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Creating a National Coral-Focused Climate Change Adaptation Plan for Fiji to Prevent Coral Species Extinction in the Face of Rapid Climate Change: Applying the UNESCO-Endorsed "Reefs of Hope" Ocean Decade Action

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Abstract

In the face of recent setbacks to coral reef conservation and restoration due to intensifying marine heat waves, new coral-focused strategies have been developed to accelerate natural processes of coral reef adaptation and recovery. In 2024, these "Reefs of Hope" strategies were endorsed by UNESCO as an Ocean Decade. This paper shares the progress made and methods used and translates the new paradigm into a proposed national coral-focused adaptation plan using Fiji as an example. The primary goal of any coral-focused adaptation plan should be to keep coral species alive despite increasingly lethal temperatures due to ocean warming and, in doing so, to retain as much genetic diversity as possible. This is done by translocating corals locally to secure cooler-water gene bank nurseries, with a focus on heat-adapted, bleaching-resistant corals, which are vital to adaptation. Secondary goals are to restore sexual reproduction to declining and rare coral species and to support natural larval-based recovery and adaptation processes via the creation of "regeneration patches", which enhance and restore natural recovery processes while facilitating the spread of heat-adapted genetic diversity of both host and symbionts. The proposed plans create a new model of proactive coral-focused adaptation that other reef-owning nations might study, modify to national conditions, and seek funding to implement. These Fiji-based plans are now ready for the next step of national stakeholder input and refinements toward approval by the government and the coral reef conservation community.

Keywords: coral reef adaptation; coral restoration; facilitated recovery; resilience; translocation; regeneration patch; assisted evolution; nature-based; gene banking; sustainable ecosystems

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1. Introduction

1.1. The Immense Value of Coral Reefs and Their Ongoing Loss

Over the eons, coral reefs have grown to build extensive geographical features in tropical oceans, growing into vast barrier reefs, fringing reefs, and atoll systems [1], often rising hundreds of meters from the depths. Coral reefs have created atoll nations [2] and coral reefs have been uplifted to form raised limestone islands and coasts, building entire nations and parts of nations, with rocky cliffs, caves, and karst formations. Over millions of years, immense stores of carbon have been sequestered into coral skeletons, removing it from the atmosphere as essentially permanent storage and thus moderating the Earth's climate. Modern coral reefs protect shorelines by absorbing waves [3] and through bioerosion, generating vast expanses of coralline sand [4], helping to mitigate

against changing sea levels, while providing food, sustainable livelihoods, and well-being to communities [5] of tropical zones in multiple countries of three oceans. Coral reefs have provided for island and coastal populations for thousands of years and have nurtured the development of diverse ethnic groups and nations, which, to this day, continue to rely heavily on coral reefs for food security and sustenance.

The white sandy beaches, rich biodiversity, and stunning beauty of coral reefs have served as the backbone of the tourism industry [6] in multiple nations for over half a century, lifting the economic prosperity of these nations. However, the ocean is now warming rapidly due to climate change [7,8], and coral reefs globally have become the first marine ecosystem actively collapsing in the face of climate change, predicted to be mostly gone by 2050 [9]. The degradation of coral reefs and the extinction of coral species have immense and dire implications for the future of not only cultures and nations [10] but also for Planet Earth. Governments and NGOs have expended considerable efforts over the past decades to put coral reef conservation measures in place, setting aside no-take marine reserves for improved ecological balance and resilience and cleaning up coastal waters, and while these measures have proven effective in helping coral reefs recover after disturbances such as cyclones and bleaching, they have proven ineffective in preventing mass coral die-offs in the face of severe marine heat waves resulting from climate change [11]. Corals continue to bleach white in the heat and are dying in increasing numbers as temperatures become increasingly lethal [12]. Recurring marine heat waves threaten to wipe away decades of progress, killing off even the corals located on pristine reefs isolated far from other man-made influences [13]. The sustainability of the many benefits that coral reefs provide will be lost unless coral species are able to survive over the coming decades.

1.2. Buying Time for Coral Reefs

Even though an impending loss of the majority of coral reefs globally in the face of rapid climate change is universally recognized as being an imminent or eventual threat by the coral reef scientific community [14–16], there is no scientific consensus on what to do as far as the corals themselves are concerned [17,18]. The reality we face is that by the time society transitions to sustainable non-carbon energy sources, it is unlikely that much of anything will be left on most reefs due to the rapid warming of the oceans. At this late point, the best we can hope for is to buy time for coral reefs by focusing on preventing the extinction of coral species [13]. As heat-adapted individuals of most coral species have been found to survive unbleached at temperatures of 33–35 °C and sometimes higher [19–23], these resilient corals have a good chance of surviving into the future, especially if relocated to cooler waters [24,25].

In discussions with coral restoration professionals and reef ecologists in recent years, key points of agreement on active strategies to keep coral species diversity sustained into the future have emerged, and while anecdotal, they appear to be widely applicable talking points that the wider coral reef scientific community can embrace:

1. Further loss of coral genetic diversity must be prevented by securing what remains.
2. Sexual reproduction of rare and declining coral species must be restored and maintained.
3. Restoration efforts must focus on and include heat-adapted, bleaching-resistant corals.
4. Coral-focused work must support natural coral reef regeneration and adaptation processes.

These four points of agreement have been expanded to address the threats posed by ocean warming and to delay coral reef decline and ecosystem collapse, becoming part of a new coral-focused paradigm [13]. This “Reefs of Hope” paradigm was endorsed by UNESCO as an Ocean Decade Action in February 2024 [26].

Recently, the field of coral reef restoration was critically assessed for risk by a select group of coral reef ecologists, including such topics as disease transmission and genetic bottlenecks. The multi-author workshop report "Managing the Ecological Risks of Coral Reef Interventions" [27] highlights Reefs of Hope restoration strategies as being one of several "promising interventions with potentially lower inherent ecological risks", singled out for being nature-based, "leveraging assisted natural recovery using heat resistant local corals", and concluded that Reefs of Hope "may be particularly well suited to regions with lower intervention infrastructure" (i.e., communities and developing-world nations).

The present paper attempts to translate the Reefs of Hope model into a national coral-focused climate change adaptation plan suitable for implementation in developing nations, using Fiji as an example, and, based on local realities and strengths, proposes new lines of action designed to prevent coral death in the face of severe marine heat waves while facilitating nature-based regeneration. These active coral-focused adaptation strategies have the potential to reinforce, reinvigorate, and secure gains made by existing coral reef conservation efforts at government, NGO, resort, and community levels, and, as such, represent new tools in the fight to keep coral reefs alive in the face of climate change, should governments and the conservation community choose to move in this direction.

However, ocean warming intensified suddenly in 2023 and is holding at >1.5 °C above pre-industrial levels [28]. This has caused a new urgency to emerge: the need to rescue and secure heat-adapted corals from the most heat-stressed waters before lethal temperatures arrive. This is based on data from the most impacted coral reefs of the Caribbean and South Pacific, where entire populations of corals of shallow lagoons and reef flats have died in the face of bleaching of an intensity that Fiji has not yet experienced [29] but which is certain to arrive at some point in the future. Many of these stressed shallow water coral populations are situated in a "hot tub" thermal layer that forms at the surface during low tide on cloudless, windless days. These corals commonly withstand temperatures of 34–37 °C without bleaching. However, at the present rate of ocean warming, these areas can be expected to reach lethal temperatures potentially as high as >38–40 °C in the coming decades.

While some may insist that more information is needed before developing plans involving coral rescue and precautionary gene banking, the situation with coral reefs has become so dire with the recent spike in ocean heat that actions to save corals from approaching marine heat waves are needed urgently. Such precautionary actions were carried out in Florida in 2023 during a severe record-breaking marine heat wave, moving thousands of corals of many species and genotypes into land-based facilities successfully, saving them from heat stress and mass bleaching, while most of what was left in situ on Florida's coral reefs bleached white and died [30–33]. However, just to the south in the Caribbean, such rescue measures were not possible in country after country. The intense heat waves of 2023 and 2024 caused mass mortality events with local-scale extinction of multiple coral species; particularly devastated were the *Acropora* species [34,35]. The ocean temperature spike of 2023 then spilled into the Pacific at the end of the year, causing extinction-level bleaching and massive coral die-offs in Kiribati and Tuvalu in 2024 and in PNG in 2025 (predicted by NOAA (National Oceanic and Atmospheric Administration) data and confirmed by observations), with major bleaching and coral loss in most Pacific Island nations. Fiji's first back-to-back bleaching occurred in 2023 and 2024, extending into 2025 in some sites. The record-breaking global bleaching event has resulted in 84% of reefs impacted globally by heat stress in what has become the fourth and largest coral bleaching event on record, impacting reefs across at least 83 countries and territories. As of the writing of this paper (September 2025), bleaching alerts have continued to develop across the world (ICRI (International Coral Reef Initiative) and NOAA press releases, 2025).

The endgame for highly diverse *Acropora*-dominated coral reefs appears to be approaching, with some reefs already experiencing the decline or local extinction of formerly abundant *Acropora* species and with phase shifts toward lower-diversity reefs dominated by *Porites* and other more resilient species [13,29]. Scientific institutions in the developed world have begun focusing adaptation efforts on the selective breeding of bleaching-resistant corals [27]; however, for developing nations, no coral-focused adaptation strategies have yet been approved or set in place that are appropriately low-tech to prevent coral biodiversity loss, other than perhaps crown of thorns starfish (COTS) removal post-bleaching. This paper is a first attempt at creating a nature-based coral-focused adaptation plan, translating the strategies described in the UNESCO-endorsed Reefs of Hope Ocean Decade Action into a national coral-focused climate change adaptation plan designed to prevent coral species loss and species phase shifts in the face of rapid climate change.

1.3. The Need for National Coral-Focused Adaptation Plans

Existing strategies and government programs do a good job in many countries at addressing pollution, controlling negative tourism impacts, and preventing overfishing on coral reefs; however, none of these programs actively intervene to keep declining coral species alive and ecologically intact in the face of increasing ocean temperatures. This deficiency is addressed by the Reefs of Hope Ocean Decade Action strategies, which are the foundation for the present document. Being facilitated by the Fiji-based NGO, Corals for Conservation, the diverse strategies were developed based on lessons learned at the frontline of bleaching-induced coral reef decline [13,29], where extreme marine heat waves have previously hit areas of the South Pacific. These UNESCO-endorsed nature-based solutions are based on forecasting future impacts and intervening to prevent local coral species extinctions. As global temperatures have reached >1.5 °C above pre-industrial levels and continue to rise quickly [36,37], it is vital that we plan for what is coming and begin acting to secure what remains, rather than simply hoping for the best.

1.4. Promoting Coral-Focused Adaptation

The development and implementation of national-level coral-focused adaptation plans along the lines of what is being proposed by the Reefs of Hope Ocean Decade Action can best be carried out as a series of small trials, each monitored and evaluated before upscaling. In this way, action plans and strategies are precautionary and can be adjusted for diverse implementation sites as new information and results emerge. Only by adopting such a learn-as-you-go adaptive management approach can successful directions be established and rapid progress made in highly diverse reef environments. Reefs of Hope strategies can, in this manner, be refined and adjusted based on the realities of each coral reef system and country, differing in emphasis between severely impacted coral reefs versus coral reefs that remain largely intact.

The goal is to move forward with strategies designed to save coral diversity, reboot natural recovery processes, and facilitate adaptation, while at the same time strengthening the functioning of existing MPAs and coral reef conservation programs. Continuing to wait for more information before acting carries a significant risk to coral survival. Only by acting on new strategies and working hypotheses of coral-focused adaptation can they be verified or modified for diverse situations, helping steer a course that prevents the loss of heat-adapted coral and symbiont genetic diversity.

1.5. Mainstreaming ROH Strategies into Existing Programs and Policies

SPREP, the South Pacific Regional Environmental Program, an intergovernmental organization with the mandate of guiding governments of the South Pacific region, has developed the Pacific Coral Reef Action Plan, which includes addressing climate change

and coral-focused adaptation. The plan has been endorsed as a UNESCO Ocean Decade project along with Reefs of Hope, and both are nested under the South Pacific Community's Ocean Decade Program: Pacific Solutions to Save Our Ocean [38].

