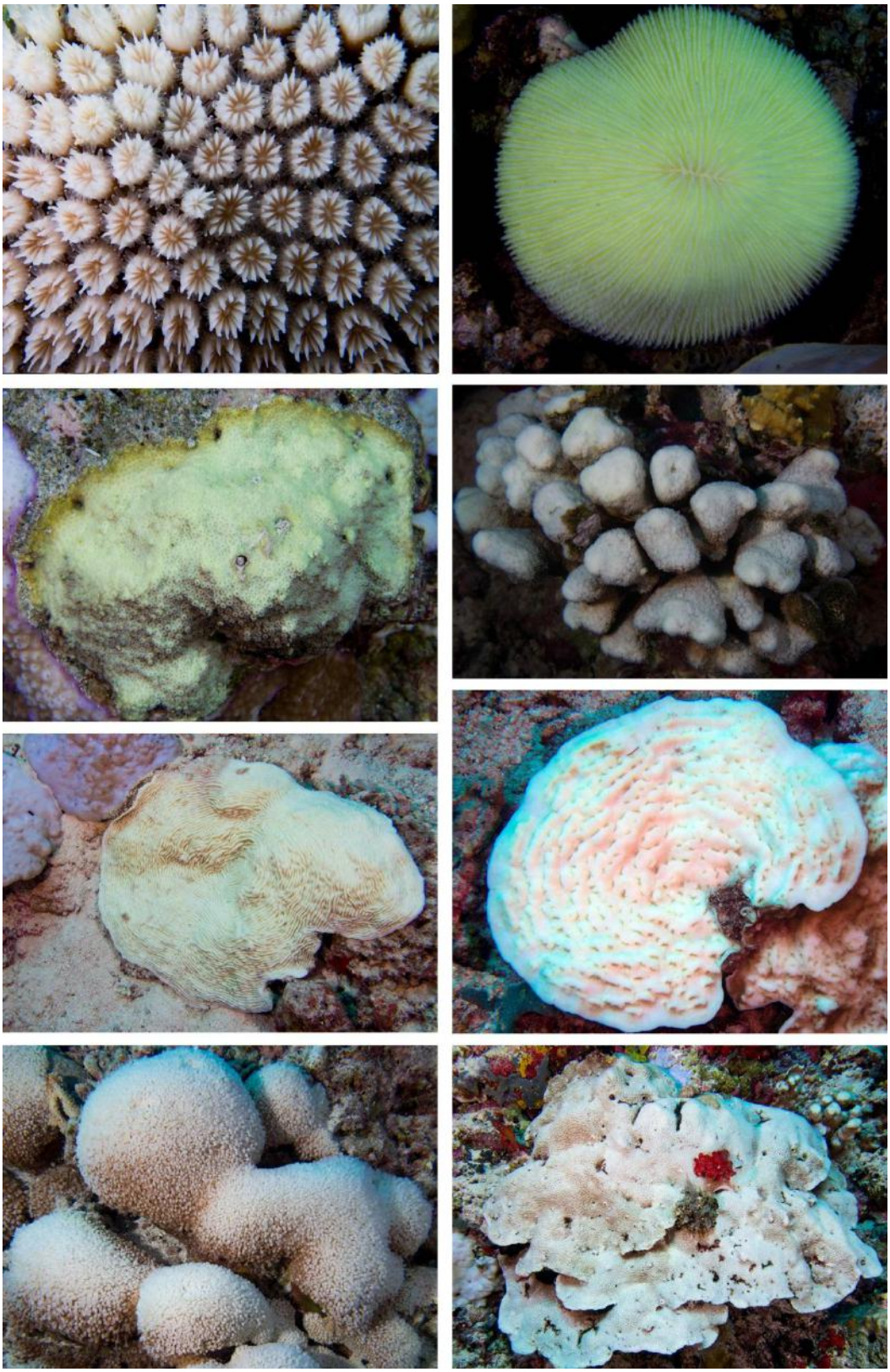


Fig. 15. The less common corals such as *Galaxea, Fungia, Cyphastrea, Pavona maldivensis, Pachyseris, Leptoseris, Goniopora*, and *Gardeneroseris* (left to right; top to bottom) also became light/lemon yellow or fully bleached.

Fig. 16. Most other species of corals also bleached. Some colonies became light yellow or only showed partial bleaching. Early signs of bleaching in *Goniastrea* tended to affect the walls, while the deeper recesses of the corallites still remained pigmented (top left). Similar patterns were seen in colonies with ridges and valleys such as *Merulina* (top right). *Turbinaria* (2nd row, left) and *Lobophyllia* (2nd row right) became yellow before turning white. *Physogyra* (3rd row left) often were pale brown with upper portions of the colonies being lighter than the bases. Other bleached genera included *Favia* (3rd row, right), *Pavona varians* (bottom left) and *Pavona clavus* (bottom right).

