Restoration and Natural Recovery of Corals after Unprecedented Mass Bleaching and Coral Death in the Line Islands, Kiribati

Working Paper, of work completed June 2016 through March 2020

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Overview

Coral reefs are the most diverse marine ecosystem, but they are unfortunately the most sensitive to climate change, predicted to be the first marine ecosystem to collapse due to increasing temperatures and altered water chemistry. If we can save the coral reefs, we can save the planet. However, if coral reefs go, the geological processes, which form, maintain, and protect tropical atolls, coasts, and beaches will go, taking with them societies, cultures, and nations that depend on coral reefs. If coral reefs are allowed to collapse, seagrass, mangrove and strand ecosystems sheltered by these reefs will follow. Saving coral reefs is thus the front-line of saving the planet, and where we must now take our stand. The following report focuses on one of the most bleaching impacted coral reefs on the planet, and shows that even after near total coral mortality, recovery mechanisms exist which give unforeseen resilience and hope. Efforts to work with natural recovery processes to accelerate the restoration of the now greatly diminished coral species are also detailed.

Opinion: Some scientists have suggested that we abandon such gravely impacted coral reefs as hopeless, devoting all of our energies on saving more resilient reefs that stand a better chance of surviving the approaching catastrophic bleaching. But what that amounts to is abandoning our front line in an escalating war, retreating to the stronger refuges in fear. This defeatist approach is dangerous, as it abandons the majority of our coral reefs and discounts the great resilience and strengths that these battle hardened areas might contribute to winning this war.

Abstract

On Kiritimati (Christmas) and Tabuaeran (Fanning) Atolls, Line Islands, Kiribati, over 90% of corals on reefs died from bleaching caused by hot water, during an ten-month period in

2015-16. While some branching coral species appear to have become locally extinct, we have succeeded in finding ‘’super corals’’ of several branching coral species which resisted the bleaching and survived, and we are propagating bits of these within a coral nursery, to begin the process of restoration and adaptation to a hotter climate.

The ongoing project focuses on the restoration and facilitated natural recovery of branching Acropora and Pocillopora coral species. Encouraging findings of initial recovery are proceeding through three processes: surviving adult colonies, colony regeneration from surviving micro-tissue fragments deep within coral colonies (what we are calling “resurrection corals”), and larval recruitment of unknown origin, coming from as of yet undiscovered deep water coral populations, on currents from other islands, or from stress-induced asexual larvae formed as the result of “polyp bail-out”.

We have succeeded in finding a small number of adult Pocillopora and Acropora colonies which resisted the bleaching corals”, to begin the process of facilitated restoration and long-term adaptation of the corals to a, and we are propagating bits of these within a coral nursery as bleaching-resistant “super hotter climate. Our nursery presently includes multiple genotypes of eight species of Acropora corals, all of which have become extremely rare on the Atoll and unlikely to recover on their own. Two of these coral species are recognized as globally threatened.

This humble project has broken new ground, and has thus become a leading edge in the battle against coral species extinction and permanent damage to one of the planet’s main life support systems in the face of climate change. Corals for Conservation has in recent years expanded similar work to bleaching affected reefs in Fiji, Tuvalu, Samoa, Vanuatu, and French Polynesia. Additional resources and partnerships must be found to support, expand, and upscale this strategy of securing and propagating bleaching resistant “super corals” to reverse Acropora decline, while facilitating natural adaptation and recovery processes, helping coral reefs withstand increasing temperatures due to climate change.

Introduction

Kiritimati, or Christmas Atoll (Figure 1), and Tabuaeran or Fanning Atoll (Figure 24), in the Line Islands, Kiribati, experienced mass coral bleaching in 2015 and 2016, due to extremely hot waters caused by a strong El Niño event, super-imposed onto increased ocean temperatures due to climate change. Oceanic temperatures remained over the bleaching threshold for corals (29-30°C) continuously for some 10 months (Claar et al, 2019), undoubtedly with considerably hotter patches within the enclosed lagoons. This is the first time in recorded history that coral reefs anywhere have experienced such hot water for such long a time. In 1997-98 these islands experienced nine months of bleaching, which was the former global record. Kiritimati may thus be an important window into the future of coral reefs globally.
http://bulletin.aviso.oceanobs.com/html/produits/indic/enso/welcome_uk.php3
http://www.climatecentral.org/news/coral-reefs-crystal-ball-climate-change-19762

Figure 1. Overview of Kiritimati, showing survey sites as yellow dots, and the Cook Islet nursery in red. The atoll is over 50km long and has the largest land mass of any atoll on the planet. The population of around 7,000 mostly lives in the London/Tabwakea and Banana areas, with an additional settlement at Poland, while Paris is an uninhabited area.

The project began in June 2016 and initial surveys found that an estimated >90% of lobate and massive corals and >99.9% of all branching corals had died (Figure 2), undoubtedly affecting the quality of vital habitat for small fish and crustaceans. This level of coral death due to bleaching is perhaps a first for an entire coral reef system. The inner lagoon was hit particularly hard, with virtually all corals dying (Figure 3), while the outer reef slope and outer lagoon had up to 10-20% survival of massive corals in some areas. Since June 2016, eight trips have been made to Kiritimati to survey for surviving corals and to work on coral restoration alongside the Line Islands Fisheries Department. One trip was made to Tabuaeran as well. This report discusses the results and findings of these trips, as well as the future plans and needs for coral recovery and restoration efforts in the Line Islands.

Figure 2. Very large completely dead *Pocillopora* colony of the fore reef, kept clean by fish grazing.

Figure 3. Completely dead staghorn coral thickets of the shallow inner lagoon, June, 2016. Live-coral associated damselfish were still present, but have since all disappeared.

Coral Nursery Establishment

A coral nursery was established in the proposed Cook Islet Conservation Area in mid-June 2016, focused on the preservation and increase of branching corals that had survived.

However, in the initial June trip only two *Acropora* corals could be located in spite of three days of searching. Of these, one colony was a small remnant of a much larger adult colony that had died (Figure 4), and one was a small 5cm juvenile.

Figure 4. The last standing *Acropora* coral remnant that could be found in June 2016, from a shallow tide pool at Cook Islet. Greater than 90% of the original *A. globiceps* colony had died.

Only four surviving adult Pocillopora colonies could be located at that time, one at Paris and three at the pass near the coral nursery (Figure 5). Extensive searching of the lagoon and shallow outer reef slope found expanses of dead corals, with only a few partially alive massive corals remaining, most with only patches of live tissue

All of the six surviving branching corals found in June 2016 were brought into the nursery. The single colony of juvenile *Acropora* coral was collected with the rock it had settled on, and both of the small surviving branches of digitate *Acropora* were brought in and re–fragmented into seven pieces. The *Pocillopora* "super corals" that had survived completely intact were big enough to trim branches for cultivation. A bright purple plating *Montastrea* that had survived in the extreme conditions of the inner lagoon were also included, the only non-massive super coral we could find surviving in that zone (Figure 10). The surviving massive corals were not sampled, because it would have involved thousands of collections. We therefore chose to focus on the more vulnerable branching coral genera.

Follow up trips were made In November 2016 at four months, in May 2017 at eleven months, in April 2018 at twenty-two months, and in December 2018 at two and a half years, in November 2019, and in March 2020, and with the exception of the last trip, additional corals were added to the nursery each time, with the corals thriving and growing within the nursery (Figures 6, 7, 8 and 9).

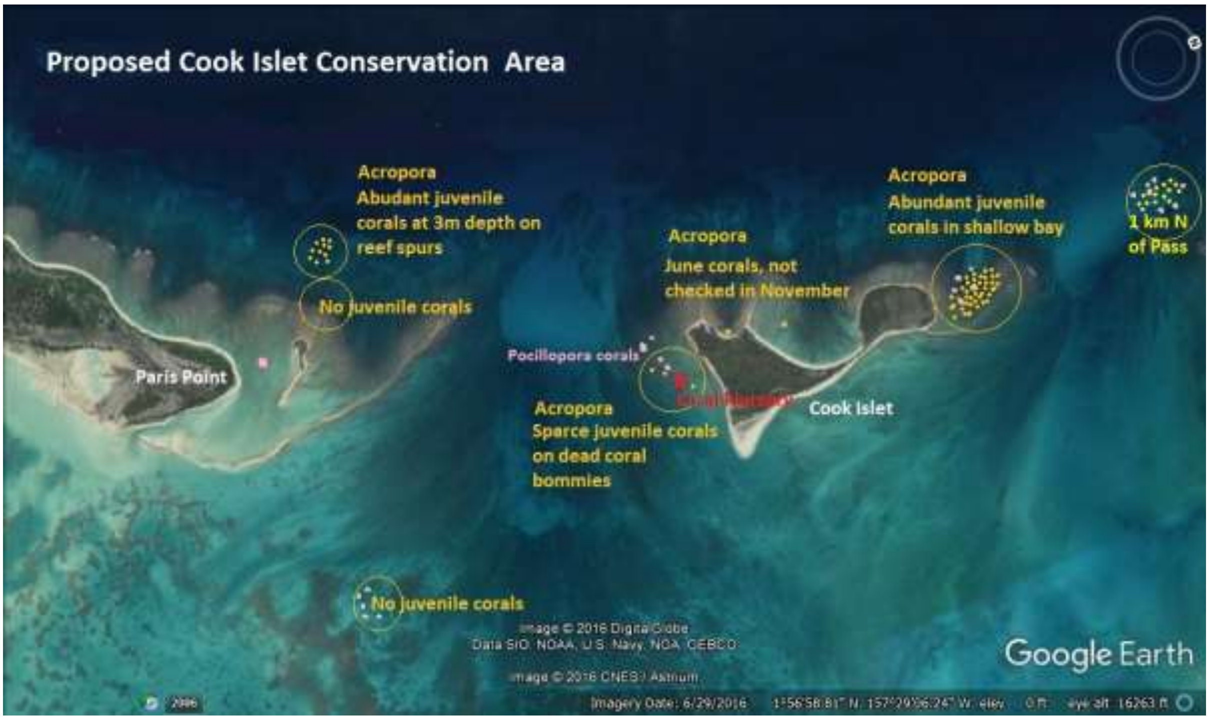

Figure 5. Map of the Cook Islet Conservation Area, Christmas Island, Kiribati, an important seabird nesting island. The location of surviving adult and juvenile corals found at eleven months is marked. ***Pocillopora*** **'super corals' and colonies regenerating from remnants are in pink. On the fourth trip, at 22 months, many of the outer reef areas at 3-4 meters depth (not marked here) had become colonized with juvenile** ***Acropora*** **recruits.**

In November 2016, additional reefs were searched, in the hope of finding additional corals. A scoping of lagoon reefs opposite the pass found no Acropora corals but many other coral species were found to be alive and healthy there, including several massive species such as *Porites*, lobate *Pavona*, and *Leptoserus* brain corals, as well as *Fungia*, *Heliofungia* and four adult colonies of *Pocillopora*. On a site visit to Crystal Beach reef, 8 km North of the pass and in clear waters with abundant fish and sea urchins, one juvenile *Acropora* coral was found, but no living *Pocillopora* corals were seen. The big waves and strong surge confined this search to the deeper portions of the reef flat. An attempt to access the reefs of the North Coast in November failed, due to high surf.

At 11 months, a few coral colonies were removed and re-attached to give more room for growth, as contact was causing *Pocillopora* to kill the purple *Montastrea* colonies. A bright purple genotype of *Pocillopora* was also brought in. At 22 months, the initial *Pocillopora* colonies had grown too big for the table, 25-35cm in diameter, which was sagging and in danger of collapse. The table was reinforced and the original *Pocillopora* corals were out-planted to the reef nearby using cement or placed in shallow reef crevices, discussed later.

Two 40-50cm colonies of pink Pocillopora have thus far been found, one to the north of Cook Islet in April 2017 and another on the outer reef flat at Crystal Beach in May 2018, three and five samples respectively were taken and included in the nursery (Figure 17.11).

Other than cleaning a few hydroids and a small bit of Caulerpa seaweed from the nursery table, the nursery required no maintenance due to the high numbers of herbivorous surgeonfish in the site.

Figure 6. Juvenile *Acropora tenuis* brought into the nursery on the rock it had settled onto with remnant Porites: top left June 2016, top right at four months, bottom left at 11 months, and bottom right at 22 months, April 2018. Freedom of seaweed overgrowth, even with virtually no cleaning, indicates good water quality and abundant herbivorous fish to clean the nursery table.

Figure 7. The Cook Islet coral nursery, showing corals overgrowing the cable strap which secured them to a cement disc and the underlying plastic mesh (left) and the one problematic patch of hydroid which was removed. Note the *Acropora globiceps* coral overgrowth onto the cement base.