Ministries of Environment and other government agencies of most nations have developed action plans to reduce biodiversity loss on land and sea due to various and diverse stressors via National Biodiversity Strategy and Action Plans, which emphasize the integration of biodiversity values into national accounts, encouraging the participation of government, businesses, and stakeholders at all levels. Among the accomplishments of the Pacific Islands are hundreds of community-based no-take MPAs established to safeguard coral reefs. National Adaptation Plans (NAPs) have also been developed in partnership with the UN Environment Program (UNEP) and are designed to enhance the climate resilience of land and sea.

In Fiji, the focus of coral reef management is within the context of Locally Managed Marine Areas (LMMAs). The restoration of the customary practice of setting aside "tabu areas" (MPAs) for the rehabilitation of overfished resources, traditionally widespread but discontinued for several generations, was first reestablished in Cuvu District in 2001, with the creation of four tabu areas [39]. From this initial work and other community-led eff1st sorts, a national movement emerged, resulting in over 300 tabu areas within Fiji's LMMA network, (FLMMA, pers. comm.), most functioning as rotational no-take zones [40,41]. While this represents a major accomplishment in community-based resource management, climate change now threatens to erase much of these gains, as coral mortality from increasingly severe marine heatwaves degrades essential fishery habitats [14,42]. Reinforcing LMMAs with heat-adapted bleaching-resistant corals offers a promising emerging strategy to mitigate these impacts and support ecological and social resilience [13,18,23].

Communities and resorts in Fiji have shown great interest in planting corals as a conservation measure [43], but unfortunately, most coral work has failed due to the random selection of corals for the work. Coral reef adaptation plans can take advantage of this receptivity and widespread grassroots energy by focusing on capacity building in sustainable coral gardening methods using properly selected heat-adapted corals, reinforcing community-based and resort-based coral reef conservation efforts. The goal must be to empower reef-dependent communities and tourism businesses, whose livelihoods will be severely impacted by coral loss, those on the front line of climate-induced coral reef decline, to build resilience within their MPAs and areas of operation.

1.6. Background Important to Developing an Adaptation Plan for Fiji's Coral Reefs

Fiji has among the most extensive coral reefs of any island group in the Pacific Ocean, with over 10,000 km^2 of coral reefs (Figure 1). Fiji's reefs contain over 340 stony coral species (Lovell and McLardy 2008) [44], and over 2300 fish species (Seeto and Baldwin, 2010) [45]. Connectivity between the reefs of Fiji appears to be very high [46], as indicated by fish genetics studies and by the rapid recovery rates after disturbance, which is dependent on intact breeding populations of corals at up-current reefs. Fiji's shallow, leeward reefs have shown notable resilience and recovery following mass bleaching disturbances [47] and cyclones [48]. Thus far, the coral reefs of Fiji retain good species diversity, functionality, and coral cover despite multiple challenges, which include land-based runoff and associated siltation, ecological imbalances due to overfishing, COTS plagues, and mass coral bleaching [49,50].

These findings underscore the importance of connectivity and larval supply in sustaining reef resilience. The prevailing southeast trade winds and corresponding westward-flowing surface currents play a key role in transporting coral larvae from the more pristine reefs of the Lau Group toward the more environmentally challenged reefs of Viti Levu and

Vanua Levu [51,52]. However, during La Niña years, the reversal or weakening of trade winds and changes in regional oceanography can alter current directions [53], potentially sending coral larvae from the Great Sea Reef and western reef systems back toward Lau and the eastern islands.

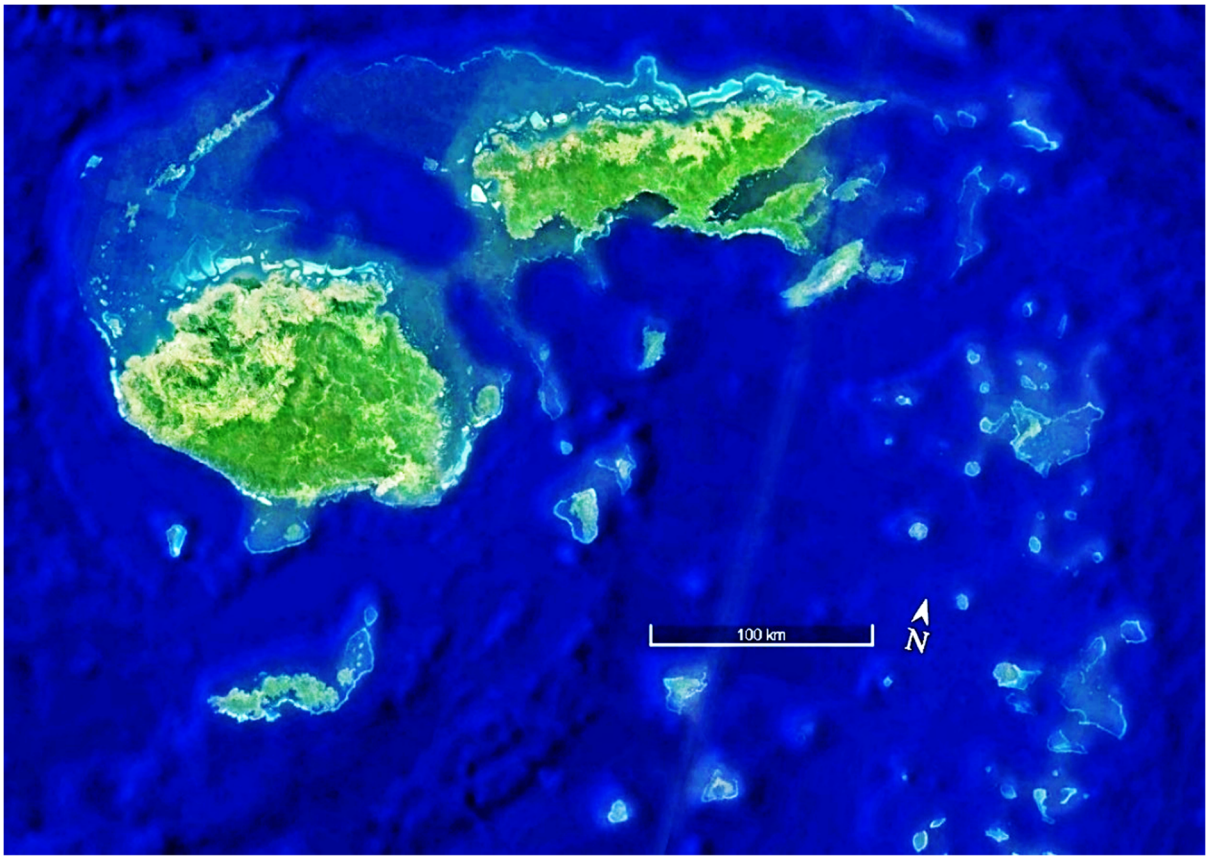


Figure 1. Overview of Fiji's coral reefs, except for Southern Lau, which extends over a hundred kilometers to the south.

With global warming, mass coral bleaching first became a problem for the coral reefs of Fiji in the summer of 2000, with a severe marine heat wave (>12 DHW, condition 3) striking the nation and resulting in 90% mortality in the southern half of Fiji. Equally severe coral bleaching events leading to major mortality followed in 2014, 2023, and 2024, indicating an increasing frequency as the oceans warm. Five moderate, condition 2 (>8 DHW) bleaching events have also hit Fiji since records began in 1985, all after 2000 and with patchy impacts and moderate-to-low levels of mortality (Figure 2).

Fiji has experienced four major mass bleaching events, and while this stress has been comparatively moderate thus far, condition 3 bleaching at 12–13 DHW, in comparison, most of the Caribbean has recently experienced stressful condition 5 bleaching of 21–26 DHW, while Christmas Atoll, Kiribati has experienced 27 DHW, over twice the relative heat stress that Fiji has experienced (Figure 3). Figure 4 is a previously unpublished graph that compares the bleaching stress levels and frequencies of the Pacific Islands nations against each other and to selected nations of the Caribbean. As a word of warning to the Pacific, the Caribbean region had similar trends to those of similar latitudes in the Pacific up until 2023, when the entire region had a >20 DHW mass bleaching mass mortality event.

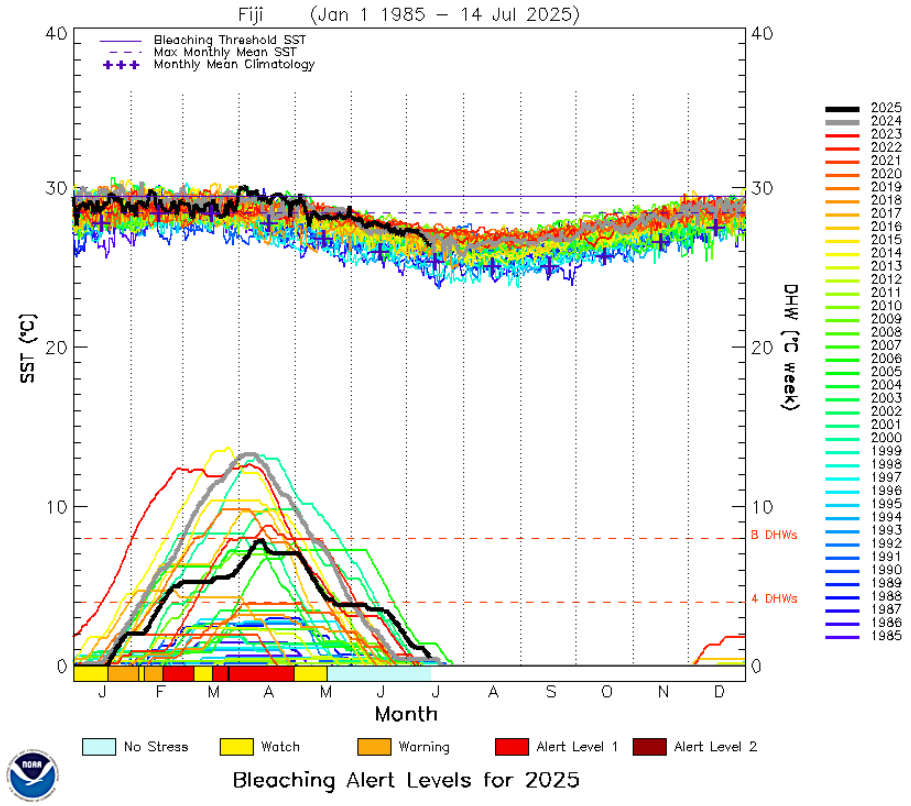


Figure 2. History of marine heat stress and ocean surface temperatures on Fiji's coral reefs, with the bottom hill-shaped graph showing summertime bleaching stress levels in "degree heating weeks", DHW, and the top graph showing mean ocean temperature. Dashed lines indicate 4 DHW and 8 DHW. 4DHW = Condition 1 heat stress, 8 DHW = Condition 2 heat stress. Notice the rainbow-like appearance of the top graph, with the oldest data in blue and the newest in red, grey, and black, clearly showing a warming ocean since the 1980s and 90s. Reprinted from Ref. [54].

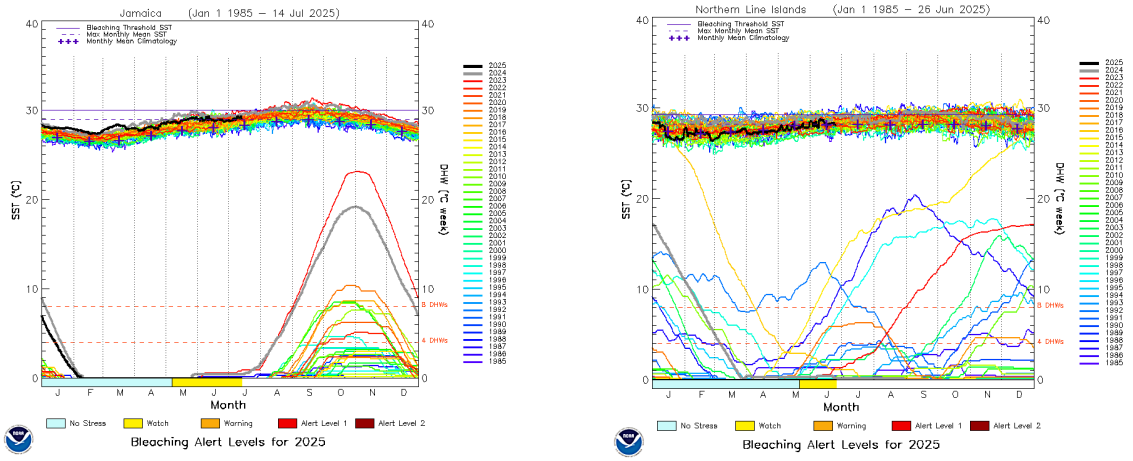


Figure 3. Heat stress levels in Jamaica (**left**) and equatorial Kiribati (**right**) since 1985. Dashed lines indicate 4 DHW and 8 DHW. 4DHW = Condition 1 heat stress, 8 DHW = Condition 2 heat stress. Jamaica is at a similar latitude to Fiji and represents what Fiji can expect in the future. Fiji has had four 13–14 DHW events, while Jamaica had previously only experienced 10 DHWs once, but Jamaica has now experienced consecutive years of 19 and 23 DHW, which is extinction-level coral bleaching. The Line Islands of Kiribati have experienced 27 DHW as well as six years of >15 DHW, and most coral species are locally extinct. Fiji still has time to prepare for this level of heat stress via hot-to-cooler translocation of corals, preventing the loss of a wide diversity of corals. Reprinted from Refs. [55,56].