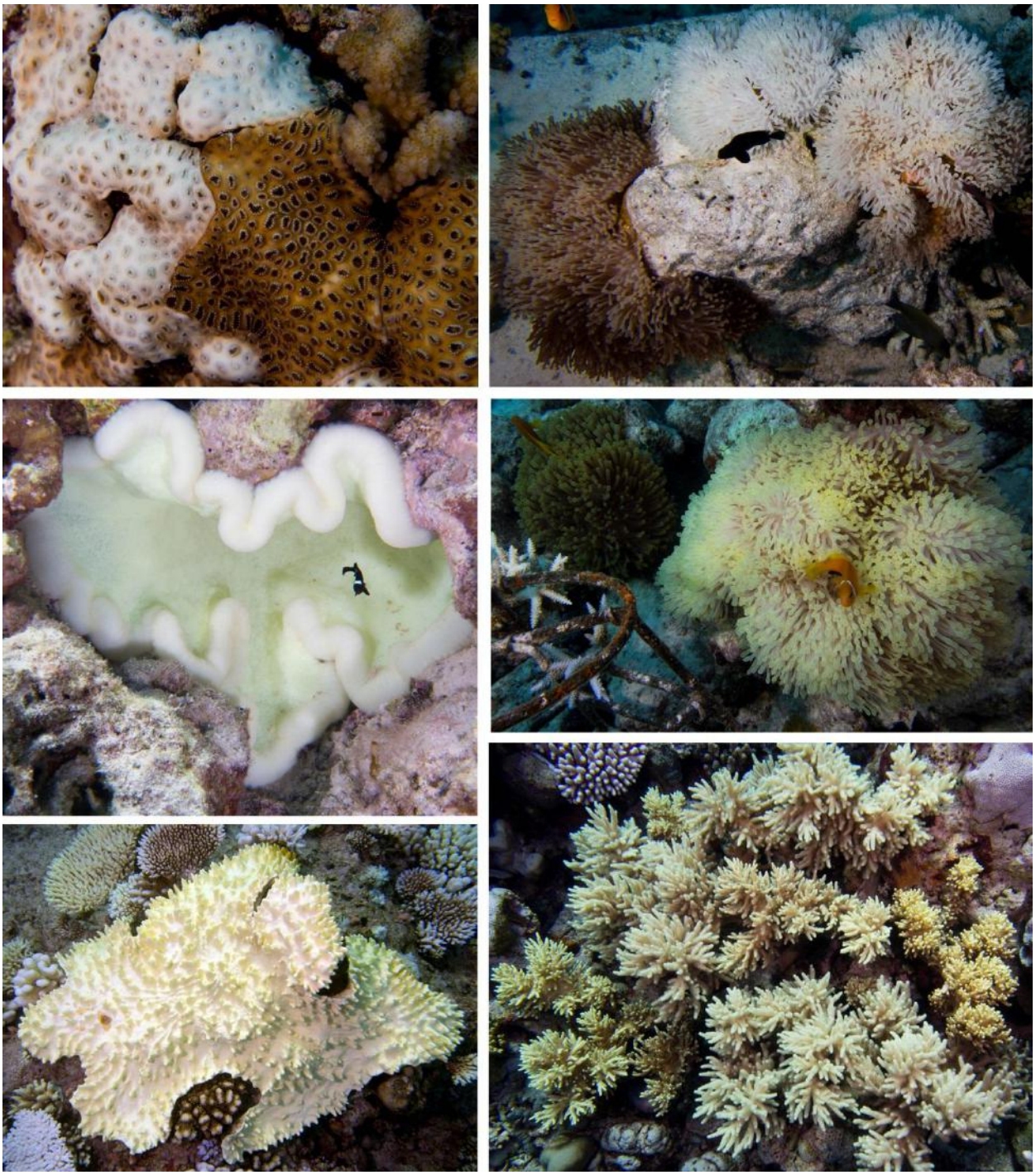


Fig. 17. A number of other cnidarians that contain symbiotic algae also bleached during April, 2016. A bleached and normal colony of *Palythoa* colonial anemone (top left). *Heteractis* anemones that are normal and partially bleached (top and middle right). *Cryptodendrum* anemone that is completely bleached (middle left). A lemon yellow colony of *Sarcophyton* leather coral. Pale colonies of soft corals (*Sinularia).*

Patterns of mortality

Early signs of coral mortality were first noted on April 12, 2016 in fore reef locations among *Pocillopora meandrina* colonies. As these were the first corals to show signs of bleaching, they also showed extensive partial mortality within a week of bleaching. The initial signs of mortality primarily affected the branch tips, which were quickly colonized by algae. Over time the sides of the branches began to die, and in severe cases the entire colony. The branching and table acroporids also began to exhibit partial mortality by mid April, and by early May a number of corals, especially table acroporids, had completely died. Typically, the tips and sides of branches of staghorn coral died, while the bases and shaded portions remained living.

Other species also succumbed to the bleaching, with the most extensive mortality noted among foliose *Echinopora* colonies on Kihavah. Many solitary and free living fungids also died by early May.

Very few of the encrusting, submassive and massive corals died from bleaching. A few had lost small areas of tissue, but in general these were still surviving by the end of our mission. Notably, very few massive boulder corals (*Porites lobata*) showed partial mortality.

On lagoonal reefs in Dhigu, especially Sand Bank and Raaebundi, there was considerably more mortality among the massive and plating corals, including colonies of *Porites rus*.

Fig. 18. Example of a table coral (*Acropora* sp.) that bleached and has mostly died. Much of the colony is covered with filamentous algae; some white (recently dead) branches are still visible and one small portion of the colony is still living.

Fig. 19. Examples of bleached corals that are starting to die or have recently died. A *Pocillopora meandrina* (cauliflower coral) with recent mortality only on its branch tips. Note the fine algae on the skeleton (top left). A group of Pocillopora colonies, some bleached (white) and several that are dead or nearly dead in the lower portion of the image (golden brown) (middle left). A table coral (*Acropora cytherea*) that has died and is colonized by algae (top right). A table coral that has lost about 60% of its tissue and is covered in algae. The margins are bleached but still alive. A large massive/encrusting colony of *Porites* that is fully bleached and starting to die (lower left). A bleached colony of *Porites* with several COTS lesions and small patches of tissue that died due to bleaching (lower right).

Super Corals

The patterns of bleaching in individual corals was highly variable with some colonies becoming completely white, others turning a bright fluorescent color, and some exhibiting a mottled pattern, with pale r white branch tips and upper surfaces and darker sides and bases of branches. On most reefs, 10-20% of the corals bleached and acquired a vivid fluorescent pigment that was lemon yellow, light green, pink, purple or red. A small percentage of the corals did not bleach at all. Some of the colonies were shaded from full sunlight, but there were also many that were completely exposed to light and were located next to colonies of the same species that did bleach.

We believe the corals that did not bleach may be better adapted to higher temperatures and these so called "super corals" may survive future stressful high temperature events associated with El Niño and climate change. It is possible that these have acquired a type of symbiont that is more tolerant of temperature fluctuations, or the coral animal itself is better able to produce certain proteins such as heat shock proteins that allow it to combat the production of toxic oxygen molecules produced by the symbionts.