Figure 8. Digitate *Acropora globiceps* coral colony divided into seven fragments, one *Pocillopora woodjonesi* colony divided into eight fragments, and one *Montipora petula* colony divided into two fragments. At planting, 5mo., 11mo., and 22mo. Growth, overgrowth of cable straps and robust health is striking, even without maintenance or care. Montipora removed at 12 mo., to prevent crowding and overgrowth.

Figure 9. Twelve coral fragments harvested from bleaching resistant *Pocillopora woodjonesi* "super coral" colonies and planted in the coral nursery. Photos are from June 2016 at planting, November at five months, May 2017 at eleven months, and April, 2018 at 22 months.

Figure 10. The plating coral *Montipora petula*, at two and a half years in the nursery, with two year old Pink *Pocillopora verrucosa*, and various younger digitate Acropora corals.

Larval- Based Coral Recruitment

Searching for corals on subsequent trips became more and more encouraging, as juvenile Acropora corals began recruiting. In November 2016, just five months after the initial trip, we found three ~3cm Acropora recruits near the coral nursery, as well as another 47 juvenile Acropora corals in an enclosed reef bay to the north of Cook Islet (Figures 17.12 and 17.13). These abundant juvenile Acropora corals provide hope for recovery of the coral population over time. Numerous adult and juvenile Pocillopora corals were also observed in this same "coral cove" area (Figure 17.14). Massive Porites and Pavona corals were the most common surviving corals of the area.

Further searching during the November 2016 trip resulted in finding 11 juvenile Acropora colonies on the Paris reef slope, located in 3 meters of water at the top of reef spurs. The new recruits were found among surviving adult Pocillopora colonies which had been overlooked in June, however no juvenile corals and no Pocillopora corals were found in shallower waters at that site.

On the outer reef slope off London, one km North of the pass but still under the influence of warm water leaving the lagoon, 14 juvenile Acropora corals and about six adult-sized Pocillopora colonies were found on the November trip, with no massive corals seen alive. This is a very dead reef, and with murky waters, but with abundant herbivorous fish and black-spined *Diadema* sea urchins.

We noticed that Acropora recruits were most common near surviving adult Pocillopora colonies and massive Pavona corals, which could possibly indicate that these adult corals are serving as a settlement signal for the coral larvae? *Tridacna maxima* clams are also particularly abundant at the coral cove site and might potentially be a settlement signal? Photos of many of the juvenile corals were taken and several are presented in Figure 12.

On the May 2017 trip, we found that the juvenile corals of the cove had grown to 8-12cm in size, with some smaller corals of the 2-4cm size also found, although no adult corals of any Acropora species could be found on Kiritimati which could serve as parent stock, both by our own searching the shallows and by asking divers of the aquarium fish trade who dive daily on many deeper sites in the West and South of the island.

The discovery of so many juvenile corals is a very exciting development in the recovery of the reefs, as we now have multiple genotypes within several of the Acropora species, which gives potential for successful spawning and the formation of planktonic coral larvae in the future, enabling the wider recovery of these locally endangered species through natural larval recruitment processes, and eventually leading to the recovery of this badly damaged coral reef system.

The numerous juvenile corals found on the November 2016 trip must have been present during the initial June 2016 visit, although too small at that time to be seen easily. It appears that the corals have recruited in two events, as there seemed to be two fairly distinct size classes, a 20-40mm size class and 80-120mm size class. Photographic data on colony size was taken but has yet to be analyzed, however predation by parrotfish may affect the size class data.

Figure 11. Searching for and finding juvenile *Acropora* corals on the reef North of Cook Islet, Kiritimati. Note the blue juvenile coral colony among the dead coral rocks.

Figure 12. Juvenile *Acropora* corals of at least species, giving hope for the future recovery of the coral reefs on Kiritimati. Their 3-5cm size range indicates that they are about one year old.

We can only assume that their parents all died in the mass bleaching shortly after they spawned, or perhaps they came in as larvae from another area, possibly Fanning Atoll, which is over 250 kilometers up-current. Another possibility is that polyps detached from the stressed corals and set out as asexual planula larvae, through a process called polyp bailout. Such asexual larvae contain the symbiotic algae and could therefore possibly swim into shaded microhabitats of the reef, potentially settling temporarily and remaining viable until the waters cooled off, at which point they could emerge and settle on the exposed parts of the reef. https://reefbites.wordpress.com/2018/05/16/bailing-out-of-trouble-can-polyp-bailout-save-the-day/ Regardless of origin, these baby corals are exceedingly precious and important to the recovery of the reefs.

May 2017 Nursery Expansion Using Threatened *Acropora* Recruits

The May 2017 visit found all of the corals in the Cook Islet nursery healthy and growing well. The large school of surgeonfish initially seen in the site were still present and had maintained a high level of cleanliness on the nursery table witout any maintenance. No parrrotfish bitemarks or any sort of physical damage was apparent during that visit. The juvenile corals on the coral cove area were revisted, and while they had increased in size, they were still too small for trimming, and had not growing as fast as the corals in the nursery. Many were seen with fresh parrotfish wounds and missing branch tips, which appeared to be the main reason for their slower growth. Due to the ongoing damage from the high abundance of parrotfish in the site, plus a lack of branches long enough for trimming, a decision was made to remove entire colonies- those which could most easily be chiselled off of the hard coral substrate, and to bring then into the expanded coral nursery, away from the threat of so many large parrotfish and overgrowth (Figure 13).

Figure 13. Removing juvenile corals with a hammer and chisel. Note the two surviving lobate coral colonies nearby.

A total of 63 colonies were moved in this way and planted to a new nursery table, which was filled to capacity. Ths collection represents about 10% of an estimated 600 juvenile *Acropora* recruits to the cove (Figures 14, 15, 16).

The new nursery table was located parallel to the initial table and 2M apart, and the tables were secured to one another by 3M metal bars for added strength and to allow space for rope culture of staghorn corals, as is the common set-up in our other sites in the South Pacific and the Caribbean.

No mortality occurred over 19 months, in spite of parrotfish bites to corals at positions located towards the edges and ends of the table, with corals growing an estimateed 5-10 fold over the period in spite of that, and sometimes growing together and beginning to compete with each other for space (Figure 17).   The juvenile corals that we had left on the reef remained much smaller, a third the size or smaller, suppressed by parrotfish predation.

Figure 14. New coral table planted with juvenile corals collected from the field- with the older nursery table in the foreground, planted with three pink *Pocillopora verrucosa* corals, taken from one of two surviving colonies of this species and color morph found thus far.

Figure 15. Close up of the coral nursery, new corals in the foreground and showing a line containing small broken bits from the juvenile corals, which otherwise would likely die.

Figure 16. Close up view of the newly planted juvenile corals, some planted to cement cookies for easy removal when mature, and some planted onto the plastic mesh secured over 2x2 inch iron mesh. While uncertain due to small size, many individuals appear to be *Acropora tenuis, Acropora selago,* or *A. globiceps*.

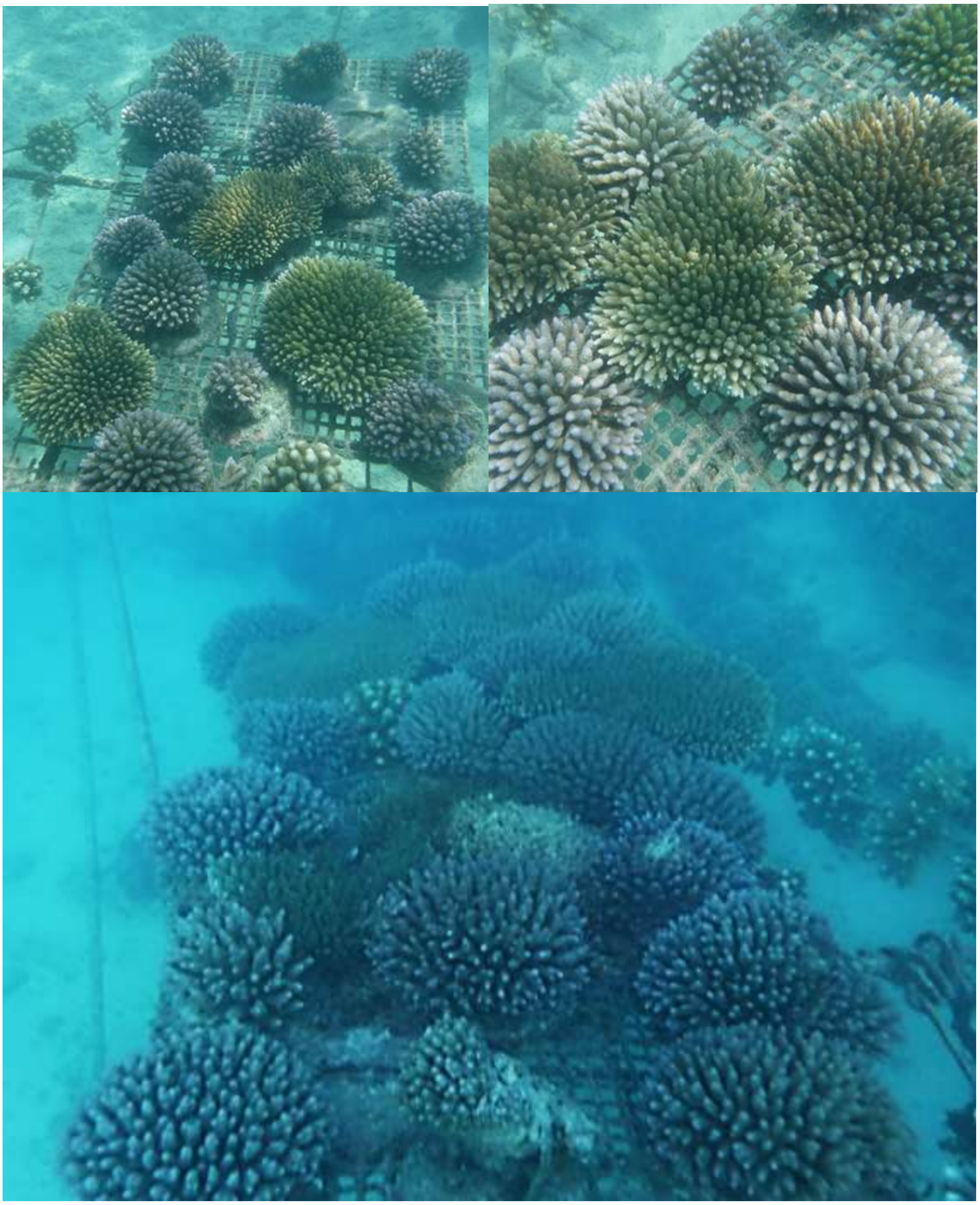

Figure 17. The coral tables 10 months after planting (April 2018), at 17 months (December 2018), and at two years and 5 months (November 2019), when mortality of *A. selago* was occurring due to crowding, and when one end of the table collapsed durig a high wave event.

Within two years the corals on the nursery table had grown very big, some >30cm across, and overcrowding each other, with A. selago (brown in the photos) experiencing some mortality due to competition, and apparently being the faster grower but the inferrior competitor.   The corals which we had left on the source reef were estimated to be only a quarter the size, so our strategy had worked well (Figures 16,17).

The Discovery of Regenerating Coral Colonies via Surviving Tissue Fragments

In spite of the difficulty of accessing the reef front zone, site visits were made in May 2017 to the shallow <0.5M reef flat zone at Poland on the southwest of the Atoll, at Crystal Beach on the northwest, and to the reef flat at the Airport on the northeast of Kiritimati (Figure 18). After extensive searching, we found multiple small *Acropora* colonies regenerating in the northern two of the three sites, at Crystal Beach and at the Airport reef, all in direct association with dead Acropora colonies. In the two 2018 visits additional regenerating populations were found west of the Airport. Rather than being larval recruits, these "resurrection corals" appear to have regenerated from micro-tissue remnants on much bigger micro-atoll coral colonies in the extreme shallows, all very near the shore. From one to twenty small colonies were found per remnant poplation, with all multiple colonies within a population having identical and distinct coloration- yellow with green polyps, blue tipped, purple, cream, or brown, and representing what appears to be more than one tightly-branched coral species (Figures 19, 20). These remnant colonies were always found on dead acropora branches of similar growth form, most often on the dead colony edges (Figure 19). Single colonies with these characteristics are also assumed to be remnants, although that is uncertain (Figure 21). From the apperance of the remnant colonies, it appears that small areas of coral tissue must have survived in the shaded depths of the original larger colonies, or perhaps on the colony edges under shaded overhangs.

Figure 18. Airport reef flat, with the location of remnant Acropora corals marked. An estimated 700 meters of the nearshore was surveyed and 6-7 genotypes found of what appears to be *Acropora tenuis or A. nasuta,* and perhaps one or two other species.