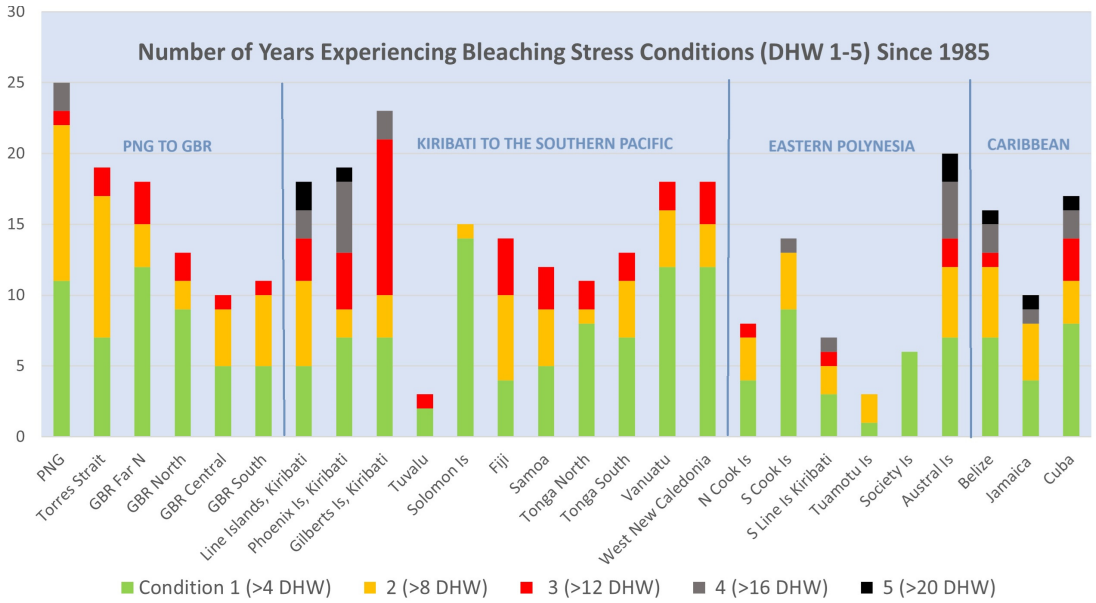


Figure 4. Previously unpublished analysis using data obtained from the NOAA Coral Reef Watch website using the newly expanded thermal stress scale based on "degree heating weeks". The scale, from 1 to 5, is a proxy for the probability of coral bleaching. The table compares South Pacific and selected Caribbean nations for heat stress frequency and relative severity, arranged by geographic area and latitude, with the Y axis representing the number of years experiencing bleaching events. Mass mortality of *Acropora* corals generally occurs at 3 and above.

1.7. Fiji's Resilient Reefs in Peril

Because breeding coral populations have continued to survive intact on some of Fiji's reefs despite multiple bleaching events, the recovery of coral reefs has continued to proceed rapidly via larval-based processes. However, this resiliency depends on healthy breeding populations of corals in up-current areas. However, sexual reproduction often fails after a mass coral die-off event when the remaining colonies of a particular coral species become too few and far apart for effective fertilization to occur (generally >10 M), termed the "alee effect" [57]. Once breeding populations of corals are no longer located up-current on Fiji's reefs, larval-based recovery processes will fail at the reef scale. The increased bleaching frequency now evident in Fiji will eventually begin to harm coral reproduction and thus slow coral recovery—if it has not already. Bleaching is predicted to become an annual event in the coming years [58], threatening the larval-based recovery process, and with the recent back-to-back bleaching years, we appear to be drifting closer to that reality. As bleached and partially bleached corals may not produce viable coral larvae due to the great loss of energy resources due to stress, bleaching-resistant corals could continue to produce offspring effectively, assuming that we can secure these corals within reproductively viable, close-proximity patches [13].

1.8. An Ideal Crucible for the Evolution of Thermal Tolerance in Corals

Climate resilience is particularly high on Fiji's coral reefs due to strong larval-based connectivity and the simple fact that the coral reefs cover such a broad extent: roughly 500 km × 500 km, which provides added resilience as even major cyclones and bleaching events will spare some reefs, allowing breeding populations to persist.

Another possible factor in Fiji's impressive resilience is the presence of extensive shallow heat-stressed reefs throughout the islands. Fiji has by far the greatest expanse of such shallow-water reefs in the Pacific Islands region, as indicated by surveying the region with Google Earth (Figure 5). The extensive shallow leeward reefs of the two main islands provide excellent potential for the evolutionary process of adaptation to thermal stress.

These wide reef flats and shallow nearshore waters are thought to be a major driver of evolutionary selection, especially in the "hot tub" thermal stress layer. Hot pocket reefs are defined as areas of extreme thermal stress and hot-to-cold temperature fluctuations diurnally on the rising tide as cold water floods the hot zone, and for higher latitude reefs like Fiji, annual hot summer to cool winter temperature fluctuations. Thermal stress has undoubtedly been a selection pressure in these areas for thousands of years, resulting in thermal adaptation and bleaching resistance. Thermally resistant coral populations have been confirmed to exist in such chronically stressed shallow reef areas in many places globally [59–61]. The corals of adjacent deeper and cooler waters in these evolutionary hot spots are also of heightened interest, as they have a high chance of receiving the larvae of heat-adapted corals, as genetically based heat resilience would naturally spill out of the hot pocket reefs and into the general coral population via spawning and subsequent larval transport and recruitment processes. Despite the potential importance of Fiji's extensive leeward hot pocket reefs to thermal resiliency and climate change adaptation, biological surveys of these shallow reefs have not yet been published.



Figure 5. Shallow coral reefs and reef flats dominate the leeward sides of the two main islands of Fiji (**top**), presenting an excellent crucible for the evolution of heat resilience. Close-up view of Viti Levu Island (**bottom**), showing shallow hot pocket reefs with excellent potential for containing populations of jeopardized heat-adapted corals. Source: modified Google Earth images.

Other smaller reef areas of known heat-adapted coral populations are scattered throughout Fiji; of particular note are the 500–1000 m wide fringing reefs of Fiji's Coral Coast, where reef flats abut the land, forming large elevated tidepools, where an algal rim re-

tains water well above MLW during low tide, creating ideal conditions for thermal heating at low tide, and with high temperatures >33 °C during January through April and >35 °C during marine heat waves (personal observations). These same reefs experience thermal stress from cold waters during low tides occurring at night from June through September.

Bleaching resistance is the ability of a coral colony to maintain photosynthetic processes despite extreme temperatures. Photosynthetic integrity is more complex in corals than in macroalgae or flowering plants, as corals have the added complication of being a combination of species, and bleaching resilience can be based on either the host animal, the algal symbionts, symbiotic bacteria, or in combination [62–64]. Evolutionary selection acts on each component of the holobiont, which then impacts the whole [65,66]. The primary driver of resilience in corals is the algal component and is based on resistant algal species or clades (e.g., *Durusdinium trenchii*) [67–69]. However, certain coral hosts have been shown to be capable of maintaining even sensitive algae within their tissues in temperatures above the normal bleaching threshold for corals, presumably by neutralizing the impact of free radicals that would otherwise burn the coral tissues [70,71]. Host-based bleaching resistance is inheritable.

While acclimation or stress hardening may be involved to a certain extent in bleaching resistance [19,59,72], this acquired resilience is limited, as it is not passed on to the next generation of the coral host via genetics. Evolutionary theory dictates that inheritable traits that give a survival advantage to a species are the result of natural selection among individuals over time. Natural selection requires environmental stress, which lowers the survival or reproduction of individuals with less desirable traits and selects for those individuals best able to survive and pass on these traits to the next generation [24,73]. For corals to evolve a high degree of bleaching resistance, thermal stress levels beyond simple acclimation potential are required [70,74], resulting in lethal levels of stress to coral holobionts without genetic traits for thermal resistance among the component members, weeding out poorly adapted individuals.

Heat-adapted corals of shallow heat-stressed reefs have been shown to be living close to their upper temperature threshold, and thus, they are unable to adapt further to increasing temperatures due to rapid global warming [23,75]. However, these same corals have been shown to retain their resilience [22,76] when translocated to cooler waters. This provides a rationale for human-assisted migration to rescue and secure such heat-adapted corals while restoring cooler degraded reefs with thermally resistant corals from stressed reefs. Global studies have shown that the range in coral thermal tolerance across a single reef can be as large as differences observed across vast latitudinal gradients [19,21,60]. This indicates that long-distance translocation is not required to keep corals alive into the future and provides the rationale for the implementation of local-scale hotter-to-cooler water translocation of corals as a strategy to keep heat-adapted corals alive into the future as the ocean warms, assuming that strong thermal gradients exist within a particular coral reef system [20,77].

Our operating assumption for the Reefs of Hope paradigm is that areas less than one meter deep at low tide have been the driving force behind the evolution of thermal resistance over the millennia, experiencing both extreme daytime heat in the summer and becoming the coolest waters in the evenings of the winter months [13,22,77]. However, with increasingly severe marine heat waves, these stressed reefs have begun to experience lethal levels of heat stress, putting entire coral communities in peril [29].

Coral breeding work, which has now become commonplace [24,78], focuses on the coral animal rather than the symbionts, and therefore, to be effective, must first select corals with host-derived bleaching resilience as broodstock [73,74]. Recent studies have found that heat-adapted corals are widespread in some coral reef systems [21,23], even

in deeper, less heat-stressed environments, only showing their resilience during mass bleaching events. It thus appears that while heat resilience evolves in the hot-stressed shallows, heat-adapted traits can spread throughout coral reefs via larval dispersal resulting from sexual reproduction within shallow heat-adapted coral populations [19,79].

As the larvae of spawning corals such as *Acropora* do not carry with them algal symbionts [80], nor have they been found to carry bacterial symbionts, it is the host genetics of these species that spreads with the larvae, not the symbiont genetics. Brooding coral species such as *Pocillopora*, on the other hand, carry algal [81] and bacterial components [82,83] best adapted to the conditions of the source reefs (hot pocket reefs); however, these symbionts may be maladapted to their new environment [84,85]. Therefore, coral bleaching resilience in corals found in cooler or deeper waters is more strongly associated with host-based factors than symbiont-based factors [19,86,87]. In shallow-water environments, corals are more likely to be resilient based on heat-tolerant symbionts like *Durusdinium* [20,68]. Understanding this tendency could help revolutionize the collection of corals for breeding purposes [13], with researchers targeting coral populations of cooler or deeper waters during mass bleaching events as a more effective way to seek out corals exhibiting host-derived resilience, while targeting larger/older coral colonies of hot pocket coral populations, even during non-bleaching seasons, to acquire heat-adapted algal and bacterial symbionts. During extreme heat stress, these same shallow areas could be targeted to seek out bleaching-resilient colonies, which might contain multiple sources of resilience, both host-derived and symbiont-derived.