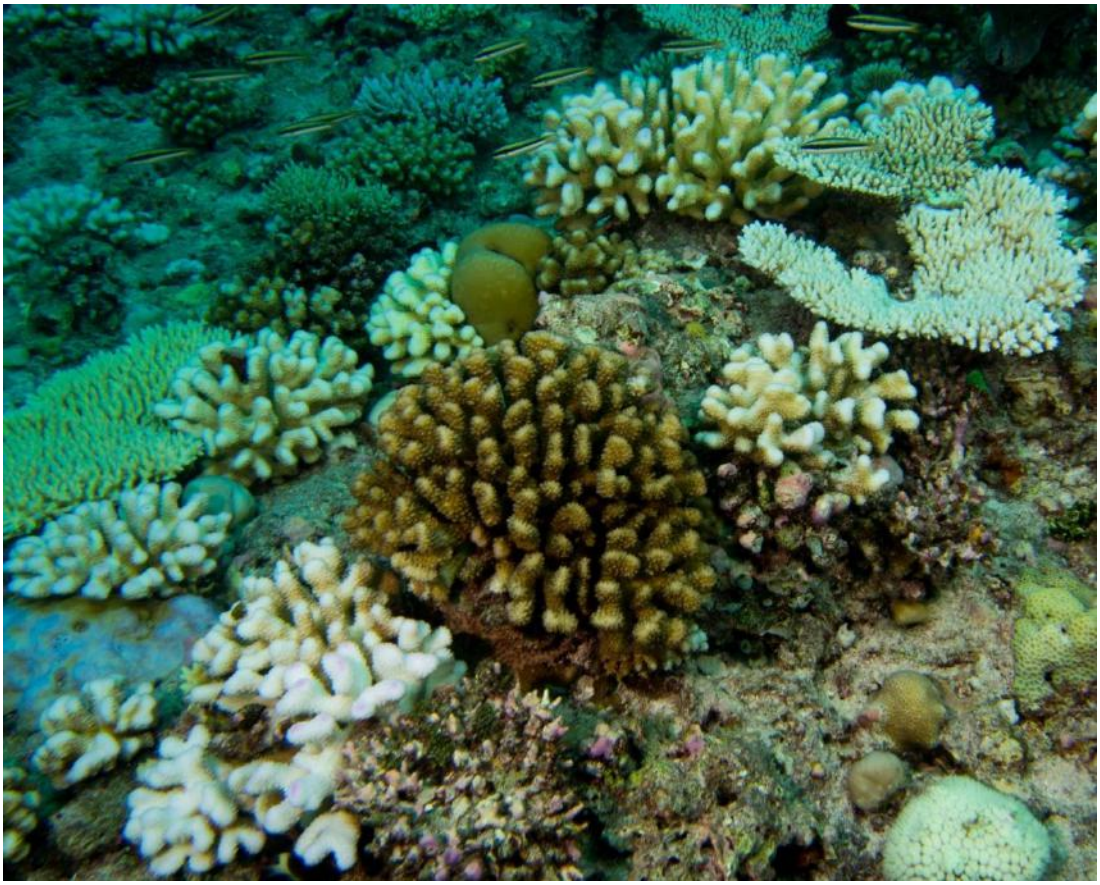


Fig. 20. A normal, fully pigmented colony of *Pocillopora meandrina* surrounded by bleached colonies of the same species (and other bleached coral species)

Fig. 21. Four colonies of *Pocillopora meandrina* (cauliflower coral) displaying a variety of bleaching responses (above). The top colony has produced a purple/blue photo-protective pigment; the right colony has become yellow and the two colonies in the middle show a fully bleached (white) colony and a light brown (minimally bleached) coral. A bleached and recently dead *Pocillopora* colony is in the lower right.

Fig. 22. Two massive *Porites lobata* colonies. The left colony is completely bleached and the right has full pigmentation.

Fish

Fish diversity, density and biomass was recorded at all permanent monitoring sites. In total, 58 belt-transects were performed at various depth contours. The species recorded during these transects was added to the list produced in January. Several new species were added to this list, including wahoo (*Acanthocybium solandri*), Andaman butterflyfish (*Chaetodon andamanensi)* and pompano spp. (*Trachinotus ballont, Trachinotus blochii*).

The most noticeable pattern observed in Anantara Kihavah was the juvenile recruitment. At several sites, particularly those adjacent to channels, juveniles of most species were observed. Schools of thousands of juvenile redtooth triggerfish (*Odonus niger*) were noted in the sites. This is really positive and an indicator of healthy coral reefs as some research suggests juvenile fish use chemical signals to determine the reef they choose.

Fig. 23. A very large school of redtooth triggerfish on a sloping fore reef in Kihava (top left). A group of bannerfish swimming over the reef (bottom left).

Condition of "*adopt a coral*" coral frames

At Veli/Dhigu most of the coral frames contain a single species of *Acropora* that occurs naturally in Veli Lagoon among the water villas. These frames have been deployed in Veli, at Dhigu near the reception/dock and off Aqua Bar, and near the dock at Naladhu. All of the corals exhibited sever bleaching. The frames near the reception area at Dhigu were fully bleached by April 10, and mostly dead by April 30. At Veli, they survived until the end of April and are now dead. The coral frames near Aqua Bar are fully bleached and have partial mortality, but many were still alive as of May 3, 2016. These were located in the deepest water (approximately 2.5 m) and may have experienced the lowest light levels and highest rates of flushing, minimizing temperature stress.

At Kihavah, there were many older (4-5 year) adopt a coral frames between the water villas. These all consisted of a single species of staghorn coral. They showed extensive growth, completely covering the frames and forming large stands. By April 25, 2016 these were fully bleached and approximately 50% had died and were covered with filamentous algae. The coral frames near the underwater restaurant were pale or bleached and some showed partial mortality, but most were still alive as of April 29, 2016. These frames contained a much higher diversity of corals. They were also located adjacent to the reef slope of the house reef, and are likely to experience much greater amounts of water exchange.

The coral frames provide a good opportunity for education and awareness, and they also serve an important role in sandy lagoonal environments by providing structure that is used as habitat for numerous reef creatures. Some of the issues with these frames in terms of their use to restore coral reef environments pertain to 1) the types of corals attached to the frames and the longevity of their growth; 2) the inability to remove corals from the frames once they have grown; 3) degradation and rusting of the metal rebar over time; and 4) difficulty in cleaning and maintaining frames and preventing pest species from colonizing and attacking the corals. Other challenges include the location of placement. The lagoonal areas used are very shallow and exposed to large temperature fluctuations, salinity changes during periods of heavy rainfall, and considerable movement of sediments.