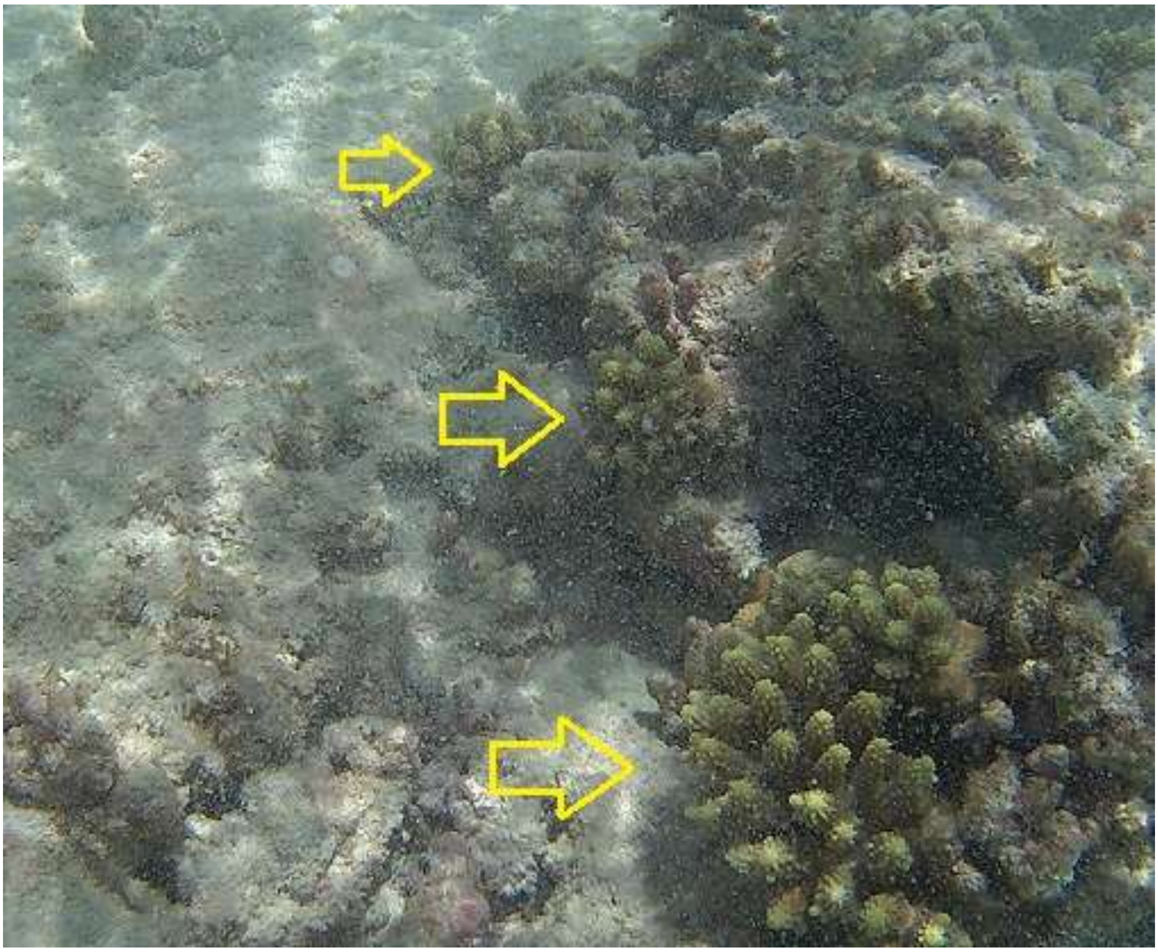

Figure 19. Remnant colonies of *Acropora*, possibly *A. retusa*, with over 15 small colonies of identical form and coloration found in this immediate location.

A total of what is though to reprsent six different genotypes of coral were found at Crystal Beach, with eleven found at the airport reef flat, indicating that there could be thousands of genotypes of reef flat adapted Acropora corals surviving on Kiritimati, a very promising finding indicating a slow recovery of formerly abundant species in progress.

Ressurrection coral colonies were collected from Crystal Beach in May 2018 and from the Airport in December 2018 (Figures 22, 23) and brought into the coral nursery.

Recovery via resurrection corals is patchy and is not everywhere. A similar extensive search at the Poland reef flat on the south of the atoll found no such remnants, in spite of an abundance of dead Acropora skeletons.

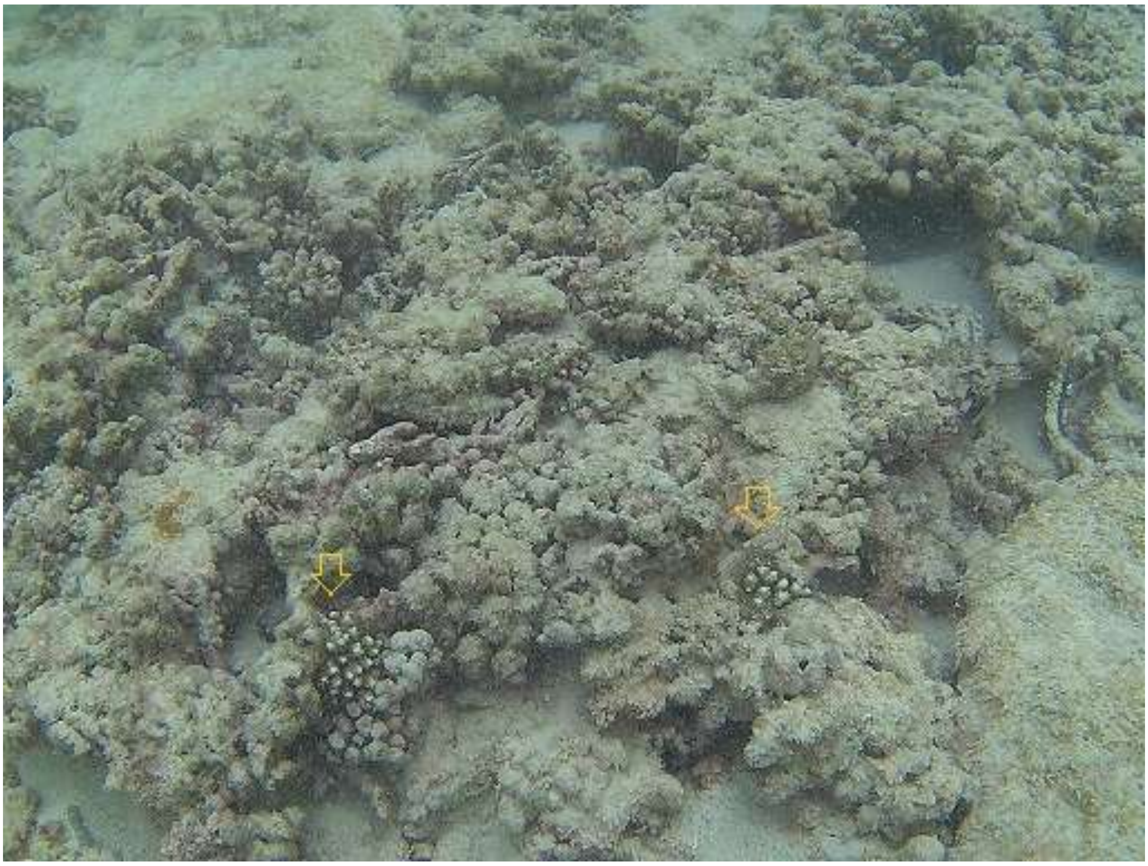

Figure 20. Remnant colonies on the edges of a once much larger reef flat colony of *Acropora*. Over one year since the die off, coraline algae are infilling between the dead branches and overgrowth of algal turf is making the original skeleton more and more difficult to discern.

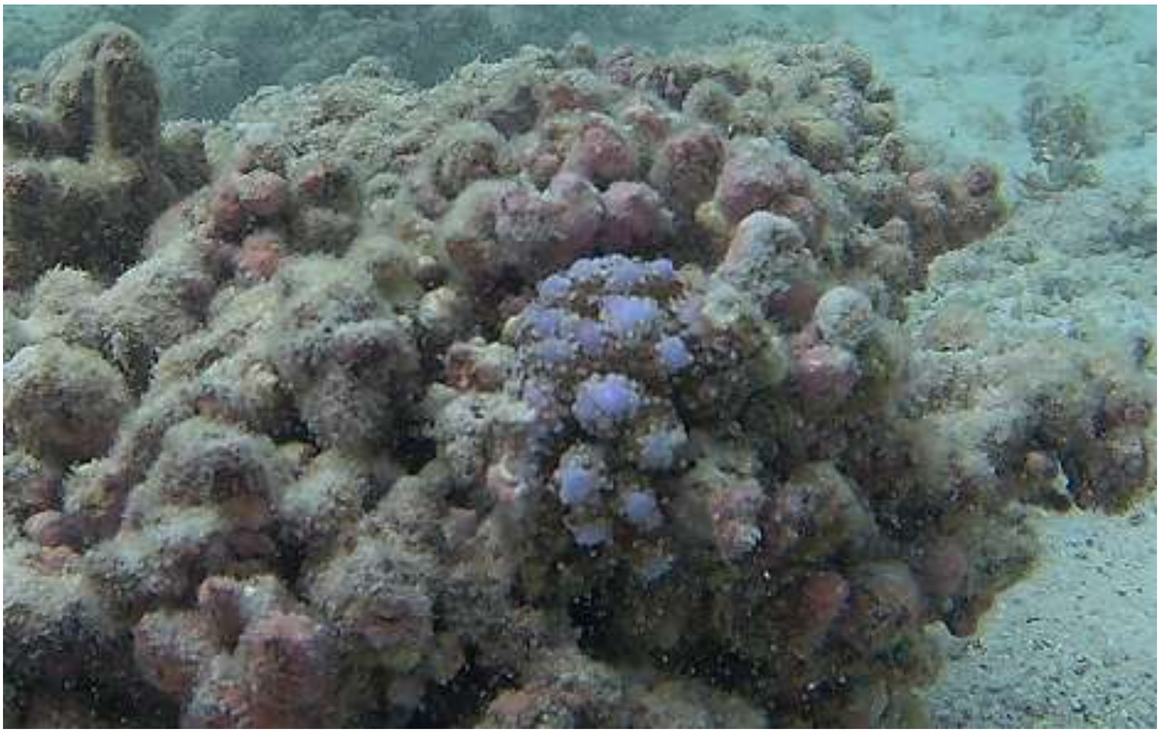

Figure 21. Solitary coral assumed to be a remnant "ressurection" coral growing from within the deep branches, rather than a sexual recruit. Note the old, dead Acropora seleton.

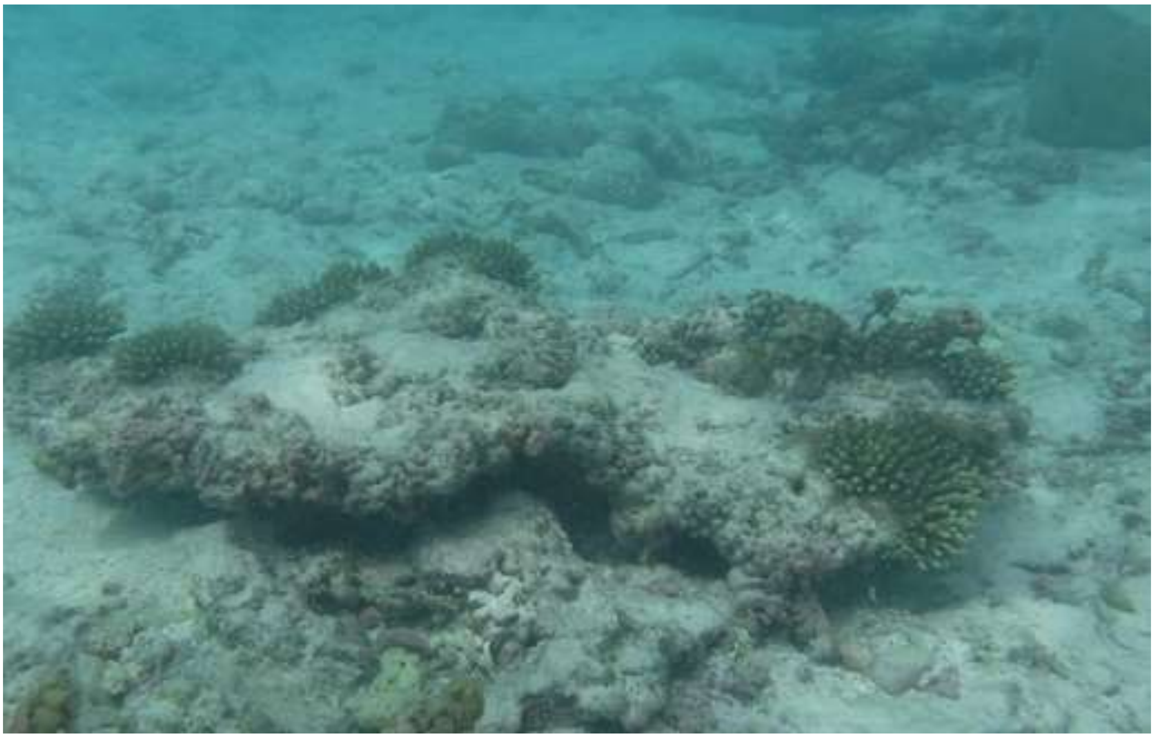

Figure 22. December 2018, two years post-bleaching, with the 'ressurection' corals growing and spreading and gradually rejuvenating the original coral colony on the reef flat.