With rising temperatures already near the upper limit of adaptation potential, lethal temperatures are becoming problematic within already heat-stressed reefs [75,88]. The coral rescue strategies proposed in this document are therefore time-sensitive and of great urgency, as marine heat waves of extinction-level intensity are now being experienced on many reefs and threaten to hit all coral reefs in the coming years [57]. A systematic rescue of jeopardized corals from hot pocket reefs can potentially save many thousands of corals located in extreme environments where they will otherwise perish. These same corals, once secured, would provide an immense resource for accelerating coral breeding and recovery aspects of climate change adaptation programs, helping keep pace with the accelerating rate of ocean warming. Unfortunately, the very coral populations where thermal resilience has evolved may soon be gone, initially transitioning away from *Acropora* dominance into lower-diversity steady-state reefs dominated by only the most resilient genera such as *Porites*.

1.9. Breakthroughs in Facilitating Natural Processes of Adaptation and Recovery

To facilitate natural coral reef adaptation and recovery processes, we must understand the ecological basis of coral reef recovery and adaptation. Coral reef restoration has rarely focused on facilitating natural processes; instead, the focus has mainly been on the development of nursery and out-planting methods, and "up-scaling" has usually been based on the numbers of corals planted, using few coral species of few genetic strains and with considerable ecological risks, including genetic bottlenecks and highly altered species compositions [27]. Significant opposition and criticism have been levied against the field of coral reef restoration for these and other reasons. Following the recent death of most of the corals planted in the multi-million-dollar restoration efforts by the off-scale marine heat wave that hit Florida and the Caribbean in 2023–24, a re-think of restoration strategies is now occurring [13,89,90]. The emerging realization is that restoration as formerly practiced is no longer possible in the presence of recurring severe marine heat waves, just like planting trees becomes futile during drought conditions and in the face of an approaching

firestorm. Efforts must now turn to securing coral genetic diversity and preventing its further loss [13,18,91].

The fundamental aspect of a coral-focused adaptation strategy is to prevent further loss of coral species and coral genetic diversity by mobilizing the collection and securing of rare and declining coral species within gene bank nurseries located on coral reefs, with an emphasis on heat-adapted coral genotypes. In the process of securing corals from further decline, diverse genotypes are brought closely together, which in turn restores reproduction via increased fertilization rates [13]. As emphasis is placed on pre-adapted heat-resistant corals, as inheritable traits conducive to bleaching resistance will likely be passed to the resulting larvae.

Saving heat-adapted corals is an important first step in preventing coral species extinction, securing coral broodstock so that the natural processes of coral reproduction, recovery, and adaptation can be maintained and assisted [13]. Ensuring that larger numbers of heat-adapted corals and individuals of increasingly rare species are relatively secure and restored to breeding condition will require moving significant numbers of jeopardized corals from the hottest coral reef areas to cooler reef areas [13]. And when bleaching hits, special efforts should be made to collect unbleached heat-adapted corals from both shallow and deeper environments to add to the nurseries, further increasing both symbiont and host-derived bleaching resistance within the gene banks. The goal is to collect heat-adapted coral stock of all declining or rare species; 10 genotypes can retain approximately 50% of the original genetic diversity, while 35 genotypes can retain roughly 90% of coral genetic diversity within the species [92].

For the relocation nurseries, a depth of 2 m at mean low tide is generally enough to get the corals out of the thermal layer and into somewhat cooler waters nearby, where maximum temperatures remain at or below 33 °C even during major stress events. The intended strategy is to enable coral holobionts to escape lethal temperatures while keeping them within the same general thermal regime where they evolved, to minimize the potential for loss of resilience through acclimation. However, as the ocean is warming so rapidly, cooler nursery sites should be sought out for relocating duplicate samples as a precautionary measure. Conversely, as climate change unfolds over the coming decades, the expectation is that rising sea levels will eventually cool off shallow hot reefs via thermal buffering, increasing circulation and depth, and thus enable conditions where the corals could potentially be moved back to the reefs where they were originally collected, assuming the corals can be kept alive in the intervening time.

2. Materials and Methods

2.1. Reefs Hope Operational Strategy

The primary method presently used for locating heat-adapted coral populations from which to collect for possible relocation and to locate potentially ideal nursery sites is via the study of satellite photographs available on Google Earth. Figures 6–8 show representative collecting areas and potential gene bank nursery sites. The shallow heat-stressed reef areas can readily be identified by the light blue and white colors of sand reflecting the light, against the contrast of the brown colors of corals and algae. Coral colonies are readily distinguished by color and texture upon zooming in, although it is not possible to determine if the corals are living or dead, so ground-truthing is required. While the present work uses boats and snorkeling, drones offer the potential to greatly speed the process, as living corals can be readily identified from dead corals at that finer scale.

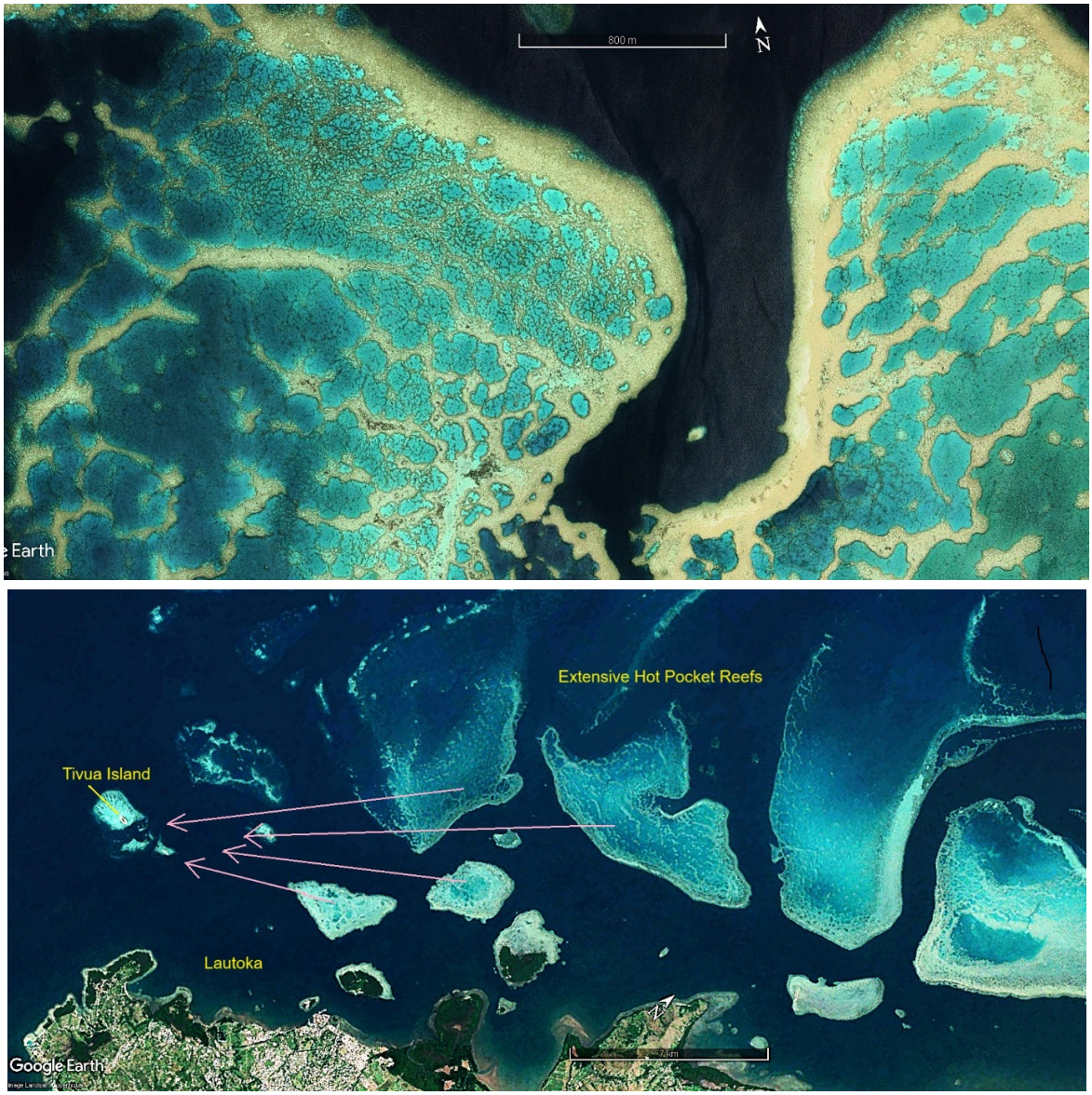


Figure 6. Close-up (**top photo**) of hot pocket reefs north of Lautoka and Ba, on the north coast of Viti Levu, with an overview (**bottom photo**) of the wider system and the location of a potentially ideal cooler-water gene bank nursery site at Tivua Island, where tourism activities potentially enable infrastructure, security, and ease of access. Arrows show proposed translocation from collecting sites tens of kilometers distant. Source Google Earth.

Ideal nursery sites provide good water flow yet protection from storm-generated waves and currents. While deeper areas might be considered for the tourism industry and sites closer to urban areas with access to SCUBA, for developing countries with less access to technology and funding, we only consider shallow areas 2–3 m deep, which allows nursery maintenance using snorkeling. Nurseries are ideally situated immediately behind a shallow reef break, where waves consistently break during high tide or rough weather. Situating the nursery a meter or so lower than the protective reef allows waves breaking on the nearby reef to roll over the top of the nursery, leaving the nursery unscathed even during stormy weather. A possible advantage of shallow water nurseries is that water motion and proximity to breaking waves may help increase coral growth and nutrient flows and could potentially accelerate the diffusion of toxic free radicals during heat stress events. However, shallow nurseries will have greater temperature fluxes and higher UV levels than deeper ones.

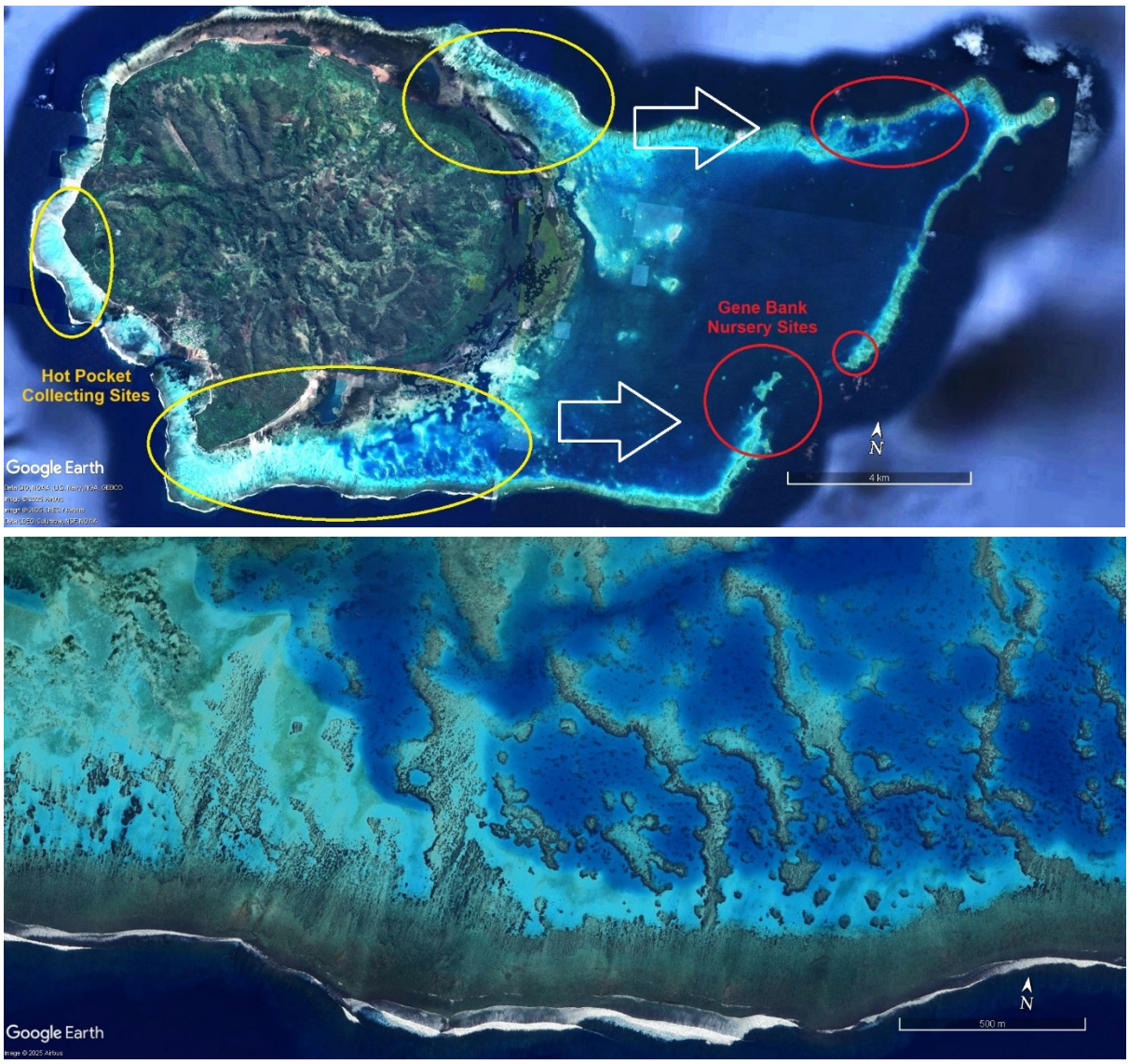


Figure 7. An example of potential nursery and collecting sites of Lakeba, Lau; overview (**top photo**) and close-up (**bottom photo**). Numerous additional remote atoll reefs are accessible within hours of Lakeba by boat. Lau is believed to be a key up-current larval source area and is thus vital to the recovery of the coral reefs of Fiji. Regular air service gives ease of access to five islands of the Lau group. Arrows indicate direction of coral movement from hot collecting sites to cooler nursery sites.