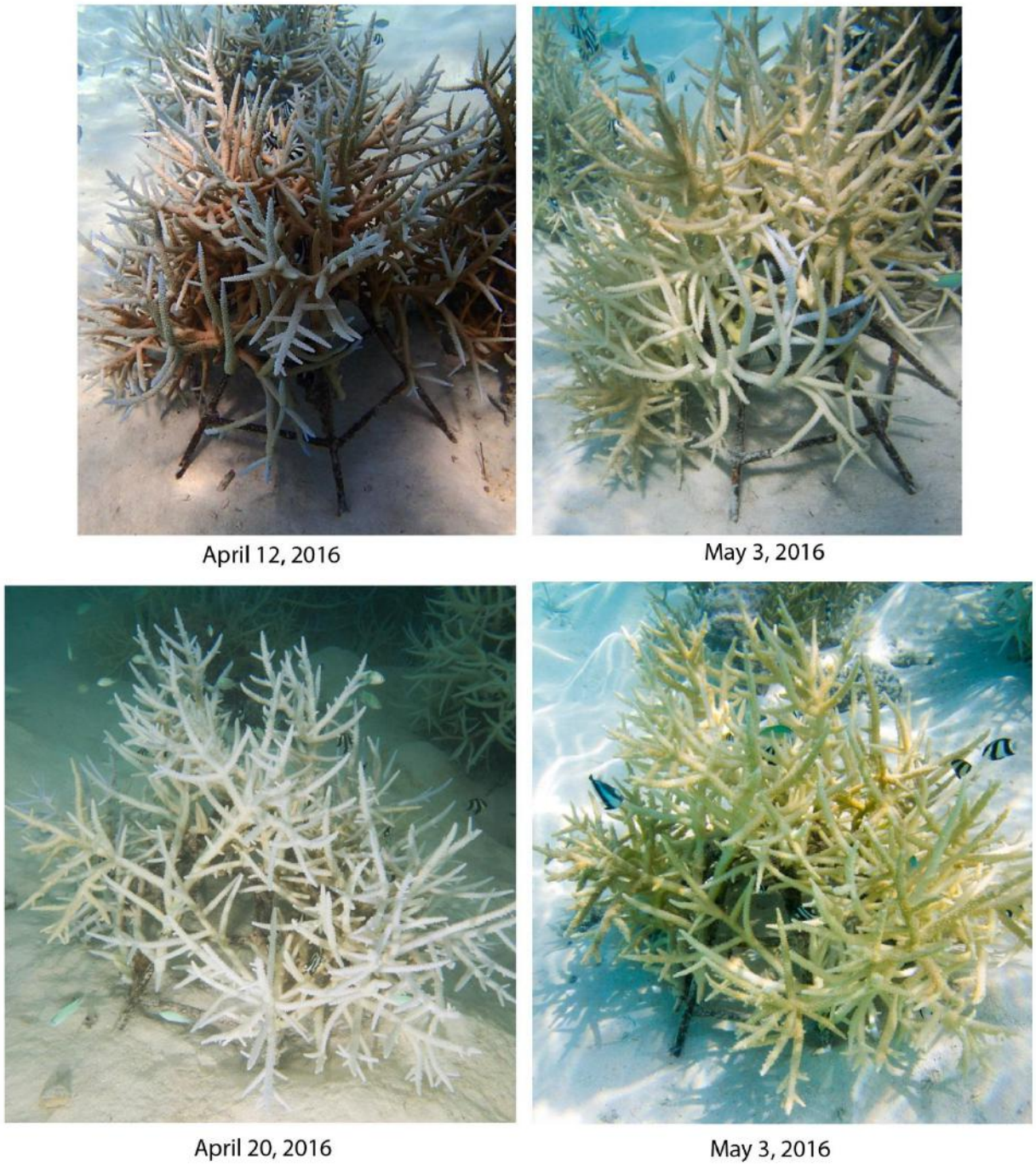


Fig. 24. Two coral frames at Veli lagoonal reef. The corals were light brown or pale in color in early April (top left), and became completely bleached by April 20, 2016 (bottom left). The same frames are shown on May 3, 2016. In the top right image, about 90% of the coral has died, with a few bleached branches remaining. The coral in the lower right image is completely dead and covered in fine filamentous algae that give the skeleton a golden brown coloration.

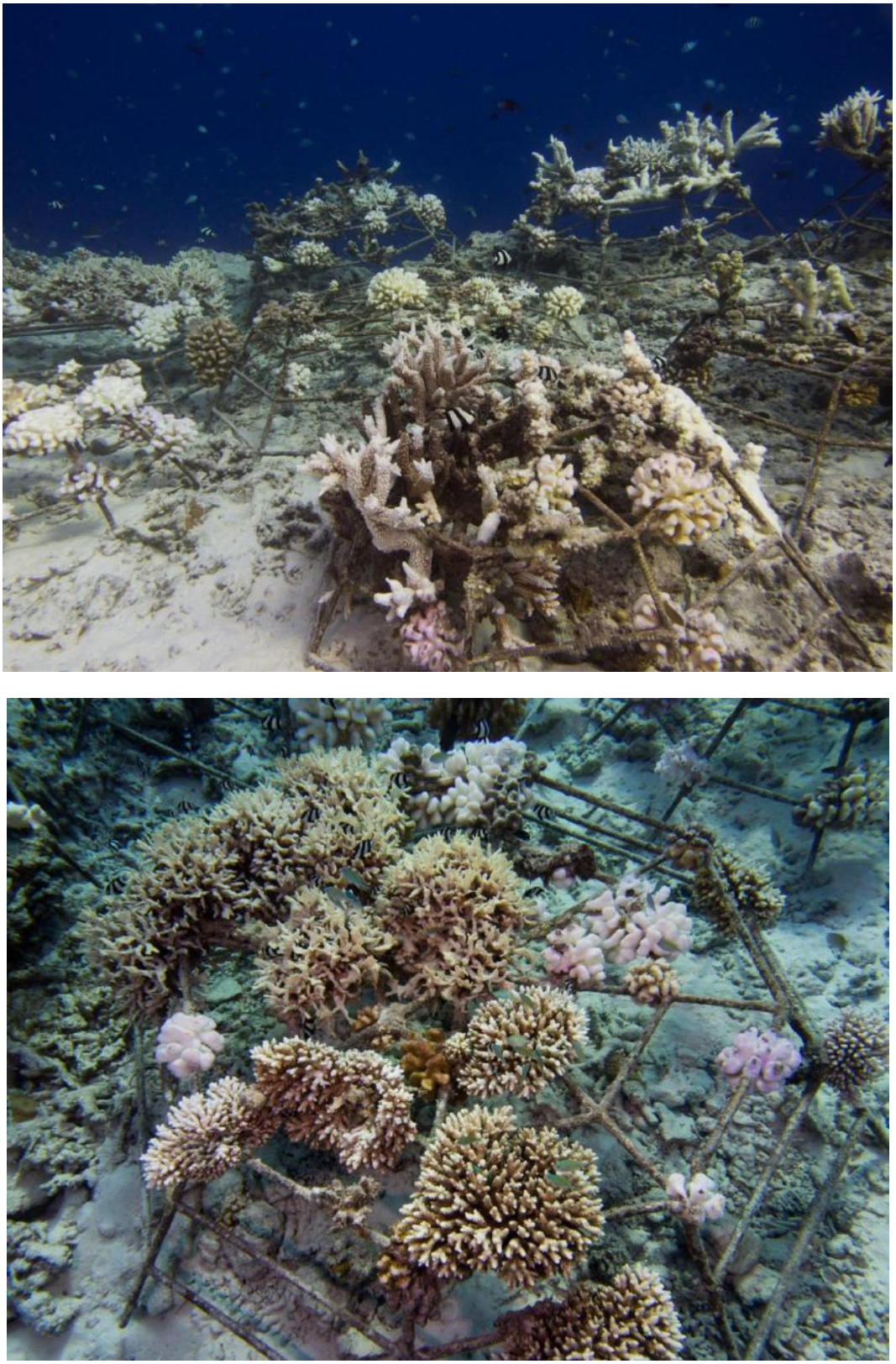


Fig. 25. Coral frames near the Underwater Restaurant in Kihavah, Baa Atoll.