Figure 23. Close up of the *Acropora* 'resurrection' corals at two years post bleaching. Note the *Pocillopora* larval recruit towards the top of the photo. Surviving *Pocillopora* corals have the ability of re-seeding the reef with asexually generated, internally brooded, coral larvae. Such recruits would have the same internal algae and thus the same thermal tolerance as their mother.

Tabuaeran Findings

A trip to Tabuaeran, also known as Fanning Atoll (Figure 24), some 200km distant from Kiritimati, was carried out in May 2017 to assess the impact of the mass bleaching there, and to seek out staghorn corals which had apparently become extinct on Kiritimati. Due to logistics and time, only one scoping trip into the lagoon was possible, accompanied by the local Fisheries officer. We surveyed a transect of lagoon reefs from north to south. The devastation of many of these reefs was virtually complete - almost no corals found alive, and with some of the very biggest Pocillopora coral heads I had ever seen completely dead. However, on four reefs, among the devastation of dead and standing colonies, we found four surviving populations of staghorn coral, *Acropora muricata*, as well as *A. vaughani* and possibly 1-2 other *Acropora* species to be confirmed at a later date.

Figure 24. Tabuaeran or Fanning Atoll, showing the approximate area surveyed.

The fact that no coral-killing COTS were seen and only few Drupela snails were present may have been significant in the survival of these corals after the demise of a conservatively estimated 90% of the coral population in the lagoon.

Due to the rough seas, and despite two attempts, we were unable to get out to the oceanic outer reefs, however several fishermen confirmed that while most of the corals are now dead, some living corals of the sorts that are often blue or purple- the Acropora corals, continue to survive. While this must be confirmed at a future date, the hypothesis that the small juvenile corals coming into Kiritimati are from Tabuaeran has been strengthened.

Samples of 10cm coral branches were taken from each of the staghorn coral populations that we found, and put on board in a shaded bucket filled with seawater, changing the water several times during the day. The purpose was to collect as diverse a set of corals as possible for inclusion in the coral nursery on Kiritimati, the voluen of which amounted to about half of a four gallon bucket full, and representing both fine and robust branched species and a diversity of color morphs within each species. It is impractical at this point to create a coral nursey or gene bank on Fanning Atoll, as it is quite difficult and expensive to get to for follow up.

The sampled corals were immediately taken to shore and planted onto ropes which were then temporarily strung between existing metal stakes in the subtidal zone near the main settlement. These planted ropes were removed two days later, three hours before the flight back to Christmas Island, carried on board in a bucket, periodically sprinkled with seawater during the 45 minute flight. We were met by Kiritimati Fisheries officers on landing, and the corals were rushed by land to a waiting boat, and taken into the coral nursery and planted by simply tying the ropes onto the expanded nursery structure (Figure 25).

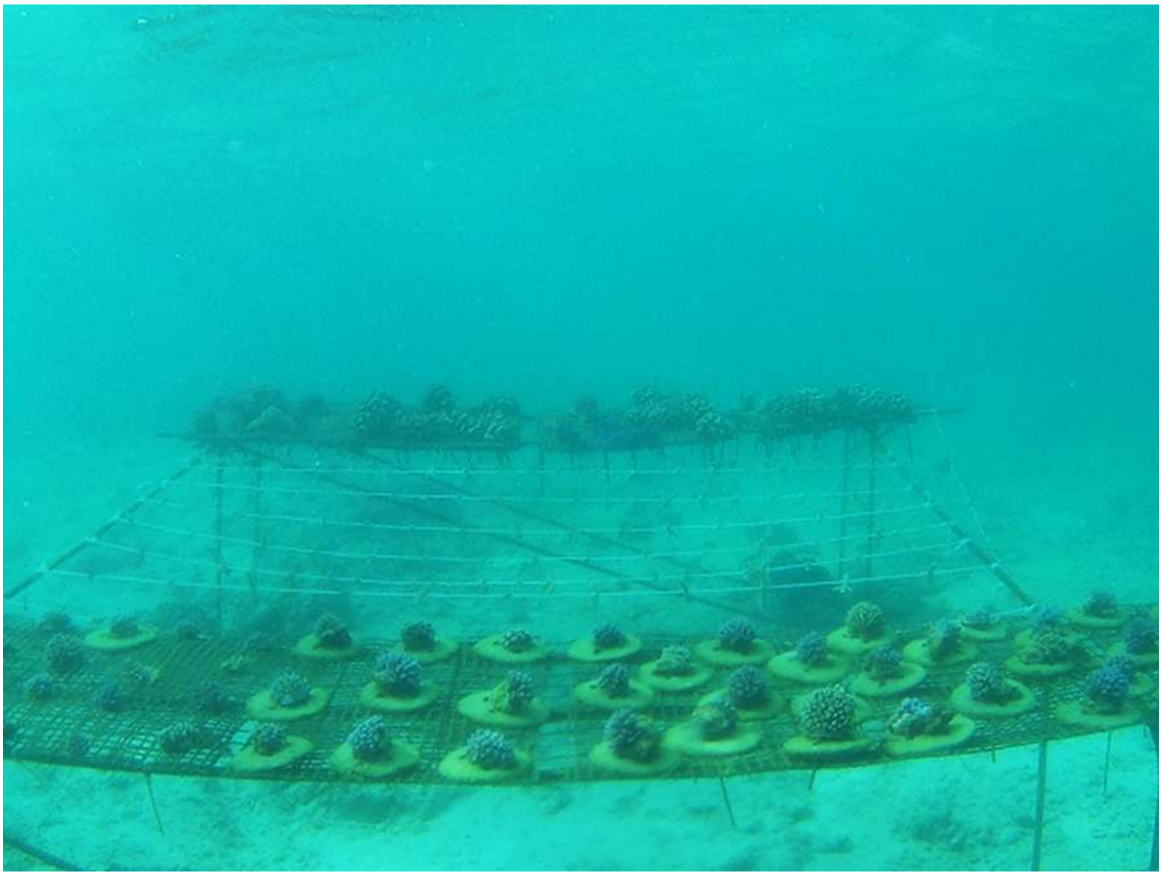

Figure 25. Overview of the expanded and completed coral nursery at the Cook Islet site, Christmas Island, 1st June 2017, with table culture for tight-branched Acropora and *Pocillopora* coral species and with rope culture for the open-branched staghorn Acropora species.

Our underlying assumption with moving these corals is that the corals of Fanning are quite close to Christmas Island geographically, existing with mere days upccurrent, so that they share the same ecoregion with Christmas Island. Moving corals between ecoregions is not promoted in our work.

Progress in the Cook Islet Coral Nursery

The corals, from whatever source, once in the nursery, suffered no mortality, despite the stress of collection and transport, and all corals were thriving when visited a year later (Figure 26). However, growth at one year for most species has been somewhat dissappointing, as the corals had only doubled or tripled in size in their first year, less than the expected ten-fold or greater increase which is typical of Acropora corals using similar methods elsewhere. The reason for this slow growth soon became apparent, as numerous parrotfish bites covered the corals, with the staghorn corals on the ropes particularly targeted (Figure 27). While the Pocillopora corals on the tables had no evidence of any bites, the *Acropora* corals on the tables were sometimes heavily impacted (Figure 28).

In order to explore a nursery site mostly free of parrotfish, two of the staghorn ropes were moved to a new nursery site at Motutapu reef where parrotfish are scarce, and the positive results are seen six months later in Figure 29. While the problem of parotfish predation seems to have lessened by December 2018, it continues to be a factor in slower growth.

In November 2019, one of the two main coral nursery tables, planted with coral cookies collapsed during a large wave event. The corals affected were those which we had taken from the reef as small ~5cm juveniles. They had become very big, some >30cm, and many times bigger that the colonies which we had left on the reef, proving the efficacy of our nursery in helping protect the corals from parrotfish predation. However the corals had been planted only 20-30com apart, which proved to be too close together for that time period, and competition was impacting the fast growing sub-tabulate corals negatively (Figure). The table was repaired and about 1/3 of the corals we replanted to the adjacent reef, scattered onto rubble and wedged into cracks in the stones. The rest of the corals were replanted back to the repaired and expanded table, with more space between them. As the cement available was old and of poor quality, our attempt to make coral planting 'cookies' failed, so we developed a new method of using common, flat tabulate coral stones from the beach, tying the corals onto the stones with fishing line.

Four months later, in March 2020, these corals replanted to the table were all thriving, however virtually everything replanted to the adjacent reef had disappeared without a trace, presumably eaten by parrotfish.

The coral rope nursery was also doubled in size in November 2019, to give more space for coral growth, as the corals were becoming crowded, with very other rope moved onto the new section, which is connected to the original structure for increased stability of the nursery. Additional collection of reef flat *A robusta* corals was also done and three additional ropes of several genotypes and color morphs were created and added to this nursery extension.

Figure 26. Rope nursery planted with several species of bleaching-resistant staghorn corals brought from Fanning Atoll to the Christmas Atoll nursery, at planting May 2017, and one year later, May 2018.

Figure 27. Parrotfish bite marks clearly visible in May 2018, resulting in slower growth, but no mortality occurring.

Figure 28. ***Acropora tenuis*** **corals on the nursery table at May 2018, some damaged by parrotfish bites.**

Figure 29. Cook Islet nursery at 17 months, December 2018. Comparisons of staghorn coral lines grown at Cook Islet (top and bottom left) and Motutapu (bottom right) for six months, with obvious branch shortening due to parrotfish bites, versus the site with few parrotfish.

Figure 30. The coral nursery in March, 2020. The slow growth and rounded shapes are largely the result of parrotfish grazing. The corals which appear broken, were those trimmed for outplanting.

Discovery of Surviving Staghorn Corals on a Kiritimati Reef Flat

In December, 2018 while scoping for regenerating corals on the reef flat, a remnant population of thick branched, blunt tipped, staghorn corals, *Acropora robusta* was discovered to the West of the Airport at "Crusher Reef". This is the first of this species that we have found alive. The area surveyed has the widest reef flat on the island (Figure 31). Among the dead and standing coral colonies dominating the reef flat (Figure 32), were a few surviving branches of the species (Figure 33a), plus one coral thicket was alive on all sides-which looks to be a true "super coral" not suffering from any significant mortality during the bleaching (Figure 33b). Surviving *Acropora globiceps* remnants were also found on the reef flat (Figure 34), adding a second genotype of the species that survived into the nursery.

Figure 31. The reef flat at Crusher Reef, with remnant staghorn corals marked.


Figure 32. Dead and standing *Acropora* and *Pocilliopora* corals, nearly three years after their death in 2015-16. A living massive *Porites* colony is in the foreground.

Figure 33. Three color morphs of regenerating/ remnant *Acropora robusta* staghorn corals, each thought to be a different coral genotype (top). And the sole intact adult staghorn coral colony survivor of the 14-month bleaching event (bottom), found in December 2018 among dead and standing coral colonies of the same species on the shallow reef flat at Crusher Reef, Kiritimati.

Figure 34. Dead *Acropora globiceps* coral colony and a regenerating *colony- a* "resurrection coral" at Crusher Reef flat.

List of Acropora coral species found in the Line Islands thus far, with comparisons to the species list from Fanning Atoll by Marigos, 1974.

Putting species names to the corals has been somewhat problematic, due to the prevalence of parrotfish bites at the nursery site, which as altered the shape of colonies and caused them to grow into tight multi-branched balls, not generally seen in nature. Once we find better grow-out areas, the taxonomy will become easier. It is possible that we may have underestimated the number of species collected thus far.