In a major shift in the approach to collecting corals, recognizing the imminent threat that jeopardized corals face in shallow water locations, rather than taking only a small portion of a coral colony, as is common practice, entire coral colonies are removed from situations of extreme heat stress and air exposure during extreme low tides, moving and planting them within nurseries located 2 m deeper and 2–3 °C cooler on elevated nursery structures. After being secured, rescued heat-adapted corals are grown within the nurseries over the years and serve as "mother colonies", trimmed as they grow during the cool, low-UV season, with resulting seed fragments used to accelerate nature-based adaptation and recovery processes [13].

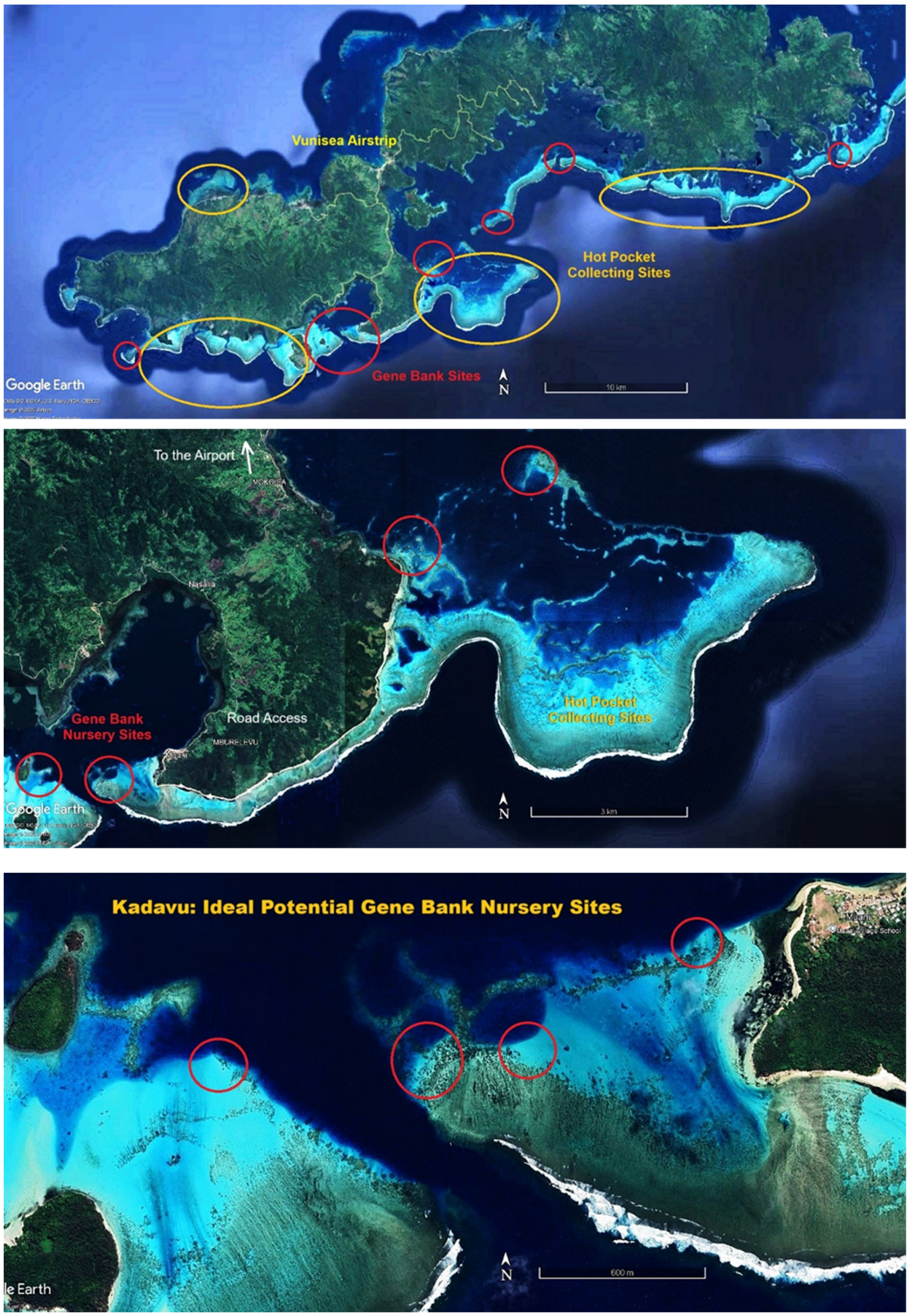


Figure 8. Kadavu in southern Fiji, with regular air service, offers easy access to ideal hot pocket collecting sites and sheltered nursery sites. Overview (**top photo**), southern reef hot-pocket detail (**middle photo**), and close-up of potential nursery sites (**bottom photo**). Shallow nurseries allow for continuing moderate heat stress, faster growth rates, and SCUBA-free access, as well as higher community involvement. Source of aerial photos: Google Earth.

Wherever heat-adapted coral colonies continue to exist in abundance in jeopardized conditions where long-term survival is impossible and where degraded cooler water reefs are nearby, the nursery phase can be bypassed, with colonies removed for direct planting into regeneration patches. During approaching bleaching events, corals can be saved in this manner, with the rule being that they are moved from shallow to deeper and from hotter to cooler conditions. In this manner, copious coral genetic diversity can be saved during marine heat waves or as they approach. However, in such cases, the corals that are moved directly into restoration sites will not be elevated within a nursery structure and thus will remain highly vulnerable to coral predators such as COTS and also potentially more vulnerable to cyclones. The same can be said for second-generation regeneration patches, discussed later, and so regular monitoring is required, with the removal of predators when encountered.

In both nurseries and regeneration patches, coral colonies of unique genotypes are clustered by species to restore sexual reproduction to declining coral species, overcoming the alee effect so that copious numbers of coral larvae are released into the wider coral reef system. While the long-term outcome of this strategy may be difficult to monitor, the present situation of declining and rare coral species releasing gametes with little or no chance for fertilization is a tragedy, and by restoring sexual reproduction, natural larval-based processes are restored. The Reefs of Hope paradigm is about restoring natural recovery and adaptation processes, rather than forcing nature into less natural configurations such as with the planting of thousands of less diverse coral fragments, as is the dominant paradigm.

2.2. Nursery Design and Construction

Gene bank nurseries are intended to serve as long-term refuges for corals and therefore must be built to last for decades. They should be designed to become self-maintaining within a year or so, cleaned and maintained by herbivorous and planktivorous fish populations that increase within the corals over time. Nurseries should be located close to the reef to encourage herbivorous fish to cross over and help clean the structure. If several meters of sand separate the nursery from the reef, small grazing fish will be prevented from crossing, and in such cases, "fish bridges" are installed, consisting of corals planted to mesh A-frames or welded reef stars, providing fish with shelter so that they can safely cross open ground to access the nursery.

The preferred gene bank nursery structure is built of 16 mm deformed steel bars. Each bar is six meters long and is typically cut in half for ease of transport and use. A basic small nursery is therefore slightly smaller than 3 m × 3 m (2.8 × 2.8 m). Supporting legs are made by bending bars into U-or L-shapes to form supporting legs, hammered into the sand or rubble sediments. The unbent bars are laid out into a square on the sand or rubble substratum to outline the nursery, and the legs are then hammered into place before lifting the straight bars and attaching them with heavy(at least 5mm wide x 250mm long), black nylon (UV resistant) cable ties, looping the tie over twice before zipping in place. To create the nursery top, heavy 3 mm gauge, 200 × 200 mm welded reinforcing floor mesh is used. Available widely as 3 × 12 m sheets, the mesh is cut into four 3 × 3 m sections, each coated with two coats of epoxy resin to form four nursery tabletops. One of these sheets is attached to the top of the completed 2.8 × 2.8 m metal bar frame substructure to complete the "table nursery". Nurseries can be easily expanded by linking them together, and sections of rope nurseries can also be included for easy cultivation of branching species. Braces are also added to the completed nurseries for increased cyclone resistance, and the design has proven to be highly resistant. Of significance for reefs under threat from predation by COTS is that both rope and table nurseries have proven completely immune

to COTS predation. A short film on nursery and A-frame construction can be found in Ref. [93].

Nursery designs that depend on regular human maintenance for their continued existence are risky, as precious coral diversity is at stake. Personal experience during the COVID-19 pandemic showed that disruptions can prevent access for months or even years, with suspended rope nurseries growing so heavy that the ropes broke and some nurseries collapsed under the weight of the corals, with many corals falling to the sand below and perishing. While design can certainly vary, methods such as tree nurseries and other sorts of nurseries suspended from floats are never used as they require SCUBA, are not self-cleaned by fish, and are not structurally sound during cyclones, plus they sink as the corals grow heavy. Rope nurseries suspended from metal bar frames become self-cleaning if placed adjacent to reefs with abundant herbivorous fish, and when reinforced with additional braces and support bars, the corals can grow for many years without maintenance or trimming, even if abandoned. As fish do not typically live within rope nurseries, table nurseries are integrated into rope nursery design to provide fish shelter habitat (Figures 9 and 10).

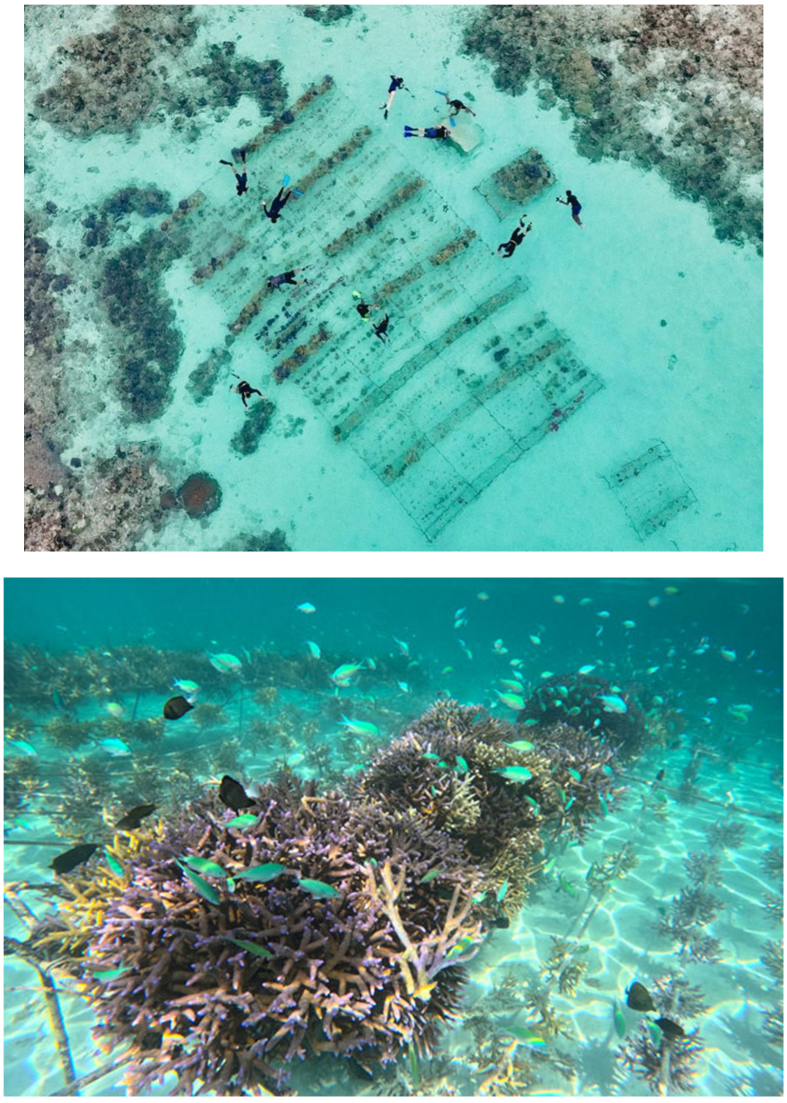


Figure 9. Self-cleaning mixed rope and table nursery in Fiji, located in 2–3 m of water in a moderately heat-stressed site that reaches 32–33 °C during the hot season. **Top photo**: Note the A-frames and small table nursery installed to create "fish bridges" to improve fish access to the nursery for improved grazing. **Bottom photo**: note the abundant fish and the resulting clean ropes.