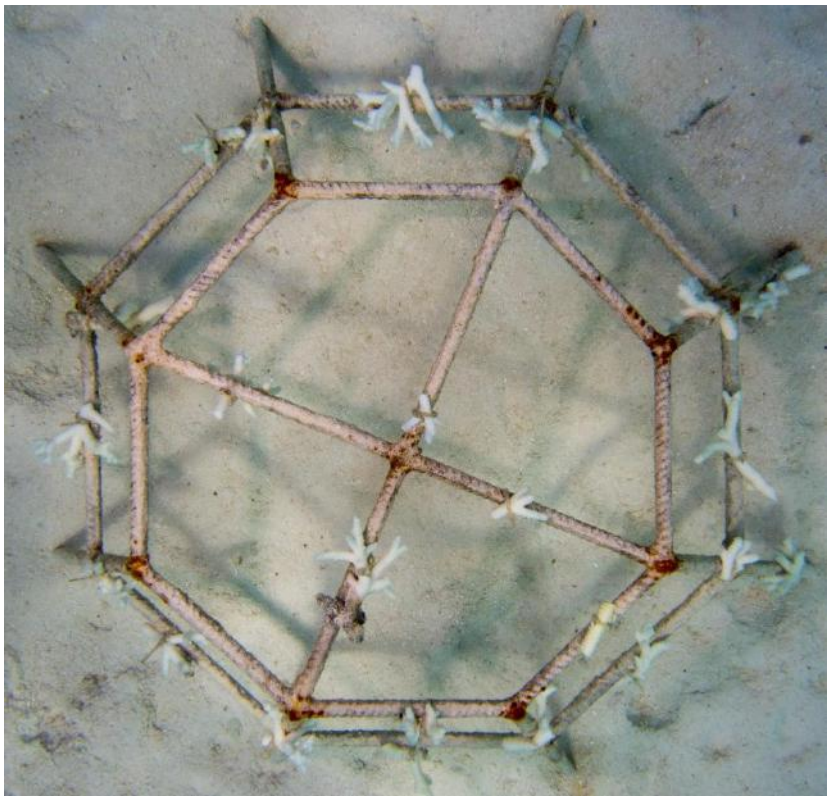


Fig. 26. Top view of a new adopt a coral frame (upper left). Small fragments attached to the frame bleached within a few days, and some have died. One of the problems with the use of rebar, even though it is coated with epoxy and sand, is that it eventually rusts, initially at the welds. The rust introduces an element (iron) that promotes the growth of algae which is harmful to corals.

Fig. 27. An older coral frame on (lower left) colonized by filamentous algae and cyanobacteria. Rust is visible, and all coral on the upper portion has died. The remainder of the coral is bleached and has started to die.

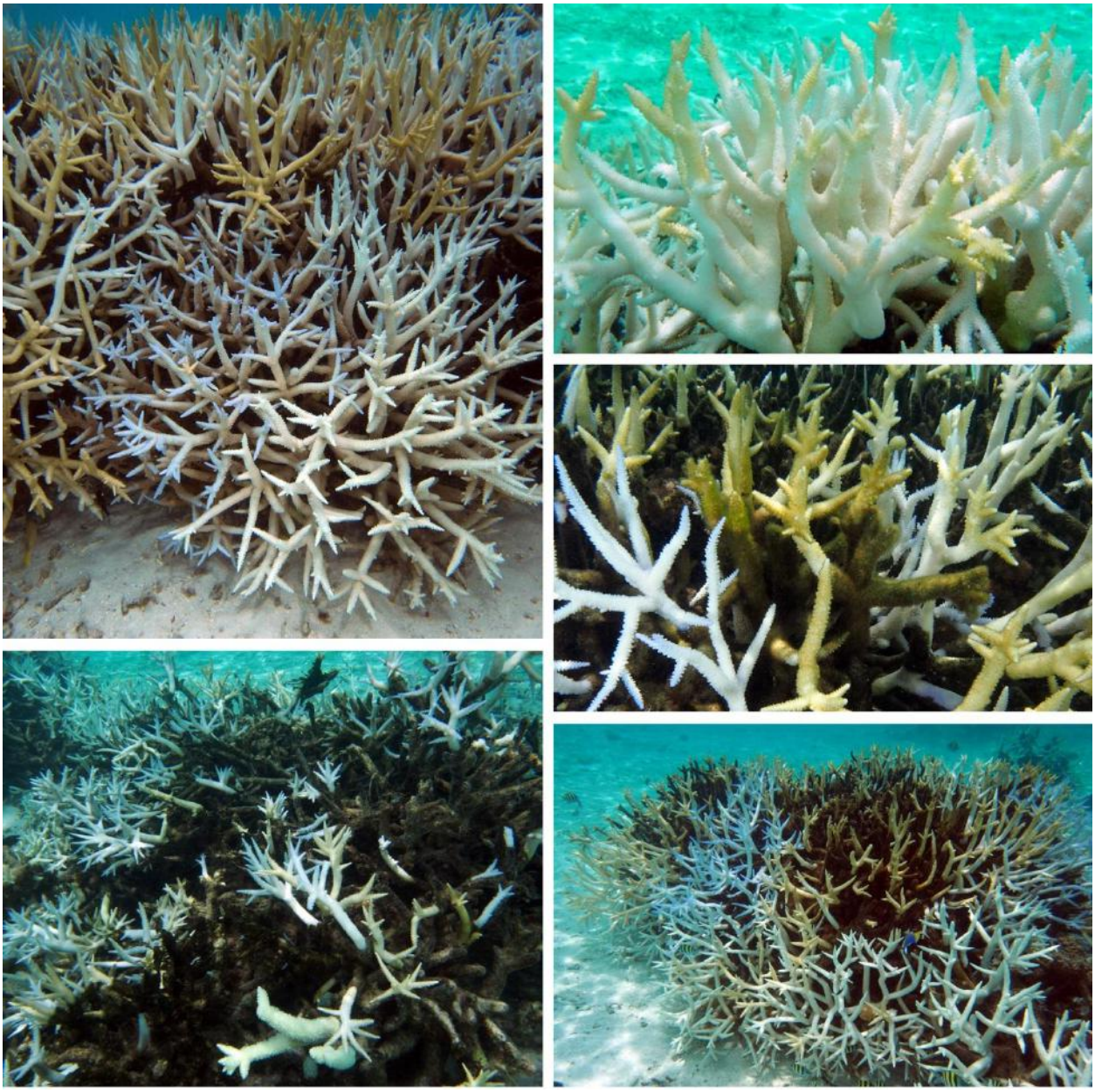


Fig. 28. Coral frames at Kihavah near the water villas. Patch of staghorn coral that bleached and the branch tips are dying (golden brown branches) (top left). Close-up of branch tips that are bleached and the tips are covered in filamentous algae (top right). A large coral frame with living (bleached) coral only on the branch tips. All of the inside of the frame and lower branches have died and are covered in dense algae (lower left). A close-up of bleached branches of staghorn coral that are in later stages of algal colonization (right center). Several coral frames where the coral coalesced, died on the inside and is now bleached (blue) and has large areas that recently died (light brown)(lower right).