Species of Maragos 1974 confirmed* or otherwise found as new species:
<u>*Acropora muricata*</u>* (synonym for *A. formosa* in Maragos, 1974) staghorn coral of lagoons. Dead and standing thickets of this species dominate the inner lagoon of Kiritimati, but now apparently locally extinct. Found in the lagoon on Tabuaeran at several sites and brought into the Kiritimati nursery.
<u>*Acropora robusta*</u> Thick branched reef flat staghorn coral similar to *A. itermedia*
<u>*Acropora globiceps*</u> Found as remnants of a large colony at Cook Islet and Crusher Reef flat, and some appear to be coming in as larval recruits. Recognized internationally as a threatened coral species.
<u>*Acropora cerealis*</u> (synonym of *A. cymbicyathus of Maragos, 1974*) Forms small tables with interlocking branches. *Found as remnants on Tabuarean and brought into the Kiritimati nursery. Not found on Kiritimati as of yet.*
<u>*Acropora vaughani*</u> * (similar to *A. horrida*), forms bushy clumps on upper reef slope and lagoons, at micro-level it takes on a small staghorn growth form, often with blue tips. *Not yet found in the wild on Christmas Island, but collected in Fanning Lagoon and brought into the Christmas Island nursery.*
<u>*Acropora retusa*</u> *Regenerating uniform golden brown corals found at Crusher and nearby reef flats as 'resurrection' colonies, clearly showing the compact corymbose growth form of the original colonies. Recognized internationally as a threatened species.*
<u>*Acropora selago*</u> * (synonym of *A. delicatula* of Maragos, 1974) similar to *A tenuis* but forming tables, upper reef slopes and lagoons. Coming in as new recruits in some areas. Uniformly grey color in Kiritimati, and with polyps often extended during the day.
<u>*Acropora tenuis*</u> Delicate tubular branches similar to *A. nasuta or Maragos, 1974*, upper reef slopes. A major component of the new recruits and the major recovering reef flat species regenerating from surviving micro tissues.

Species not yet found
<u>*Acropora florida*</u> (synonym of *Acropora polymorpha* of Maragos report), large upright staghorn corals with very short side branches
<u>*Acropora longicyanthus*</u>, (synonym of *Acropora syringodes* of the Maragos report), bottlebrush Acropora of lagoons
<u>*Acropora cytherea*</u> (synonym of *A. reticulata* of the Maragos report), large, flat, table corals, blue, cream, or brown, upper slopes and lagoons.

A. abrotanoides Similar to A. robusta. Shallow reef environments, especially reef margins exposed to strong wave action.
A. humilis finger-like Acropora, similar to *A. gemnifera,* which has more tapered branches, found on reef slopes and reef flats.
Acropora corymbosa No longer a valid species name, and not know what this represents in the Maragos report, perhaps another table species.

A synopsis report for Palmyra Atoll (Williams et al, 2008), a US territory in the Northern Line Islands, and with considerable time spent on multiple collections over several years, gives a total of 38 species of Acropora for Palmyra, considerably more than the 11 acropora species reported by Maragos for Tabuaeran in 1974. We have thus far only found a total of 5 acropora species surviving on Kiritimati, with 3 additional species brought in from Tabuaeran, to make 8 acropora species in the coral nursery presently.

Two of the Acropora species that we have found surviving on Kiritimati, *A. globiceps* and *A. retusa*, were not found on Tabuaeran by Maragos in 1974. Both of these species have in recent years been recognized and listed as threatened corals internationally.

We consider the absense of so many coral species formerly present concerning, and at the current rates of natural recovery, it appears that only two of the eight remnant acropora species, *A. selago* and *A. tenuis* will in future years be able to reproduce and recover on their own, without assistance, due to the presence of numerous juvenile colonies recruiting to reef flats and in the shallows, coming from an unknown larval source, whether sexual or asexual. Also considerable numbers of these two species are regenerating as clusters of “resurrection” corals on reef flats. However, if another mass bleaching hits early on, even these corals might become locally extinct due to their present low abundance. Our strategy to minimize this threat is to maintain populations of the surviving Acropora corals in cooler waters around the atoll, and at present our coral nursery is located at a major lagoon pass with good water flow, open to oceanic water exchange.

The species recovery plan we have implemented focuses on increasing the biomass of each Acropora species in the nursery, with as much of the surviving genetic diversity remaining as possible, and then outpanting to dense patches in areas of lower parrotfish abundance, order to restore sexual reproduction in each coral species, so that larvae will be generated and can settle onto the wider reefs, which are presently dominated by pink crustose corraline algae, an ideal settlement surface. Our strategy assumes that the bleaching already past will be a rare and extreme occurrence, and that the surviving corals are also more resistant, and that the incoming coral recruits, as they acquire their algae from the remnant coral population, will have a higher likelihood of being bleaching resistant than the former coral population. This is the approach we are using in Fiji and a similar approach is being carried out with endangered Acropora corals in the Caribbean (Kuffner et al, 2020).

Out-planting of Corals from the Nursery

In May of 2018 the original nursery table was being weighed down by heavy adult-sized *Pocillopora woodjonesi* corals, which had grown from small fragments over the two years. All of the original 24 colonies of four genotypes of these corals had survived and grown 20-30cm in diameter at 22 months (Figure 35). These corals were harvested and planted nearby, with several cemented securely to dead corals. However, as cementing proved difficult due to the motion of the currents, the majority of the colonies were then planted without any attachment onto the reef about 30 meters away, wedged within the grooves of a large dead lobate coral head into a 3-4 meter circular area (Figure 36). In December, six months later, all colonies were healthy, with no mortality or partial mortality, and most of the colonies had self-attached firmly to the substrate. Two colonies had turned sideways, but most were still in the bottom-down position.

By March 2020, the corals of this aggregation had increased in size and continued to thrive, with no mortality and no parrotfish bite marks observed. This genetically diverse cluster of adult-sized colonies should now be a spawning aggregation, and is located where they can also continue to serve as mother colonies for trimmed fragments in the coming months and years, as needed. We found that *Pocillopora* is avoided by parrotfish, as it has a much denser skeleton, and so bite marks are rare, and its growth is not impacted by parrotfish.

Figure 35. ***Pocillopora woodjonesi*** **coral colonies at 22 months ready for removal for outplanting.**

Figure 36. Harvested *Pocillopora woodjonesi* corals at 22 months (top) and the result of out-planting six months later- self-attached and healthy.   24 colonies of four genotypes ~30cm in diameter, have now become a diverse cluster able to spawn, and located where they can continue to serve as mother colonies to produce trimmed fragments for more work.

An experimental out-planting of small 2-3cm branches of *Acropora selago* corals, trimmed from colonies growing on the nursery table, was also trialed in May 2018. Multiple branch tips of the same genotype were set together into balls of wet cement placed onto dead corals near the nursery, however parrotfish bit the branches completely off within 48 hours. It was thought that the corals were dead, however in December, some five months later, we found that tiny microfragments of flesh had survived and had grown together to form viable patches of live coral tissue, 5-10cm wide (Figure 37). In subsequent months, branches were seen forming in the tissue discs, and although elongation was expected in the coming months, the branches failed to emerge. By 22 months, the discs continued to hold their own, but had not expand much more over the rock, and the tiny apical buds which formed been obviously been bitten off by chronic parrotfish predation. A tiny Tridacna maxima clam recruited to the edge of the coral disc and grew more than ten-fold in size over the same period, burrowing into the rock for protectionm (Figure 37).

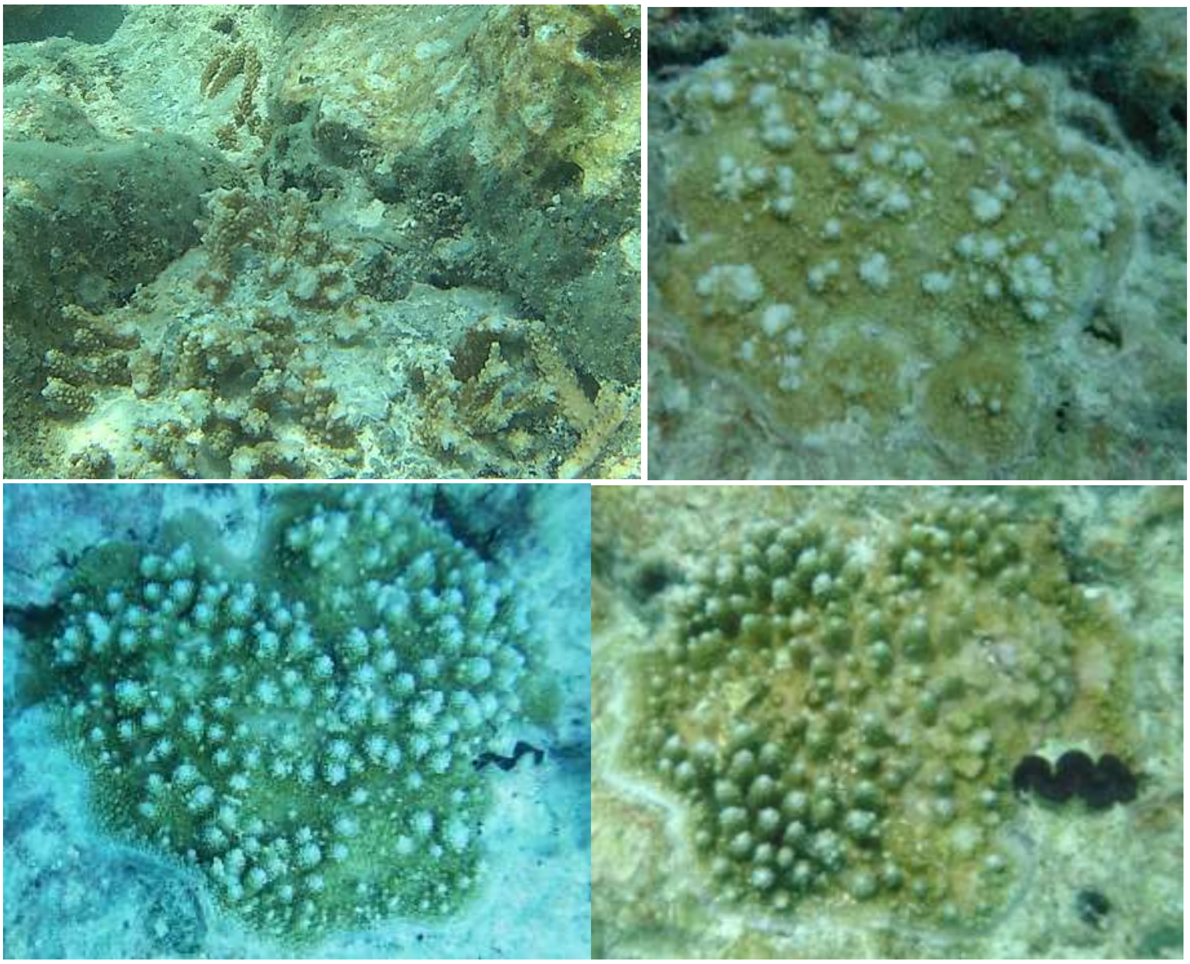

Figure 37. *Acropora selago* planted and then bitten off by parrotfish (May 2018, top left). Surviving micro-fragments merge at six months, (Nov 2018, top right), form branches (Nov 2019, bottom left) and continue to struggle against parrotfish bites (March 2020, bottom right). Coral growth is suppressed over a 22 month period, but note the adjacent *Tridacna* clam which recruited and grew rapidly over the same time period.

Directly adjacent within 3 meters, on the coral nursery table, the same species of corals were able to grow and to maintain a tightly branched growth form, with branches over 10cm long. The tightly branched form appears to protect coral branches from being bitten off, with the fish only being able to nibble and not able to get a good bite. This protection is lost with branches planted to the reef rocks and with spaces between the branches, as this enables the fish to get a good bite. However, it is striking that just being elevated onto the nursery tables helps the corals avoid predation for unknown reasons, perhaps simply by confusing the normal foraging patterns of the fish?

In March 2020, as some nursery ropes were too close together and becoming heavy (Figure 38), so the corals of two of these original ropes were cut apart and the coral colonies planted onto a heavy 20x20cm wire mesh A-frame, painted with “rust-kill” oil based paint several months beforehand. (Figures 39, 40). This was done as an experiment in methodology, to determine the best way of growing the mother corals to a very large size that ropes might not be able to support. We are also interested in trailing the method for its relative effectiveness, as far as being able to survive parrotfish predation. The method would be possible for reef flats, sandy areas, and even areas of surge, securing the frames with concrete nails at multiple points, driven into the reef rock and tied with cable ties. The method would also be easier than cementing colonies onto the reef. The potential is to create multiple outplanting frames, with multiple genotypes of each species of corals per frame, and after completed, to place the planted frames onto degraded reef areas of the lagoon and reef slope, creating spawning aggregations of corals so that natural larval formation processes are restored and increased larval-based recovery facilitated. We have used this method effectively in the Caribbean with Acropora corals, serving to elevate the corals over sand and rubble substrates. The corals overgrow the frame with time, and the frame lasts for up to ten years, transforming into a permanent coral thicket.