Figure 10. Rope nursery over sand. Each rope represents a single genotype of a species. Spaces indicate coral mortality from a severe *Lyngbya* infestation before the nursery was moved to where fish could access it better. Narrow table nurseries with branching corals provide fish habitats. This particular nursery needs additional support rods to prevent the ropes from sagging as they become heavy.

Another factor in gene bank nursery design is ease of shading, should an off-scale marine heat wave impact the nursery. The standard design of rope nurseries lends itself to ease of shading during bleaching emergencies, and shading can also be installed during high-UV summer months, enabling the coral work and the collection and use of fragments to continue without delay (Figure 11).



Figure 11. Temporarily shaded rope nursery during the summer season, preventing reoriented coral fragments from being burned by high UV levels. Regular cleaning is required to prevent algal build-up on the shade cloth.

2.3. Planting Corals to Table Nurseries

Coral colonies are usually planted directly into the table nurseries, attached with UV-resistant cable ties in areas of active current flow, or for calmer areas, nested unattached onto the mesh, recessed within the spaces of the 200 mm × 200 mm mesh, where they will self-attach within several months. Larger and heavier massive coral colonies are generally left unattached and remain stable during cyclones due to their weight and the sheltered nature of the nurseries. Another method is to cement the corals to concrete "cookies", large 30–40 cm disks with 4 holes in them for ease of attachment to the structure, allowing ease of movement later, while corals placed directly onto the nursery will adhere strongly and become difficult to move over time. Tabulate and short-branched species of digitate and corymbose *Acropora* corals are well-suited to attachment to concrete disks (Figure 12), while large, branched staghorn growth forms are not. For staghorn corals collected from *Stegastes* farmer damselfish territories and with dead lower branches, the dead portions are trimmed off, and 5–6 branches are then tied into a sort of bouquet using long, thin cable ties or fishing line, with the completed bundle nested within the mesh spaces of the nursery, or these large branching corals can simply be grown on ropes.



Figure 12. Table nursery with corals attached to large cement-disk "cookies". Holes in the disk allow for attachment to the tabletop via cable ties for areas of higher current potential. This is a self-cleaning nursery, as the fish population helps keep the corals healthy and clean.

Experience indicates that the arrangement of corals within the nursery according to growth form is important. Fast-growing, open-branching coral species are given more room and are separated from slower-growing, tightly branched, and massive species. However, including the larger-branched corals in the nursery greatly helps ensure functionality and low maintenance by attracting or recruiting abundant resident fish populations; however,

overgrowth must be kept in check. Planktivorous fish of several species, in particular blue- and green-colored *Chromis viridis* and black and white banded humbugs *Dascyllus aruanus*, were observed on multiple occasions helping keep drifting cyanobacteria out of their host colonies, and herbivorous fish such as juvenile parrotfish and surgeonfish graze diligently, helping keep the dead parts of corals and the nursery table clean. All these small fish prefer large branching corals, and so it is important to locate clusters of colonies of these corals throughout the nursery, not forgetting the importance of pairing each coral species with 2–3 other genotypes of its kind, to encourage successful spawning and larval generation.

Another goal of the nurseries is to produce corals for establishing regeneration patches on degraded reefs. This is integrated with annual cool-season trimming of fast-growing corals in order to prevent competition and overgrowth between corals. Slower-growing massive corals and tightly branched corals can serve as donor colonies for restoration work, but trimming is rarely required as a maintenance measure. Where coral species have become uncommon or rare, a duplicate nursery should be created elsewhere as insurance against loss due to unforeseen disasters. All corals trimmed for inclusion within regeneration patches also serve to secure the genotypes.

2.4. Regeneration Patch Design and Construction

Regeneration patches are defined as being dense coral plantings often elevated on structures designed to maximize fish and invertebrate habitat for improved ecological functioning and substratum cleaning. The patches are intended to reboot larval-based recovery processes via the creation of strong settlement signals, which enhance larval settlement to the reef. The fastest-growing corals will produce the most biomass for out planting and might be considered over-replicated in the restoration efforts; however, they are the best corals for the job of patch creation due to their rapid growth and ideal habitat-forming characteristics, and the initial low diversity patch (in theory) will subsequently attract coral larvae of many species, resulting in a highly diverse, naturally structured reef patch over time [13].

"Regeneration patches" are the primary Reefs of Hope out-planting strategy for degraded reef areas. Trimmed fragments, generally between 15 and 30 cm in length, are attached via cable ties to mesh A-frames, created from the same 200 × 200 mm heavy floor mesh as used for the nursery tabletops. Four frames, eight-squares-wide each, can be cut from a single 12 m sheet, bent into an A-shape, and then coated with epoxy resin. Coral fragments trimmed from a single mother colony are ideally kept within separate containers so that they can all be planted together onto a single section of an A-frame, with the goal of the branches merging into a single reproductive coral colony within 1–2 years. At least two genotypes of each coral species and preferably 4–6 genotypes should be planted in this manner onto a single A-frame, creating an effective reproductive unit for deployment to the field. Fragments are usually attached via plastic cable ties at each welded cross-junction to prevent movement, and a planted A-frame contains 104 coral fragments, avoiding the bottom row of junctions to avoid direct contact with the substratum by the corals and some elevation as partial protection against benthic predators (Figure 13). The A-frames are generally planted in a boat or on shore, regularly sprinkling the corals with seawater during production, and the planted A-frames are then deployed into the desired site, undergoing the same sprinkling during transport. Once deployed, the A-frames are secured with either metal stakes or with concrete blocks attached to the A-frame bottom via short metal rods.

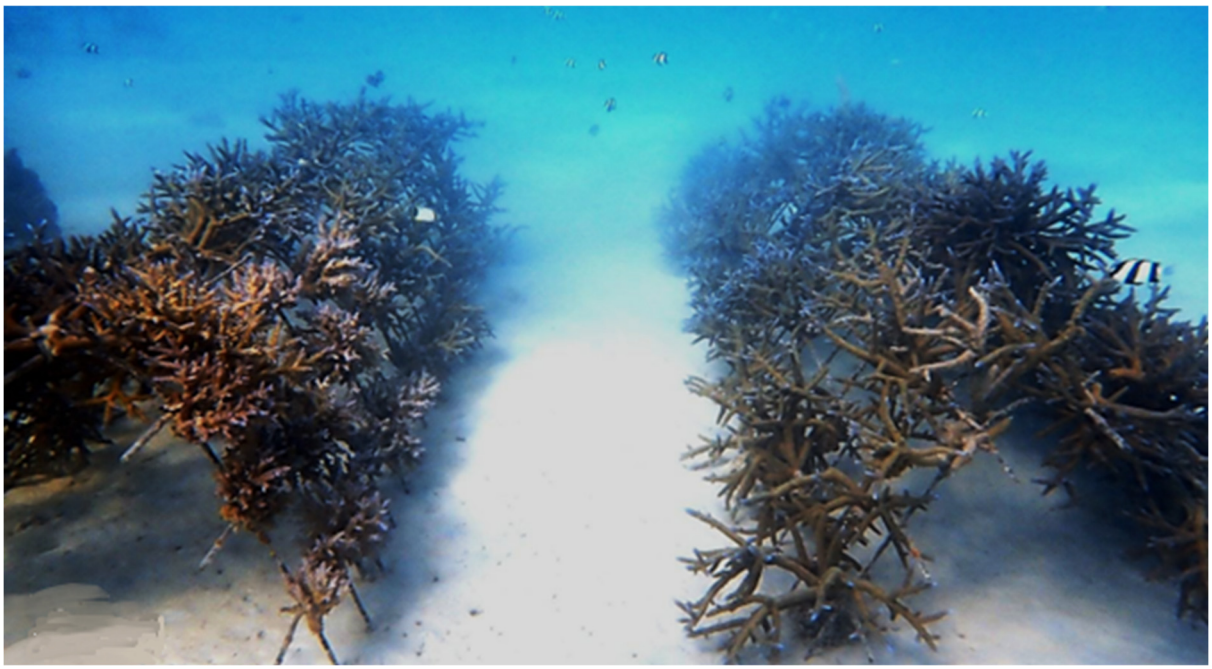


Figure 13. Mesh A-frame out planting structures. Multiple genotypes of a single coral species are planted together to restore sexual reproduction. Located on sand, the structure gives a partial refuge from predators; however, the impact on recruitment-based recovery will be limited, as sand is not a suitable settlement surface for incoming coral larvae.

There are many unknowns as far as regeneration patch design, and there are many possible combinations, so an experimental approach should be taken. Single or multiple A-frames (or other structures) can be used to create a regeneration patch of various sizes, and various coral genera and growth forms can be used individually or in combination. Beyond restoring sexual reproduction and dispersing bleaching-resistant symbionts more widely throughout the coral reef system, the other purposes of the regeneration patches should not be forgotten: to create ideal fish habitats for positive impacts on the corals and substratum around the patch and to create strong olfactory, auditory, and visual settlement signals for incoming coral larvae. Experience hints at trends, such as *Acropora* being the smelliest of the genera, while certain *Pocillopora* species are the noisiest due to infaunal crustaceans.

Where possible, regeneration patches should be established within established MPAs to enhance functionality by creating fish habitats and to link the patches to strategies addressing problems of overfishing, pollution, and COTS over-abundance. In this way, previous advances in coral reef conservation can help with the success of the patch while building a strong foundation on which a comprehensive coral-focused adaptation strategy can be built.

3. Results and Discussion

3.1. Proof of Concept for Proactive Coral Rescue in the Face of a Marine Heat Wave

In Fiji in late 2023, the Caribbean mass coral die-off was taken as a warning, and when the NOAA Coral Reef Watch predicted an intense marine heat wave due to hit Fiji in February–April 2024, plans were made to rescue heat-adapted corals from reef areas of extreme heat stress in Malolo District and receiving nurseries were begun at the end of the cool season, in October 2023. local-scale translocation of corals was carried out, focusing on securing corals found within a shallow "hot pocket" reef. Over 1300 coral colonies were moved from a shallow <0.5 m hot pocket reef flat area at West Nuku Reef over the coming months (Figure 14), relocated only a few hundred meters away and about 1.5 m deeper,

within waters about 2 °C cooler. The nursery was built of 16 mm metal rebars hammered into the sand, and topped with 200 × 200 mm heavy welded mesh, constructed in the shape of letters to spell out "BULA", the largest (16 m × 45 m) word ever written under the sea. Bula is a greeting that means life, and the rescue nursery, in addition to its function as a coral gene bank, is a shout-out for action to address climate change (Figures 15–17). The hot pocket reached >35 °C during the bleaching event, while the nursery reached 33 °C. Tens of thousands of corals left behind were bleached severely and died, while none of the translocated corals were bleached and all survived the marine heat wave event [94]. An estimated 80% of corals on the shallow source reef died due to bleaching, and of the 20% of corals that remained, most were subsequently devoured by over-abundant COTS, and the coral cover of the source reef went to about 5% within a year. Most surviving corals were either unpalatable species or were located within protective *Stegastes* farmer damselfish territories. This intervention represents the first major local-scale translocation of corals from hotter to cooler conditions as a proactive measure to rescue corals from an approaching marine heat wave as well as to secure them from a subsequent COTS plague [95].