Veli lagoonal staghorn populations

Unusually large populations of old growth staghorn coral (*Acropora formosa*), with colonies up to 2 m in height and 10s of meters diameter, have successfully colonized shallow lagoonal habitats around the water villas. These corals provide critical habitat for numerous fish species and serve as an important nursery area.

Fig. 29. Staghorn coral near the water villas beginning to bleach (April 12, 2016).

Fig. 30. A patch of staghorn coral photographed on April 29, 2016 that is nearly dead. A few branches (light blue) are still living.

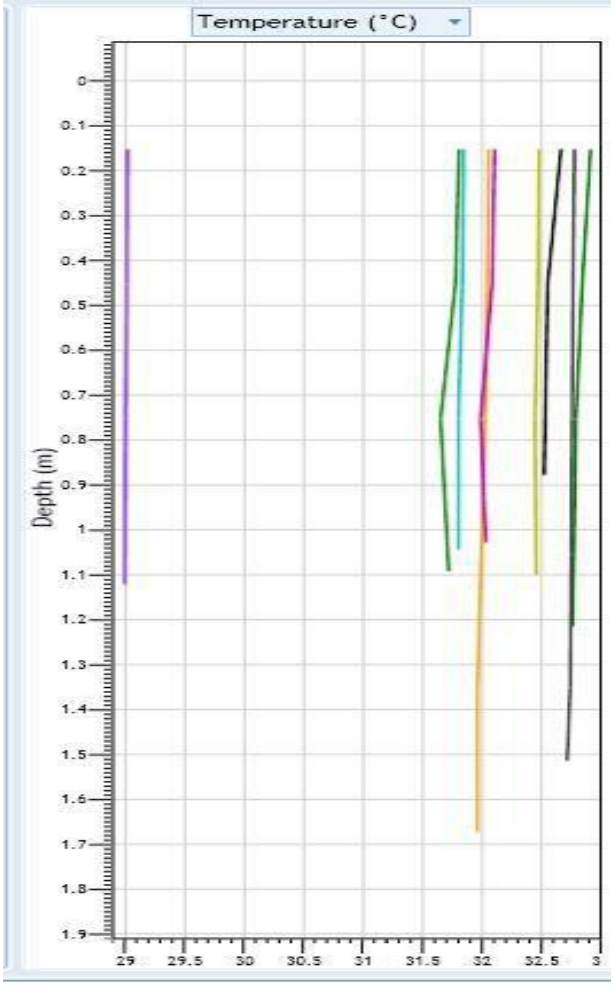


Fig. 31. Temperature profiles at Veli lagoon, near the water villas. The purple line (left side) is from April 23, 2016, one day after a major rainfall event. The four lines near the center of the figure are night time temperatures prior to the storm and 7 days following the storm. The four lines on the right side of the figure are at mid day, also prior to the storm and 7 days following the storm.

The shallow lagoonal waters surrounding the water villas at Veli experience the widest fluctuations in temperature. These exhibit a daily heating due to sunlight, minor changes with tidal fluctuation and substantial changes during storm events. The water was consistently over 32° C during the month of April, reaching 32.8° C on days with full sunlight. A strong storm on April 22, 2016 caused a decline in temperatures to 28.9° C. However, this was short-lived as water heated back up within two days of the storm.