Figure 38. Acropora coral colonies from Tabuaeran becoming heavy in the nursery, harvested and cut apart for planting to an experimental A-frame grow-out nursery.

Figure 39. Planting corals cut from nursery ropes onto the welded mesh A-frame, using cable ties.

Figure 40. Planted A-frame in place beside the nursery, tied in to the nursery structure with metal bars for added stability.

The first major outplanting of Acropora corals took place in March of 2020, using the pegged rope method, with the the nursery rope corals trimmed (Figures 41, 42) and branches woven into 2.5 meter long sections of 5mm rope.

Figure 41. Trimming rope nursery corals to produce seed fragments for outplanting.

About 300 fragments in the 2-10cm range were planted in this manner on ten outplanting ropes nailed into place on dead reef rock with concrete nails. Two sites were trialed, one with seven ropes near the coral nursery, and another with three ropes at Tabwakea village. The pegged ropes were all planted into shallow higher energy reef areas in an attempt to avoid parrotfish damage. Both efforts involved youth from the communities as an educational exercise (Figures 43, 44).

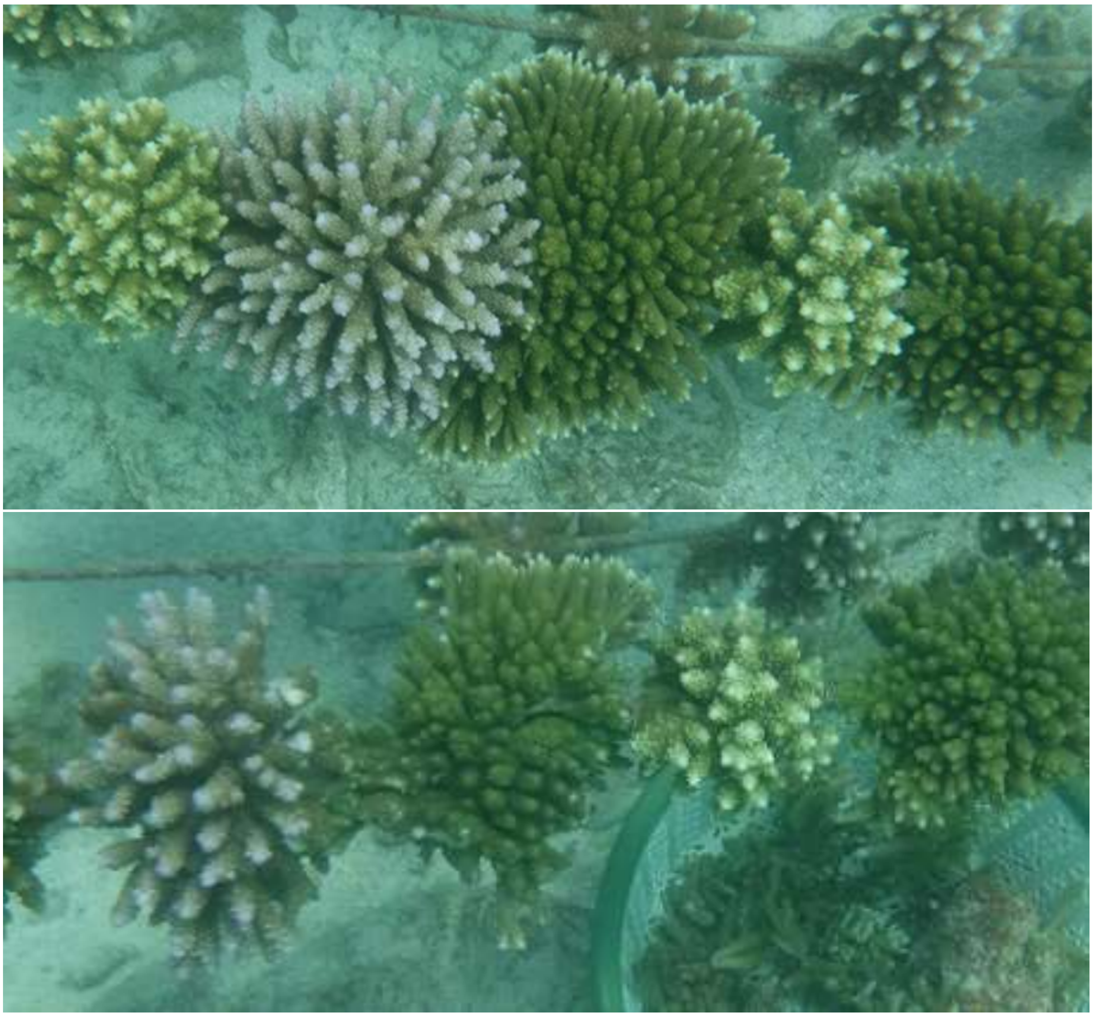

Figure 42. Trimming corals to prevent competition, while creating seed corals for outplanting. Before (top) and after (bottom). March 2020.

The success of the pegged rope method may be largely dependent on the prevalence of parrotfish grazing on the corals, and microhabitat seems to be important in the relative density of parrotfish bite marks on the dead corals rocks (Figure 45), and so even minor depth changes and wave action may have a major impact.

Figures 43 and 44. Youth involvement in the project: creating outplanting ropes at Tabwakea Village, Kiritimati, March 2020. The outplanting ropes were nailed into place onto dead reef rock, in what is now a coral-free surf zone, too rough and shallow for parrotfish to graze, except for on rare calm days.

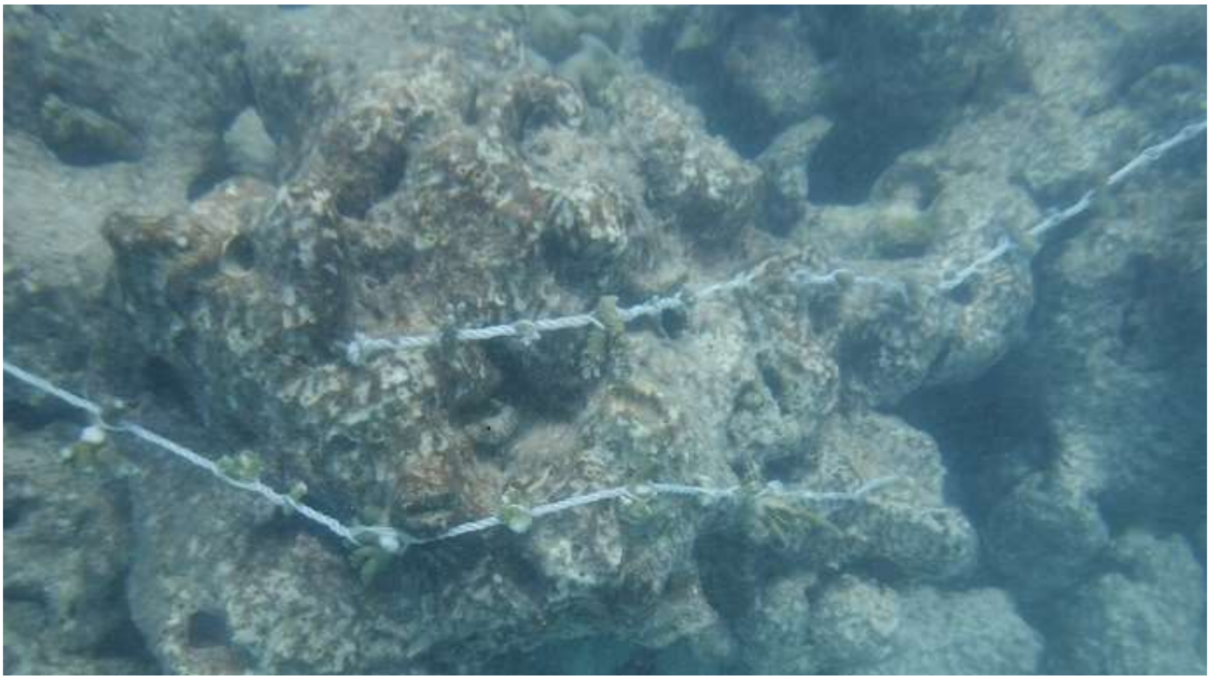

Figure 45. Outplanting ropes nailed onto reef rock near the coral nursery. Parrotfish bite marks are dense and pock patches of the rocks at this site, but are quite variable at microscale, and are less in the shallower areas. Parrotfish grazing may prevent outplanting success at this site, or it might give mixed results based on differences in depth.

Future Outplanting

While an assessment must be done, we predict that the coral out-plants in Tabwakea will escape most parrotfish predation due to the high wave action there. However, we expect that the out-planted corals near the coral nursery site might get mostly eaten, and if so, the next step might be to expand the rope nursery in order to grow the next series of outplanting ropes for several months before outplanting, as the parrotfish do not seem to be able to take bites effectively when the corals are on ropes. The idea is to grow the coral fragments into small tightly-branched colonies before outplanting them. However, based on results, the outplanting focus might be diverted to Tabwakea. Another strategy would be to out plant the corals to shallow reef flats, where larger parrotfish are not present. To locate the corals in cooler waters with less chance of overheating, we should seek out areas on the main outer reef shelf spur and groove system that are high in shark abundance and thus lower in parrotfish abundance. Such areas exist right offshore to Cook Island nursery.

Inevitably, more scoping work should be done to identify restoration sites in the lagoon with fewer parrotfish. Motutapu is a potential site, however whatever we plant there might be killed in the next mass bleaching, as the site gets so hot, so a cooler water site between the Cook Islet nursery and Motutapu would possibly be better. A-frames would be the most efficient method for sandy and rubble environments.

The original ropes of mother colonies continue to grow and are becoming heavy and too close together in the nursery, so additional trimming of the corals is needed, used to prepare outplanting ropes. The nursery should also be expanded to incorporate the head-starting of the outplanting ropes destined for restoration sites with abundant parrotfish.

Strategy for the Future

The various staghorn and digitate *Acropora* corals within the nursery have now grown into larger ‘’mother colonies’’, which can be trimmed once or twice per year to produce hundreds of second generation “seed fragments” for replanting into restoraion patches on limited areas on the main reef, both inside the lagoon and outside, creating diverse aggregations of each species (Figure 46). The stategy is to restore reproduction among the corals and thus facilitate natural coral reef recovery.

We do not plan to replant extensive areas with corals, but to rather create numerous genetically diverse patches for each species within limited areas of one to four meters square. The methods planned can be seen in Figures 47 and 48. For tightly branched species of *Acropora*, only the cementation method will be used, due to their short branches and slower growth.

Figure 46. Proposed restoration plan for 2019-21 Cook Islet Nursery, Kiritimati Atoll.

Figure 47. Pegged rope method of coral outplanting. The corals are trimmed from mother stock to create single species outplanting ropes of diverse coral genotypes, which are then pegged onto dead reef areas with concrete nails. A single rope will grow into a genetically diverse population capable of breeding. Photos from Belize.