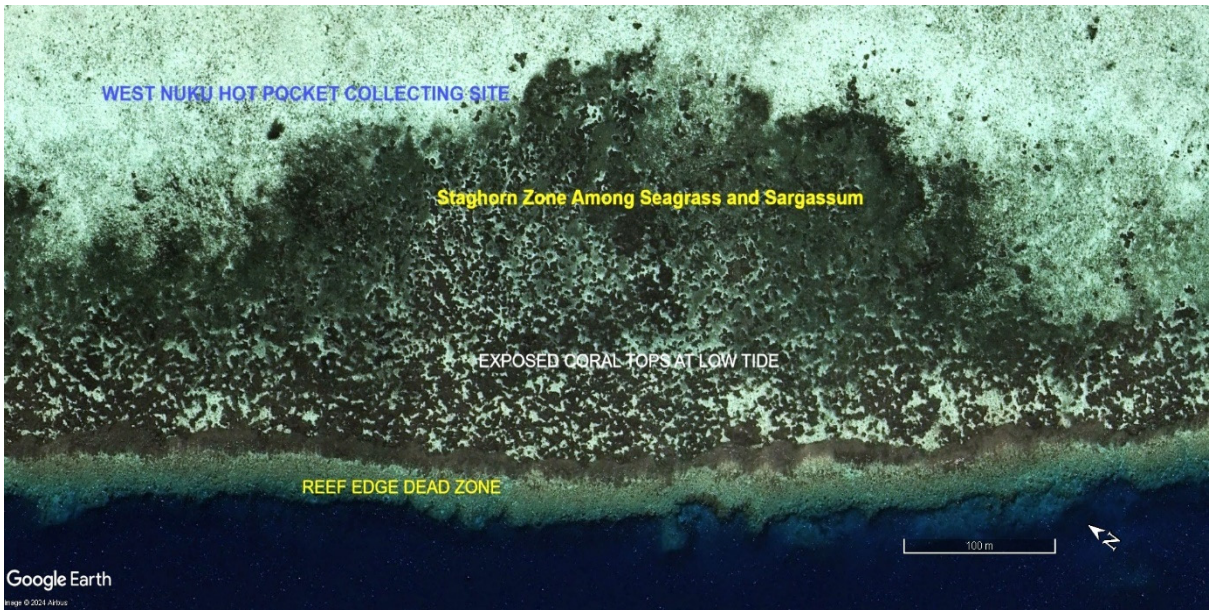


Figure 14. West Nuku reef flat hot pocket, which is part of a thermal stress zone some 900 m wide. Texture and color differentiate between corals and seagrass/macroalgae, with isolated coral patches seen beyond the sargassum and seagrass zone. The low-coral-cover "dead zone" of deeper waters is thought to be due to COTS predation, as aggressive coral-defending *Stegastes* farmer fish on the reef flat, which help prevent COTS from killing corals within their territories, are absent in these deeper waters.

3.2. Challenges of Establishing Gene Bank Nurseries

Although all the 1300+ corals on Bula Nursery survived the marine heat wave unbleached, several challenges were encountered later in the season; small butterfly fish of several species became abundant and targeted the tabulate and tightly branched corymbose coral species, spreading a white band type of disease. Several staghorn species of branched *Acropora* also caught the disease, but not colonies with abundant planktivorous fish. When multiple corals began to perish, we began removing all diseased colonies into a rubble quarantine area to try to stop the spread, and the disease ultimately led to the retirement of about a quarter of all the corals in the nursery over a one-year period. On the positive side, the *Acropora* corals remaining in the nursery have proven disease-resistant as well as

heat-resistant. The butterfly fish are now less abundant, perhaps because large predatory fish more often visit the nursery, and the coral-dwelling fish have increased greatly. As additional space in the nursery opened, we replaced the corals with large-branched corals from the nearby rope nursery known to be bleaching-resistant. Knowing which coral species were doing poorly in this low-energy site, an additional nursery was created further out in the reef system with better flow for housing the tabulate and corymbose growth forms as a possible solution.



Figure 15. Bula Rescue Nursery. Rebar and mesh table nurseries spelling out BULA, meaning "life" in Fijian. At 16 × 45 m, this is likely the largest coral rescue nursery on earth. The 24-foot boat in the photo gives perspective.

Toward the end of the cool season in September/October, we faced another crisis at Bula Nursery, with an outbreak of the black hairy/filamentous cyanobacteria, *Lyngbya*. We were fortunately familiar with dealing with this problem, which is seasonal [96]. These algae had become a major problem in established nurseries twice in years past, in 2019 and in 2021. According to the literature, this alga is iron-limited [97]. We have noticed that once the iron mesh has cured in the ocean for many months, or if it is double-coated with epoxy, the algae growing on the nursery structures become less problematic. At the peak of *Lyngbya* blooms, for over a month, clumps of algae lifted off reef flats and the algae drifted into and snagged on the branching corals, with rope nurseries especially affected. (Figure 18). This can result in the algae covering the corals to the point where the corals become invisible, and if not quickly removed, it results in high mortality [96]. During the height of the first outbreak in 2019, we noticed that *Lyngbya* cover continued to remain low on the natural reef, with *Stegastes* farmer damselfish working to weed the algae from corals and dispose of it, keeping the main reef clean and alive [96]. A solution was found for treating badly impacted nursery ropes: untying and placing *Lyngbya*-covered ropes within *Stegastes* territories resulted in 100% of the algae being removed within 24 h. However, for table nurseries, this procedure was not so feasible, so extensive hand cleaning was required. With Bula Nursery, we observed that corals with abundant planktivorous fish, blue/green *Chromis* and black and white banded *Dascyllus*, were considerably less impacted by algae. Although data is needed to better quantify this effect, we appear to have found a biological control method of planktivorous fish weeding out noxious filamentous algae.

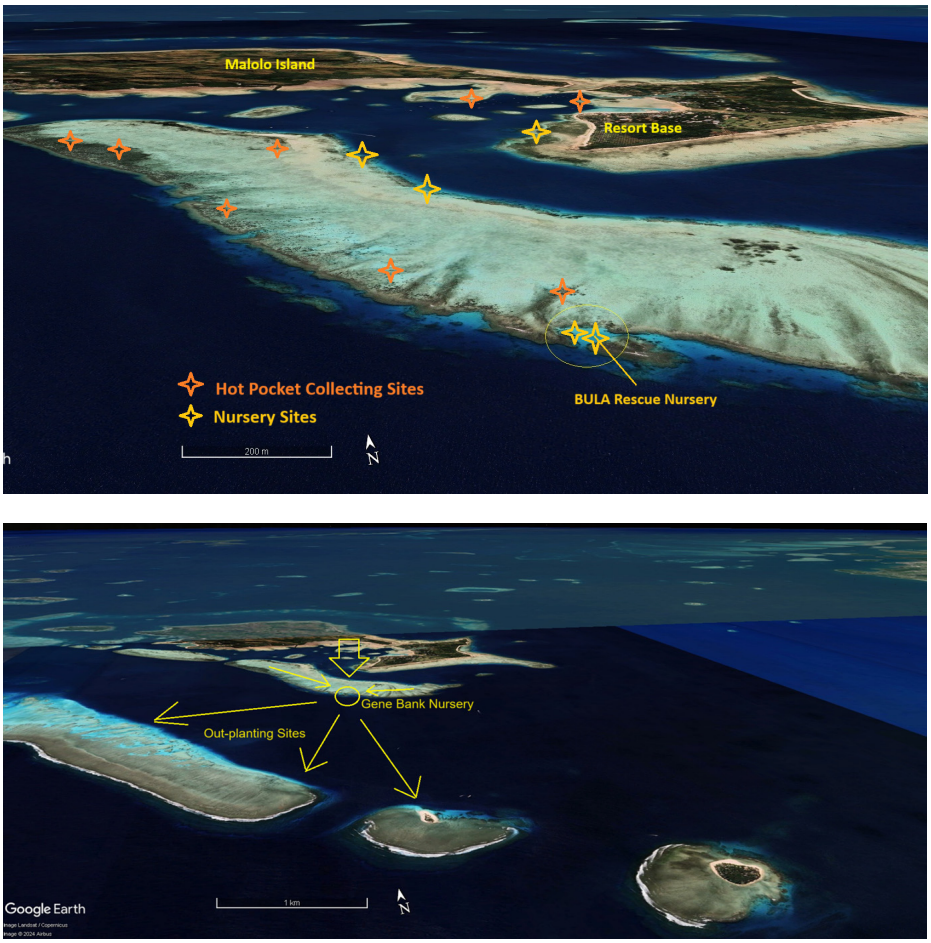


Figure 16. Nuku middle-lagoon barrier reef with the Bula gene bank nursery site and other nurseries marked and the main collecting areas indicated (close-up: **top** and overview: **bottom**). Arrows indicate the direction of coral translocation; from shallow to deeper, from hotter to cooler. The Malolo double barrier and fringing reef system is one of many examples of shallow reefs in Fiji with extensive hot pocket areas of restricted water flow, and with a strong hot to cool thermal gradient from nearshore to offshore within a few kms. Sheltered sandy-bottomed pools of the Nuku forereef serve as ideal nursery sites, while abundant out-planting sites are located on the bleaching-impacted outer reef backreef, where COTS are also less abundant presently due to low coral cover.



Figure 17. Bula Nursery, showing a diversity of (not yet fully sorted) corals. At one year, the nursery has for the most part become self-cleaning due to resident and visiting fish.



Figure 18. Severe *Lyngbya* infestation of an early-stage coral nursery in 2019, before an abundant fish population could develop, compounded by being disconnected from the reef.

3.3. Mass Coral Bleaching as a Major Selection Event for Bleaching-Resistant Corals

In addition to the Bula nursery, in two other Fiji sites, mass coral bleaching events were used to identify and collect bleaching-resistant coral colonies as soon as the heat stress began to abate, but before partially bleached corals could regain their color: Uluibau Village on Moturiki Island in 2023 and Naidiri Village on the Coral Coast in 2025. The bleaching-resistant corals were incorporated into table nurseries to create a broodstock of heat-adapted corals for future coral work by the communities while supporting climate resilience, coral reef regeneration, reproduction, and ecological functionality. While such gene bank nurseries will facilitate successful spawning, some species are represented by only one genetic individual, and so more collections must occur during future bleaching events or from hot pocket reefs to restore reproductive functionality. The three Fiji sites can now serve as model sites on which a Fiji national coral reef adaptation plan can be built.

While multiple regeneration patches have also been created in C4C's Fiji sites, time has proven inadequate to establish results-based verification of accelerated larval recruitment. However, as strong larval settlement signals for incoming coral larvae are undoubtedly being emitted by these restored coral dominated communities in the form of chemical cues (smell), visual cues (sight), and acoustic cues (sound) [98–102], clear results should become quantifiable within 3–4 years, indicated by a significant increase in the numbers of juvenile corals around and down-current from the regeneration patches, as compared to reef areas without regeneration patches. From the community standpoint of increased MPA functionality, the increased fish populations are already proof of success.

4. Developing a Fiji National Coral Reef Adaptation Plan

Fiji has tremendous advantages over other independent Pacific Island nations; not only are Fiji's coral reefs more intact in comparison to those of other nations due to the factors discussed in the introduction, but the number of NGOs operating coral reef conservation initiatives is impressive. This includes Fiji offices of international NGOs: Conservation International (CI), Wildlife Conservation Society (WCS), World Wildlife Fund (WWF), as well as LMMA, the Locally Managed Marine Area Network, Blue Prosperity Fiji, and several smaller NGOS, including Reef Explorer Fiji, Pacific Blue Foundation, Vatuvara Foundation, Coral Gardeners, Global Vision International, and Corals for Conservation among others.