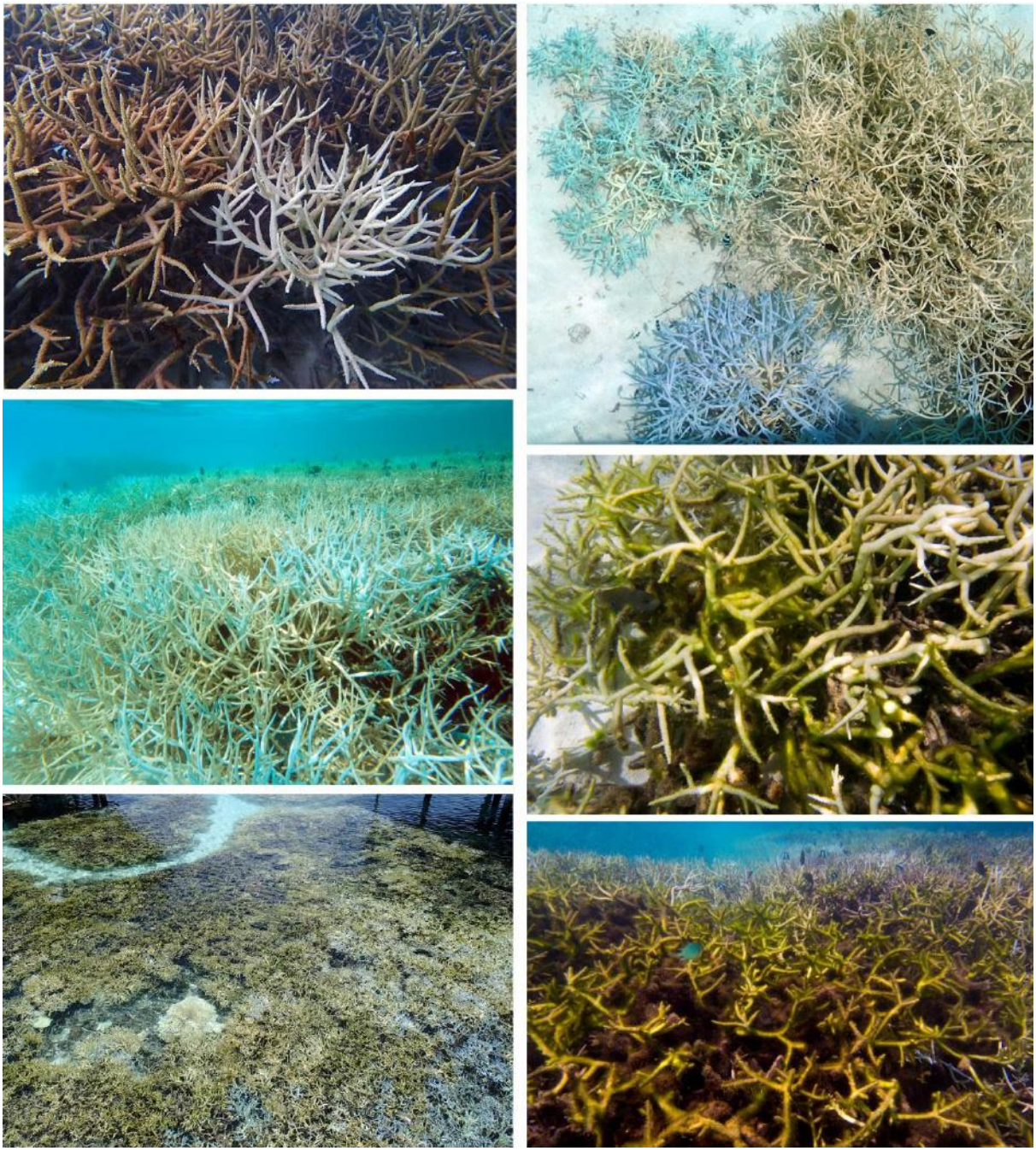


Fig. 32. Staghorn coral population at Veli lagoon. The coral was starting to bleach on April 10, 2016 (top left). By April 20, 2016, a large portion of the coral had died (light brown branches), but some remained living but bleached and numerous colonies had turned an aquamarine and light blue coloration (top right). Living, light blue branches still remained on April 29, but much had died (middle left). Areas with damselfish sustained the most rapid mortality and green filamentous algae quickly covered the branches (middle and lower right). A large stand between the villas photographed from the dock on May 3, 2016. Nearly 90% of it is dead (bottom left).

Fish communities at Veli

The reef habitat at Veli supports a huge diversity of reef fish. The structure of the coral provides habitat and refuge to dozens of damselfish (*Chromis, Dascyllus* sp.) and butterflyfish species. These unique stands of coral provide habitat to reef fish in an area that would otherwise be devoid of many fish. This habitat also acts as a vital nursery area for juvenile goatfish, damselfish, butterflyfish, emperors, groupers and snappers. On several stands the coral has been taken over by farming damselfish. These territorial damsels farm patches of algae for food.

In addition to the fish surrounding the coral stands; several species were observed utilizing the sandy channels. Goatfish, emperors, trevally and pompano were large in size and schools of mullet were also noted.

Fig. 33. Examples of fish populations in Veli staghorn populations.

COTS cleanup

The crown of thorns starfish (*Acanthaster planci*) invaded south Malé Atoll in May, 2015. An intensive removal effort was undertaken near Anantara Dhigu in October, 2015, with over 7,400 starfish removed from the reefs. There were three main locations of outbreaks. The majority of the starfish were removed from two of these (Stage and Veli), but hundreds of starfish remained at Raaebundi and they continued to eat coral. Most of the coral has been killed on the reef flat (1-3 m depth) and on the shallow part of the reef slope, but coral remains on the deeper part of the slope (10-30 m depth) and the less preferred species (e.g. *Porites lobata, Porites rus, Gardeneroseris, Pachyseris*, and other corals) remain, especially in deeper water. To avoid loss of all coral on this reef, and to prevent their movement to a new reef, a team of divers and snorkelers conducted a removal on May 2-3, 2016. Over three dives, a total of 364 starfish were removed. While this is a large percentage of the starfish, numerous starfish remain, especially below 20 m depth.

Fig. 34. A diver removing a crown of thorns starfish from the reef. The starfish were placed in mesh collection bags and brought to shore for burial.

Fig. 35. Although the massive corals were severely bleached, COTS were seen still feeding. Because most of the favourable corals had been eaten, they were most common on less preferred species such as *Gardeneroseris* (top left) and *Porites lobata* (middle). Prominent lesions were seen on many of the surviving (but bleached) massive corals such as the *Porites lobata* colony in the lower left. These corals are usually avoided by COTS.

Summary of activities undertaken during April-May, 2016

1. Monitoring of permanent sites

The team successfully completed all monitoring efforts within the ten permanent stations near Dhigu and Kihavah, covering fore reef, channel reef and lagoonal reef habitats. Temperature meters were retrieved, downloaded and replaced on each reef. Temperature and salinity profiles were also taken during each of the surveys. When possible, the profile was made from the surface of the water to 30+ meters.

Photo-transects

Belt transects (10 m x 2 m) were photographed in each monitoring station. A 10 m line, marked in 10 cm intervals, was extended along existing permanent transects between each rebar (2 per reef) and continuous images were taken using a 1 m scale bar placed perpendicular to the line at 1 m intervals. Two photo-transects were completed per line (one 1m x 10 m transect on each side of the line) resulting in the documentation of a 20 m^2 area of reef for each permanent transect. Additional permanent transects were added to cover adjacent habitats and depths. The new permanent transects involved the insertion of additional pieces of rebar (two per transect) at the beginning and end of each 10 m long transect.

Additional stations were added in Dhigu, South Malé Atoll at:

2. **Stage Reef**: two transects at 10 m depth at the edge of the reef slope. This was added because the existing transects are on the reef flat, away from the slope.
3. **Maafushi**: one transect at 10 m depth at the edge of the reef slope. This was added because the existing transects are on the reef flat, away from the slope.
4. **Veli:** one transect on the reef flat at 5 m depth. This was added because both existing transects are on the slope and they do not encompass the table acroporid community that dominates the reef flat.
5. **Sand Bank:** One transect on the reef wall at 8 m depth. This was added because one of the existing transects runs across a sandy/rubble area with minimal coral
6. **Raaebundi:** One transect at 5.8 m on adjacent spur. This was added because the two existing permanent transects run across sand channels

Additional stations were added in Kihavah, Baa Atoll at:

1. **MA 07:** One transect added on the reef flat at 4-5 m depth, extending from the edge of the slope towards the crest
2. **MA 06**: One transect added on the reef slope at 10 m depth and one transect at 3-4 m depth perpendicular to the slope on the reef flat.

Fig. 36. The marine biologist at Kihavah installing a rebar to mark a new permanent transect.

Fish transects

Reef fishes were assessed along 30 x 4m belt transects. Fish abundance was counted and each fish was identified to species-level and total lengths estimated to the nearest centimetre. Six transects were performed per site, two deep (11m+), two mid (7-10m) and two shallow (<7m). A roving biodiversity survey was also completed during dives to document additional species that were not recorded within belt transects.

Benthic Transects

Point intercept transects (100 points per 10 m line) were completed at different depths in each of the 10 permanent stations. A minimum of 4 transects per station with up to 6 transects were assessed to determine the amount of open substrate (pavement, rubble and/or sand), cover of corals, algae (by functional group), and other invertebrates, and condition of corals (extent and severity of bleaching, amount of mortality and cause of mortality). Transects were completed within surrounding coral-dominated habitats at 10 m, 7-8 m, 5 m, and 2-4 m to cover reef flat and reef slope habitats when available.