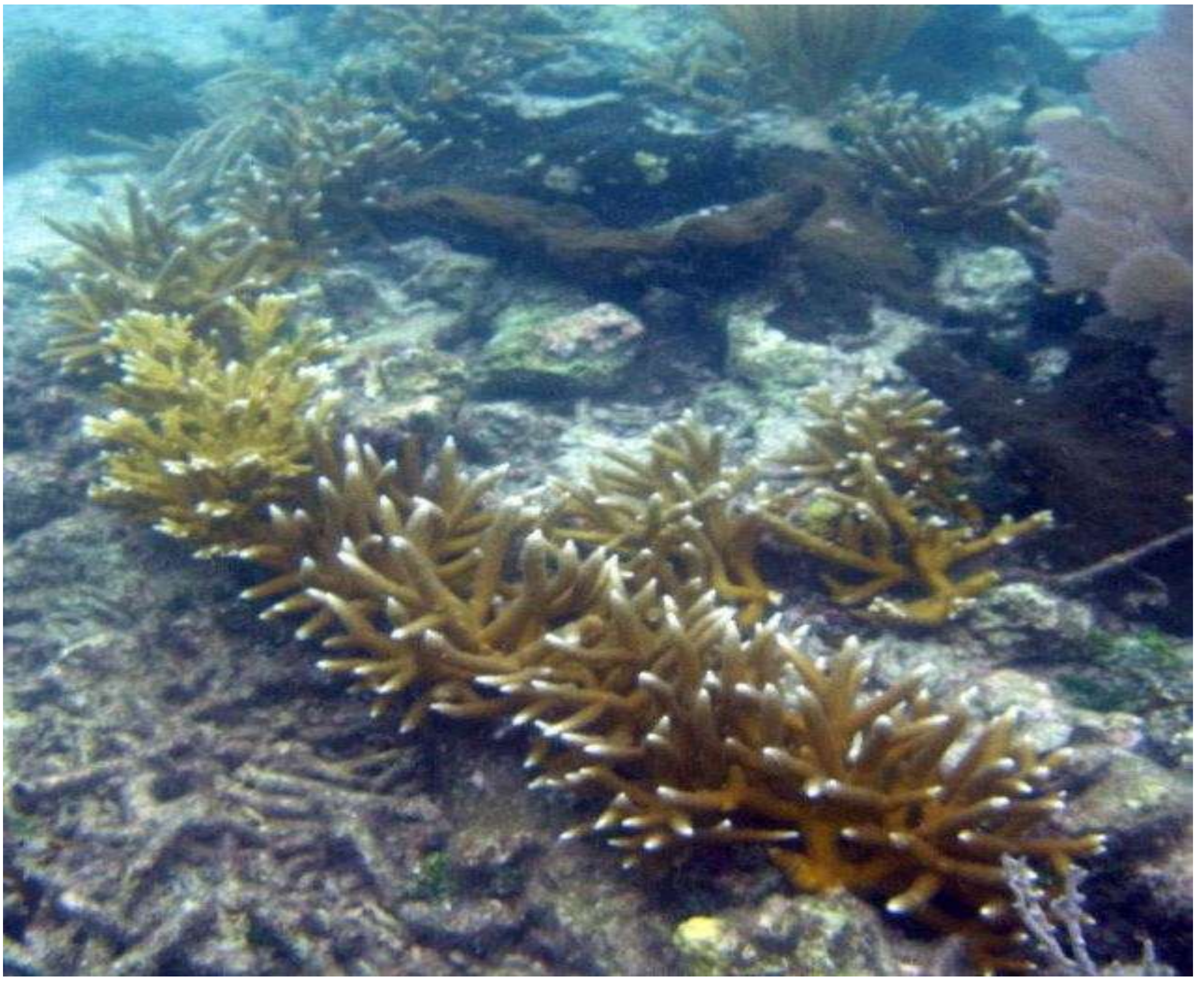

Figure 48. Pegged rope outplants in Belize at one year. The corals are strongly self-attached to the reef and have merged into a linear super-colony of diverse genotypes capable of spawning. At least three outplanting ropes are used per restoration site to increase the chances of successful breeding.

CORAL REEF RESTORATION STRATEGY FOR KIRIBATI

Christmas Island, Kiritimati, is a very large Atoll, and millions of corals have perished in the recent mass-bleaching event, therefore it will be impossible to replant corals everywhere on the island's damaged coral reefs. Outplanting large areas of dead coral reef is not our operational strategy, rather we are focused on restoring larval formation and recruitment processes within genetically diverse restoration patches located in up-current positions, thereby helping facilitate natural coral recovery process (Figure 49).

Figure 49. Proposed restoration plan for Kiritimati, Christmas Atoll, showing prevailing currents and proposed shallow water outplanting sites. An additional coral nursery is proposed for Motutapu, to test samples of each coral genotype to warmer lagoon waters, to enable the selection of the most resilient coral genotypes.

Fanning Atoll, Tabuaeran, even though down-current, might also be impacted by the Equatorial Counter Current, and as such, coral larvae might then be carried into an up-current position, where eddies might carry larvae into the prevailing east-west flow. While the recently recruited juvenile corals might be from that source, larval recruitment may be limited unless and until we re-establish local breeding populations of corals on the reefs of Christmas Atoll.

The reefs have essentially suffered an ecological extinction event of vital branching coral species, and major changes will likely occur in the coming years to the fish and other fauna. While a very few, scattered and isolated adult colonies of *Pocillopora* have been found, only one adult-sized colony of the genus *Acropora* has been found. Therefore, the ecological function of branching corals as a group is now essentially gone. Coral recovery of the *Pocillopora* species group will likely occur eventually, however it will be delayed and could take many decades, as surviving colonies are for the most part hundreds of meters apart from each other so that fertilization will not be likely, however asexual production of larvae may help overcome this problem to a certain extent for this species group.

The situation with *Acropora* will take even more time, as all the existing corals are juveniles, and will not spawn effectively for a few years. However, this recent find of numerous juvenile *Acropora* corals both recruiting from larvae and recovering from mostly dead colonies is very promising and offers hope for the future of these reefs. If left on their own, these corals have the potential to grow to form a viable spawning population of *Acropora* corals of several species, but natural recovery processes might take several decades, and many more bleaching events will undoubtedly set back recovery, potentially preventing it altogether.

Our strategy will be to cultivate as much of the genetic diversity as possible within the nurseries, and then to use trimmed second generation branches to create discrete and genetically diverse patches of spawning corals at intervals along the wider reef, to reseed the reefs naturally with larvae. Certainly, more colonies and additional species will be found in time, and pairing those surviving corals with con-generics will help ensure effective spawning. Collecting and propagating additional coral samples within the nurseries will vastly increase the genetic and biological contribution that each of the surviving coral genotypes makes to the future recovery of the island's reefs. Our long-term goal is to have the coral nursery expanded to include hundreds of distinct genotypes, of each surviving *Acropora* and *Pocillopora* species. Each genotype should be genetically tested for its algae symbionts, to determine if the coral is sensitive to high temperatures, or if it is bleaching resistant.

The coral restoration patches will serve as spawning aggregations for the natural production of coral larvae, and should be located in areas where the currents are more likely of transporting the larvae to other reefs, and not areas where they are more likely of being swept out into the deep ocean and lost. Some data on current flow would be helpful in developing this strategy and determining the best up-current locations.

Additional coral genotypes and species should be sought out, and additional nursery tables constructed as required. More *Pocillopora* corals should be included, with separate gene bank nurseries created, but only if additional financial and human resources can be found.

A high priority should be placed on creating a second duplicate nursery site, located in an area more sheltered from storm surges, which do occasionally reach these waters and could potentially severely impact the present nursery site. This secondary nursery ideally should be located in the sheltered lagoon, but in an area of good water circulation. Mother colonies of each of the *Acropora* corals should be trimmed and duplicated between the two sites, as insurance against long-term loss. Over the years, as more corals are added to the gene bank nurseries, the work will grow in importance and impact. The mother colonies should be trimmed over and over again, once or twice per year in order to maintain their vigor. Untrimmed corals lose their vigor, begin to grow more slowly, and can become susceptible to disease.

The coral restoration program should be expanded to Fanning and Washington Atolls as resources permit, and with the mass bleaching of the main Gilbert Islands, the need for the work throughout Kiribati has vastly increased. Community training and involvement may be possible, and youth would find the work encouraging and interesting as a service project.

Restoring and securing the original species of corals found on each Island prior to the mass bleaching should be our long-term goal, with each species reproducing effectively and expanding its local range through natural larval recruitment processes. However, if after several years, a particular coral species can't be found on an island any longer, it should be assumed to be locally extinct and an effort to find and bring the species from other reefs of the same island group should be made, exchanging between nurseries if possible. If a coral species is composed of only a single or a few genotypes, more genotypes should be brought in from the nearest local source available, but never from different eco-regions.

Severe bleaching can be expected to come again to the Gilbert, Line, and Phoenix Islands in the coming years due to rapidly changing climate and global warming. However, the corals that have survived the last hot water bleaching event are assumed to be bleaching resistant, offering some hope that adaptation is occurring. Our goal now is to propagate and replant populations of these bleaching resistant corals, which will then spread into the environment and restore the reefs through natural larval production and recruitment processes. The restored reefs should in turn carry bleaching resistance adaptations, and should be in a much better position to survive the hot water. Theoretically, the next mass bleaching will leave the reefs in a much less damaged position, and with many more unbleached corals.

This work gives us hope that we can help coral reefs survive into the future, in spite of the severe challenges of climate change. Restored and bleaching resistant coral reefs will in turn help secure the ecological, food security, and livelihood services that this precious ecosystem provides to the peoples of Kiribati and the world.

The work on Christmas Island goes beyond the simple recovery of this remote atoll's reefs, rather if we can establish the effectiveness of this "Reefs of Hope" program on Christmas Island, it would be vastly relevant to all coral reefs of the nation and of the planet, facing an uncertain future in a rapidly changing world. What better place to start this pioneering climate change adaptation work?

As the work thus far has been entirely based on part time volunteerism, and so what is most important at this time is to identify funding for continuing and expanding this vital and unique program as a full time effort. The work should ideally expand to include more extensive reef surveys on all parts of the island, to try to identify more of the surviving corals, the monitoring of restoration patches, genetic testing of corals and their symbionts, increased and intensifying nursery work, awareness raising work within the communities, nation, and region, as well as work to secure the no-take status of Cook Islet Conservation Area and other areas as special and sensitive to restoration and therefore of critical importance to the larger coral reef system and the nation of Kiribati.

Corals for Conservation's Coral Reef Restoration for Climate Change Adaptation Strategy

1. Rescue super corals from hot pockets (still possible for Tabuaeran Atoll lagoon and much of the South Pacific region), or if too late, collect corals from among the scattered remnants (Kiritimati and Gilbert Islands).
2. Focus on *Acropora* species initially, as this group is vital as fish habitat as well as the maintenance of geological processes vital for reef growth and atoll formation, and appears to be most vulnerable to bleaching-induced extinction.
3. Sample the corals to create gene bank nurseries, located in cooler waters.
4. Restore reproductive coral patches using second generation coral branches (Kufner et al, 2020)
5. Restored *Acropora* patches create a strong settlement signal to attract coral larvae back to the reef (Dixson et al 2014, Montoya-Maya et al 2016)
6. Bleaching resistance becomes contagious, as the super corals leak their super symbionts into the environment, picked up by juvenile corals, which settle in naked, and only acquire their symbiotic algae from the environment (horizontal transmission). http://www.coralsoftheworld.org/page/algal-symbiosis/
7. Upscale the strategy throughout the region and in hundreds of sites in order to have a positive influence of significant scale.

Protecting the Restoration Sites

Because this restoration work is so important to the future of the reefs of Kiribati, it is very important to set aside the main restoration reefs into a no-fishing marine protected areas (MPAs), to strictly limit the number of people visiting the sites and placing fishing lines, nets, or stepping on the reefs, as this will break the regenerating corals. We also need a high density of grazing fish to clean the nurseries and the dead corals, so that living corals thrive and so that once coral larvae are generated through spawning of restored coral populations, they can find a clean place to settle out on and grow. This ban on fishing should apply to all subsistence and commercial fishing activities in the restoration zone.

Controlled tourism activities and visits to the nursery and restoration sites should only be permitted on a case by case basis and assuming that the visitors will be well-controlled, not stand or kick the reef, not wear toxic types of sunscreen, and anchors should not be used on the reef, rather mooring buoys installed. Tourism activities might be used to generate income, through fees or solicited donations to fund the work.

Support for alternative livelihoods among the fishing families who have traditionally used this area should be given if possible in the form of seaweed farming, other types of fishing, and perhaps poultry as an alternative to fish as a protein source.

Proposed 500M no-go no-fishing area around Cook Islet

I addition to providing extra protection to the nesting birds of Cook Islet, a 500 meter no-fishing area is needed in order to protect the corals on the reef (Figure 50), which were badly damaged in the fourteen-month 2015-16 coral bleaching, with an estimated 95% of the corals dying. Abundant fish are needed to clean the dead coral skeletons of the reef, and to help facilitate the recruitment of coral larvae, a recovery process which fortunately is already occurring, with at least three *Acropora* corals now coming in on the currents as larvae, possibly from Tabuaeran, which was less badly impacted from the bleaching and mass mortality. The coral reefs around Cook Islet appear to have the highest remaining coral cover of any of the reefs of Kiritimati, with 10% cover in some areas, and as such, these reefs need protection from excessive boat anchors and related damage.

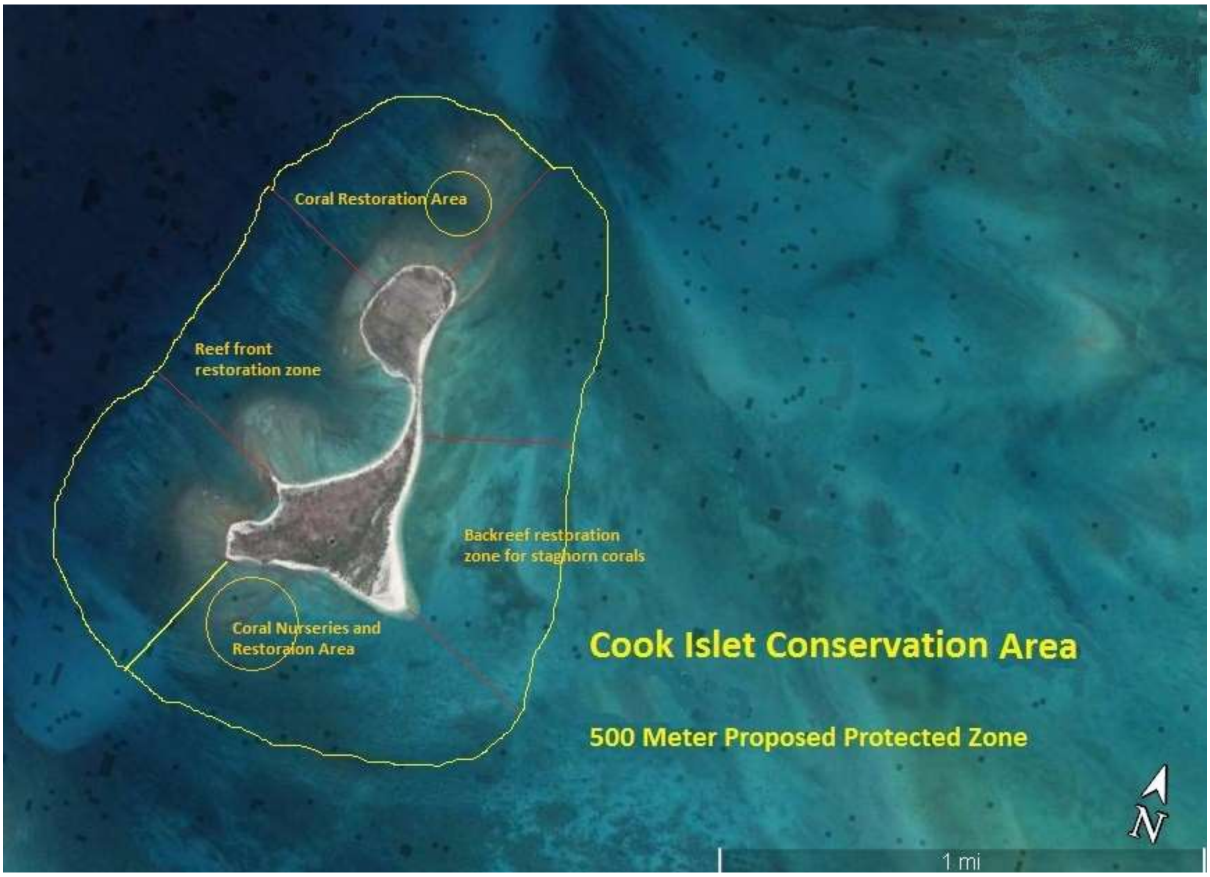

Figure 50. Proposed no take zone around the Cook Islet Conservation Area.

A process of out-planting the now rare branching corals has begun from the nursery, and these restoration patches require protection. The restoration strategy is to re-establish diverse breeding populations of rare branching corals within the protected area, which will facilitate a wider restoration of corals to the reefs of Kiritimati through the production of abundant coral larvae, which will spread to nearby reefs through the currents. Establishing a no-take area is very important in securing breeding populations of not only corals, but also of tridacnid clams, reef fish, and other species in danger of over-exploitation, and would be a big step forward for conservation and restoration of Kiritimati's wildlife.

Justification for a 500 M no-go (no-fishing) exclusion zone around Motutabu Island.

A 500 meter exclusion zone is proposed for Motutapu Island (Figure 51). In addition to providing extra protection to the bird nesting colony there, the reef around Motutapu represents the heart of the former staghorn Acropora coral zone, a zone of diverse marine life which until recently dominated the lagoon on Kiritimati, and which, since the 2015-16 mass coral bleaching, is now dominated by dead coral skeletons. The branching staghorn corals formerly provided a key nursery habitat for juvenile snappers, groupers, and other commercially important reef fish, which is of concern to the Fisheries division, as these corals are now thought to be completely extinct from Kiritimati, with negative implications for future coral reef diversity and reef fish abundance. If confirmed, this coral die-off represents the first localized coral species extinction due to coral bleaching anywhere on the planet.

Fortunately, some massive coral species (Porites and Pavona), have survived and remain on the reefs around the island. Fisheries has succeeded in finding a few surviving populations of staghorn corals in the lagoon of Tabuaeran Atoll, and have brought back living samples to Kiritimati for re-introduction, establishing them in the coral nurseries at Cook Islet and Motutabu. These staghorn coral genotypes represent hot-water adapted survivors, and are thus presumed to be bleaching resistant, and will in the coming years be tested for their ability to live and thrive around the Motutabu site. The reefs around Motutabu are thus proposed as the primary coral restoration site for the staghorn corals, to re-establish a vital fisheries nursery ground, while trialing an important climate change adaptation measure for coral reefs. These Motutabu reefs are also proposed as a testing ground for thermal tolerance among the other coral species being propagating at the Cook Islet coral nursery, with the plan being to bring in samples of each of the corals for testing in the warmer waters of the Motutabu nursery site. The reefs around Motutapu are therefore quite important to the coral reef restoration and climate change adaptation trials for the Line Islands, and the work to restore a locally endangered coral species and a badly damaged and highly endangered lagoon ecosystem.

Figure 51. Proposed no-take area around Motutapu Island, Kiritimati. The nursery was removed after just one year, due to a concern for another round of bleaching temperatures. We will reestablish the nursery as a testing ground for bleaching resistance, once more biomass of corals is available so that any loss will be more acceptable.

Ciguatera Fish Poisoning Outbreak Begins, Caused by the Death of the Coral Reefs

Ciguatera is a debilitating and potentially fatal sickness caused by the consumption of toxic reef fish. The problem, caused by several species of toxic dinoflagellate microalgae, is most prevalent on disturbed reefs low in coral cover. The toxic microalgae live on the surface of dead corals and seaweeds and enter the food chain as fish graze. Ciguatera is now increasing due to climate change, with coral bleaching and death resulting in an increase in ciguatera microalgae (Kohler and Kohler, 1992). The dead reefs of Kiritimati provide ideal habitat for toxic algae species (Figure 52). Ciguatera is thus an emerging health risk for the community, directly related to the mass bleaching and death of the corals on Kiritimati. With this new development, climate change is now directly impacting food security and the health of the community of the Line Islands.

During the December 2018 trip to Kiritimati, we first discovered that fish poisoning had become a problem, starting in Late September and October. Even parrotfish had been affected, indicating a high density of the toxic dinoflagellates in the environment. The reported problem area was initially at the Bay of Wrecks, on the eastern side of the atoll, but it had spread to the reefs off of Rondon. I had first-hand experience with this problem after eating reef fish at a local restaurant on 8th December, suffering from repeated vomiting and itching, especially the hands and feet, and back and joint pains, requiring a visit to the hospital.

Figure 52. Dead corals make an ideal habitat for the toxic dinoflagellate microalgae *Gambierdiscus toxicus*, which lives on the surfaces of the dead coral rocks. The microalgae create a golden-brown film over the dead coral rocks, much like that pictured above.

Senior Nursing Officer Mrs. Ueata Maneaua was very helpful in going through the hospital records and reported that over ten severe cases had been admitted for treatment at the hospital in the months of October and November, 2018, while in past years there might only be one case every year or so. Like my own out-patient case, which was not recorded, those hospitalized are thought to represent a fraction of the actual cases. I helped develop a sample data sheet to record the type of fish eaten and location the fish was caught, so that the community might be informed and cautioned.

In March 2020 the problem had continued to worsen, so that fishermen were adapting by avoiding the most affected reef areas, and many people were avoiding eating reef fish altogether. In July 2019, Taratau Kirata, the head of Fisheries, was hospitalized with severe fish poisoning, and another of our close project contacts, a fishing guide, Mike Maro, experienced severe poisoning, and continues to have serious recurring health problems related to the poisoning. Climate change and the resulting coral death has indeed sickened an entire community.

With this new crisis, resources must be found to closely monitor the situation, to facilitate health statistics, to sample the physical environment for *G. toxicus* dinoflagellate abundance, to map the fishing areas most affected, and if possible, to test the fish being caught for consumption. Community awareness must also become a priority, once more facts are known, and measures to facilitate the recovery and restoration of the corals should be given proper attention and funding as the only long-term recourse to diminishing the problem. Restoration of high coral cover back to the reefs is the only long-term solution. The mass bleaching and death of the reefs of Kiritimati are unquestionably the direct result of climate change and ocean warming. The death of corals on the reefs of Kiritimati are now also implicated in the poisoning of the food chain of the Atoll, with serious health and food security impacts. International bodies should be alerted, with a request for assistance with monitoring and mitigation measures.

Discussion

Is Adaptation of the Line Islands Corals to Climate Change Possible?

While the discovery of an ongoing and accelerating natural coral recovery processes is encouraging, a big question is whether the juvenile corals that are recruiting or regenerating from surviving tissues, once they become adult colonies, will be better able to withstand future bleaching events than the corals which died out. The hope is that they are indeed more bleaching resistant, having more resistant algae, or having acquired them. The fact that newly settled juvenile *Acropora* corals initially have no symbiotic algae inside them, and they must take up the algae they need for photosynthesis from the water, gives them a greater capacity to adapt. Assuming that the only corals left on the reef after fourteen months of bleaching are bleaching resistant individuals, it is hoped that the newly settled corals have acquired bleaching resistant symbiotic algae (zooxanthellae) after settlement.

The first cohort of settled corals, which must have settled during the bleaching event, must have experienced warmer waters, potentially filled with algae expelled during the bleaching. If the algae available were dominated by those dumped by the corals of the extremely hot inner lagoon, which would travel on tidal currents and exit the lagoon on either side of Cook Islet, they would potentially be available for acquisition by the juvenile coral recruits. The two pass areas do appear to have the highest densities of juvenile corals, which might help confirm this hypothesis. Genetic tests of the surviving corals, to determine the specific algal clade and thermal tolerance regime, should be done at some future date. Regardless, future bleaching events are inevitable, which will test the corals to determine if they are bleaching resistant or not.

The intention is that the coral nursery will serve as a gene bank of branching corals and their algae, especially the few individuals of *Acropora* and *Pocillopora* which have surviving the mass bleaching, becoming a "Noah's ark" of bleaching resistant corals for the restoration of the reefs of Kiritimati.

Our restoration strategy does not envision replanting large areas with corals, but rather to replant smaller patches of corals of multiple genotypes capable of spawning, in order to reboot sexual reproduction and the formation of coral larvae, so that nature can reseed the reefs naturally over time.

The prediction is that bleaching temperatures will become more and more frequent in the coming years, and so it is questionable whether the reefs will be able to adapt to such increasing levels of stress. As sea level rises, healthy and growing corals are out best defense, and so global warming must be controlled by greenhouse gas reductions for two reasons- coral reef health and to lessen sea level rise.

The future of Kiribati as a nation is gravely threatened, and international action is needed. Kiribati has been placed squarely in in the forefront of the problem, and so Kiribati must become the leader in presenting the solutions. “The first shall be last and the last shall be first.”

Update

Our project in the Line Islands has attained global recognition and has been included as a case study in a major UNEP report: “CORAL REEF RESTORATION AS A STRATEGY TO IMPROVE ECOSYSTEM SERVICES”. This is the first UN document ever produced on coral restoration, and our work in Kiribati and the South Pacific Ocean is one of only six case studies included. Download the UNEP and ICRI report here: https://www.icriforum.org/wp-content/uploads/2021/01/Hein-et-al.-2020_UNEP-report-1.pdf

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CORALS FOR CONSERVATION

Corals for Conservation is a registered Fiji-based NGO. C4C is focused on the issue of saving coral reefs from human inflicted abuses: climate change and the impacts of overfishing and pollution. Although coral reefs are facing serious problems, coral gardening methods present a practical solution that promise to keep corals alive into the coming decades. To achieve our mission, C4C has a clear focus on climate change adaptation, with a holistic approach in three dimensions: Coral gardening for bleaching resistance, community involvement in marine protected areas and sustainable livelihoods, and tourism and government partnerships for mainstreaming these strategies.

For communities, we work to reinforce participatory community decision making and youth leadership in tackling the climate and coral reef crises, by facilitating a participatory planning process through which customary users working with government, create management plans that include setting aside rotational no-fishing areas, permanent no-take zones, subsistence zones, and commercial fishing zones. Waste management issues are dealt with and alternative livelihoods are introduced to replace over-reliance on fishing as the major economic activity, including small scale poultry farming, seaweed farming, coconut products, and soap making. Coral gardening is used as an educational activity and in support of reef restoration and healthy fish habitat, community-based tourism and reef guide businesses. Healthy and well managed coral reefs, with bleaching resistant heat adapted coral populations, will provide more food for communities and will also be more resilient to climate change, with a much better chance of surviving into the future.