Coral Sampling

Small tissue/skeleton samples were taken from tagged *Acropora* and *Pocillopora* colonies that were sampled in January. In total, 85% of the tagged colonies were relocated and were still living. Samples were preserved in RNA later and carried to the USA for processing.

7. Bleaching assessment at other locations

Rapid assessments of bleaching severity were undertaken near Dhigu at Gulhi Thila, Kuda Giri and the reef south of Maafushi. These consisted primarily of photo-transects placed randomly at 10 and 5 m depth.

The population of staghorn coral near the water villas at Veli was examined repeatedly over a one month period and temperature profiles were taken multiple times per day once per week.

Rapid assessments of bleaching severity were undertaken on three reefs off Baa Atoll

8. COTS clean-up

A two-day effort to remove crown of thorns starfish from one infested reef near Dhigu was undertaken with assistance from Aquafanatics and Anantara staff.

9. Assessment of the "Coral Adoption Program" coral frames

The condition of corals on the frames placed at Veli and Dhigu (near the main dock off the reception and off Aqua Bar was assessed on April 10 and May 5, 2016.

The extent of bleaching and mortality of staghorn corals on the coral frames located on Kihavah, between the water villas was assessed on April 30, 2016. An additional survey of coral frames near the underwater restaurant was completed on April 29.

10. Identification of "Super Corals"

On each reef a portion of the colonies did not bleach, even colonies of the same species that were located next to partially or fully bleached corals. To evaluate the survivorship of corals that exhibited different scales of bleaching, we tagged 50 groups of corals on one reef (total of 150 colonies were included). The corals included unbleached (dark brown), pale (light brown), mottled (partially bleached), colored (pink/purple, lemon yellow, blue) and fully bleached (white colonies of two branching coral genera – *Acropora* and *Pocillopora*. Whenever possible colonies of the same species exhibiting different color patterns that were located next to each other were included in the study.

11. Pilot Coral Gardening Experiments

Existing coral frames were deployed off Gulhifushi ("Snorkel Island") to test the survival of coral fragments during periods of unnaturally high sea water temperatures. Two coral taxa were used (cauliflower coral, *Pocillopora meandrina*; digitate staghorn coral, *Acropora humilis*). On each frame a total of 25 fragments, 2-5 cm in length were attached using cable ties. Fragments included four color varieties (fully pigmented, blue, yellow and white) to assess the differences in growth and survival of colonies of different health. This will help us determine whether the "super corals", e.g. those that did not bleach during the current El Niño are stronger and more resilient than other corals, and also whether bleached corals that produce photo-protective pigments (yellow and blue corals) exhibit higher survival than bleached (white) corals.

12. Educational Activities

- Guests were encouraged to participate in the pilot coral gardening initiative. Two media guests and one family assisted our work by attaching coral fragments to the frames, asking questions and taking photographs.
- Guided snorkel tours were undertaken in both Kihavah and Dhigu for several guests and media groups to educate them on bleaching. The guests were taught the different types of coral and shown what healthy and bleached corals look like. They were also shown the different stages of bleaching as well as corals that produced fluorescent pigments and explained the benefits of this response. As a result, the guests have a better understanding of healthy corals, the effects of unusual temperatures and actions that can be taken to protect the reefs and restore damaged areas
- A seminar was held for a group of environmental and sustainability students from a high school in Malé. These students were educated on the HARP Program, the importance of coral reefs, threats to coral reefs and conservation measures. These students and teachers indicated interest in our involvement in a large environmental symposium being conducted in July/August, and to run an additional seminar to their 85 environmental club students.
- Three presentations for guests were held at Anantara Dhigu, where we reached approximately 150 people, to inform them on the Program, coral ecology and bleaching associated with the El Niño. Videos on the HARP Program and bleaching were shown, and fragments of corals exhibiting different bleaching responses were shown to the guests.
- Two staff presentations were held at Anantara Dhigu to allow as many different resort sectors to attend. Staff were very interested in the Program and had a lot of questions, particularly about the lagoonal reef around Veli water villas.
- An evening event, *Eat, Paint, Learn,* was held at Anantara Kihavah, and this intimate event sold out very quickly. Our involvement in this event was to present a

short and interactive presentation to the guests. The presentation was extremely well received, with a very in-depth discussion afterwards. This event was extremely successful and we hope to replicate this during our future visits.

- Andrew Bruckner and Georgia Coward met with the Minister for Education, Mr Ahmed Shafeeu, in Malé City. The background to the HARP initiative and the need for conservation to combine with education was discussed. The existing marine syllabus was discussed and the requirements for improving this. The Minister was extremely positive and expressed a great interest in working with us to adapt the syllabus to a more local context for Maldivian students. The next stage is to run a half day workshop with teachers in Baa Atoll to discuss their needs and thoughts form adapting the syllabus.

13. Outreach

We established a Facebook page (www.facebook.com/coralreefCPR) for dissemination of photographs and short videos and to provide brief updates. More detailed information, blogs, slideshows and articles are included on our website at coralreefcpr.org

Relevant findings are also being shared via Twitter (@coralreefcpr). Four videos were produced to describe the changes to coral communities we observed over the duration of the mission.

We completed the first HARP publication, entitled *Addressing Crown of Thorns Starfish Infestations in the Maldives*. This document contains information on the biology and ecology of the crown of thorns starfish (COTS), occurrences and efforts to control COTS in the Maldives, approaches to control starfish used historically and currently along with the benefits and drawbacks of these methods, first aid for COTS injuries, and a comprehensive reference list related to COTS. Numerous photographs from the Maldives are included to illustrate relevant points. This will be distributed throughout resorts in the Maldives and will be available to download on the Coral Reef CPR website.

Future Plans

Two team members (Andrew Bruckner and Georgia Coward) will return to the Maldives in July and August 2016 and will work with two marine biologists from Anantara Resorts in Phuket. These marine biologists will gain an understanding of the Program and coral mariculture efforts. During the mission, all of the permanent sites will be reassessed. Transects will be re-photographed and additional benthic and fish transects will be undertaken to assess the extent of change from the April mass bleaching event.

A major aspect of the work in Dhigu will involve the establishment of a coral nursery program and the initial restoration of the Veli lagoonal staghorn coral populations.

Several seminars and workshops are being considered for Malé High Schools, with participation in an Environmental Symposium in Malé during July/August. Additional guest and staff seminars, along with events such as *Eat, Paint, Learn* will be conducted. The artist, Christopher Hogan, has agreed to become a HARP ambassador and attend each resort during our visits to conduct evening events to raise awareness and funds for the HARP Program. There is a proposal for a half day workshop in Anantara Kihavah with the Minister For Education, local teachers and school principals to discuss coral ecology courses and adaptations to the existing marine and environmental syllabus.

Fig. 37. The lead scientist is showing a group a temperature profile from one of the snorkel sites.