All these organizations work under the scope of the Fiji Ministry of Environment and Climate Change and the Fiji Ministry of Fisheries and Forests. Through these NGOs and ministries, strategies are being developed to address coral reef decline. Of relevance, SPREP has also created the "Pacific Coral Reef Action Plan 2021–2030" [103], and in 2020, WWF and WCS formed a partnership to create the "Coral Reef Rescue Initiative" with Fiji and the Solomon Islands as part of seven countries included globally [104]. WCS is also working with the Ministry of Environment and Climate Change through the National Hub for Coral Reef Conservation to create a National Action Plan for Coral Reef Conservation (NAPCRC) [105]. CI is working to secure coral reefs in the Lau Seascape, and they have begun to integrate coral-focused work in their community sites. The present paper has been prepared as potential support for all these diverse initiatives.

Fiji has an additional advantage of having a foundation of well-established academic institutions: the University of the South Pacific with its marine science program, and Fiji National University with its fisheries science program, with hundreds of Pacific Islanders graduating with qualifications to fill roles as marine field officers at government and NGO levels. A credentials-level capacity-building curriculum has been developed by C4C specifically for the Reefs of Hope Ocean Decade Action and awaits approval by SPC for implementation through a certified training institution.

Another source of support for a national coral-focused adaptation program is the tourism industry of Fiji, which is the largest of the independent Pacific nations. As coral reefs are an essential foundation of Fiji's tourism industry, resorts have been major supporting partners for coral-focused work, providing access to field sites and logistics support, hiring trained university graduates as marine officers, and funding actions such as the Bula rescue nursery, as well as supporting MES, the Mamanuca Environment Society. The tourism industry, with its keen interest, could potentially absorb dozens of trained coral reef adaptation professionals to implement the coral-focused objectives of a Fiji national coral reef adaptation plan and as a means for securing and enhancing the tourism product. Tourism Fiji as well as the Fiji Ministry of Tourism and individual resorts should thus be regarded as important partners in a national coral reef adaptation plan and efforts to secure coral reefs into the future.

The most important foundation of coral reef conservation in Fiji is the indigenous communities and locally managed marine areas, which offer an immense source of support, youthful energy, and stewardship that is unequaled in most parts of the world. Locally Managed Marine Areas must be nurtured, guided, and supported to enable coral-focused adaptation work to expand into hundreds of community-based MPAs around the country. In some areas of the country, tourism–community partnerships also offer a potential source of multi-generational conservation and adaptation support that can stretch far into the future, independent of the need for external funding and management.

A proactive plan to save the coral diversity of Fiji from demise in the coming decades in the face of worsening marine heat waves due to climate change must build on the existing site work of Government Ministries, Academic Institutions, NGOs, communities, and resorts, weaving the various coral elements into existing conservation and capacity building programs as insurance against the inevitable impacts of extinction-level bleaching that may be unavoidable now due to increasing levels of carbon in the atmosphere and oceans. However, the extinction of coral species does not have to be the outcome.

What is required now is for coral reef-focused institutions and programs to study the plans presented in this document and to discuss the urgency and potential of working toward unified coral-focused outcomes. While UNESCO has already endorsed these strategies, an endorsement of the general concepts is needed at government and NGO levels. The specific implementation plans suggested are flexible and are given as an

example of what implementation might look like (Figures 19 and 20), as a starting point for formulating a national coral-focused adaptation action plan. The tentative adaptation sites were selected based on existing conservation work and human capacity, strong adaptation potential for thermal resistance, and ease of access (roads, dependable boats, or airports).

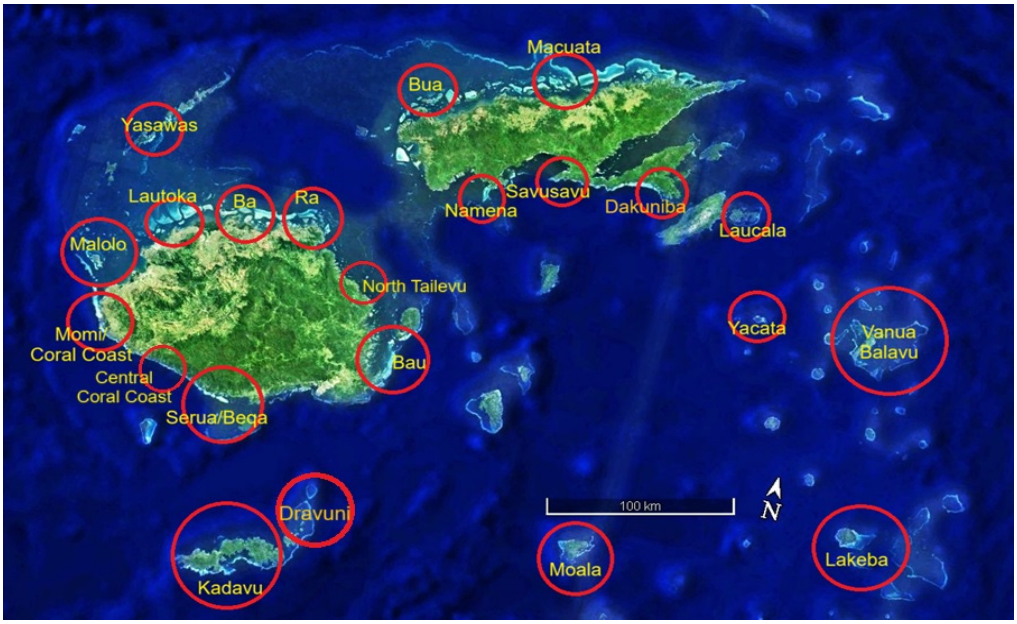


Figure 19. Proposed key sites for full implementation of a national Coral Reef Adaptation Plan for Fiji. Sites were selected based on ideal adaptation potential for thermal resistance, ease of access, and existing support for marine conservation.

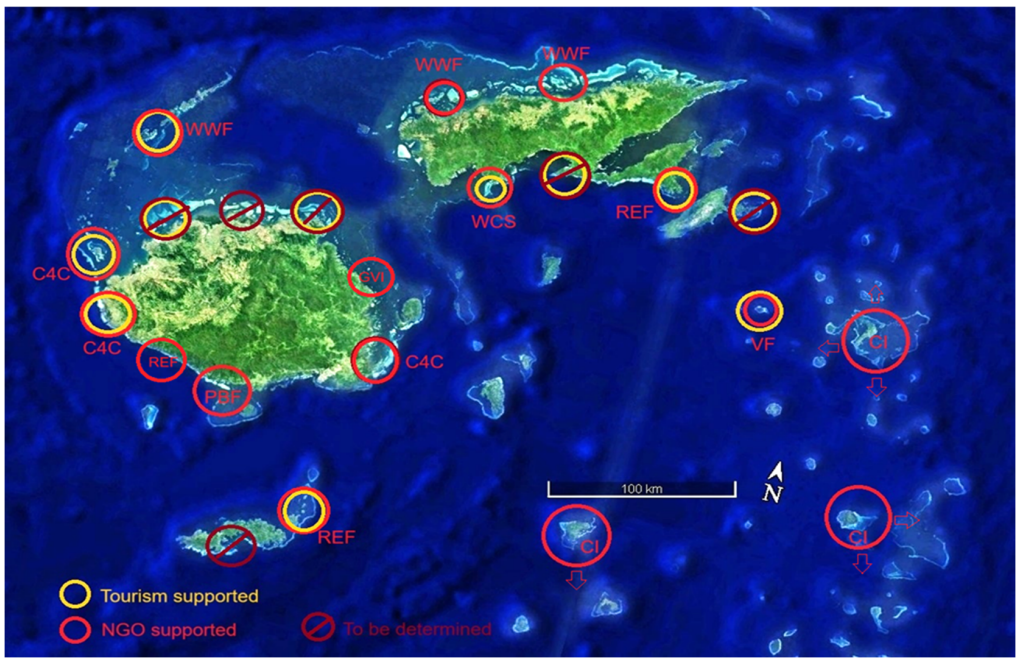


Figure 20. Existing NGO-supported sites (red) and sites with potential tourism industry support (yellow). Double circles indicate both sources of support for coral reef conservation. Conservation International (CI), Wildlife Conservation Society (WCS), World Wildlife Fund (WWF), Vatuvara Foundation (VF), Reef Explorer Fiji (REF), Pacific Blue Foundation (PBF), Global Vision International (GVI), and Corals for Conservation (C4C). Government support and oversight cover all sites. Circles with slashes represent key sites where work may not yet be occurring.

The Reefs of Hope Ocean Decade proposes that corals of even the most pristine coral reefs should be secured via hot-to-cold translocation as insurance against loss, well before imminent threats emerge. However, it can be difficult to convince those who manage such pristine reefs that an existential threat has arrived. As an example, in 2018, Tuvalu was virtually untouched by bleaching and was dominated by large-branched *Acropora* thickets, towering 3–5 m high and extending for many kilometers. C4C began a translocation project with the government but received little support due to the pristine condition of the reefs, with a consensus that it was premature, so the work was discontinued and the nursery fell into disrepair and eventually collapsed, with the corals mostly dying. However, in 2024, Tuvalu was hit by a 9-month condition 3 mass-bleaching event, causing a 99.99% coral die-off and the extermination of virtually all *Acropora* corals. Only seven *Acropora* corals could be found, all of which were in the old nursery, moved from hot to cooler waters seven years earlier. This proves that translocation works and that resilience does not fade with time. But sadly, many species that might have been saved are now locally extinct. As Fiji's coral reefs remain largely intact, a similar resistance to translocation might also be expected.

4.1. Phases of a Fiji-Wide National Coral Reef Adaptation Plan

A series of phased protocols has been formulated that can be applied to Fiji and other countries in the development of national coral reef adaptation plans. The protocols given below are outcomes of the research presented, plus years of trials and first-hand observations of restoration work over some 30+ years in 13 countries in both the Pacific and Caribbean.

4.1.1. Phase One: Coral Species Rescue and Stabilization

This initial phase focuses on actions to stop further coral loss, keeping each coral species alive and with enough genetic variability to remain in a viable condition into the future. Securing each coral species within gene bank nurseries requires finding "sweet spots" in the ocean with suitable temperature regimes, adequate current flow, shelter from storms, and easy access, to maintain the corals in healthy condition over time, increase their biomass, and trim excess material for use in subsequent reef regeneration efforts, a source of sustainably obtained corals for community and resort-based restoration work. Coral-focused work provides an effective point of entry for those most impacted by the loss of coral reefs due to climate change.

Once gathered into gene bank nurseries, the corals are propagated to increase coral biomass, with surplus heat-adapted corals then trimmed for use in community- and resort-focused programs. The out-planting stage puts corals strategically into regeneration patches within facilitated coral reef recovery sites. Despite trimming, each coral genotype is maintained within the nursery to keep the genotype under protection and monitored over the years; the goal is to secure the shallow water corals of Fiji into the mid-century and beyond. Once the various conservation programs adopt these coral-focused strategies, the work will take several years before all areas of the country have gene bank nurseries so that most coral species are secured and reproduction of rare and uncommon species restored. The suggested goal is for a minimum of 50 genotypes of each of the most vulnerable coral species secured around the country, which would secure 99% of the genetic diversity of the nation's corals [92], beginning with a focus on the most vulnerable of Fiji's 300+ coral species. If represented by 50 genotypes per 200 coral species, that would come to 10,000 coral genotypes secured and reproducing effectively throughout the combined nurseries of the country, with direct positive impacts and reducing future risk.

Based on ongoing work, a 15 m × 12 m nursery can secure about 600 corals, and so 20 nurseries could secure over 12 thousand corals of the nation. The out-planting phase of the work, 2–3 years after nursery establishment, will spread the risk of loss from natural disasters even more, sending corals of as many coral genotypes as practical within regeneration patches to multiple sites locally, restoring reproduction, facilitating symbiont sharing, and stimulating larval settlement and recovery.

The most vulnerable species group is *Acropora*, which is also the fastest growing, most genetically and morphologically diverse, and most vital habitat-forming coral species group [13]. *Acropora* is also the coral proven to produce a strong pheromone smell, which attracts the larvae of corals [101,102], indicating that a reef area is "prime real estate" so that the larvae can settle out in the best possible habitat. Pristine reefs of the past were most often dominated by *Acropora* but are now becoming dominated by more resilient species [13]. This is why *Acropora* species are a major target when securing corals from localized extinction due to severe marine heat waves. The more resilient coral species such as *Porites*, *Montipora*, and *Pocillopora* can also be planted where *Acropora* is in short supply, even though these corals grow more slowly and may not provide the same chemical settlement signals, nor do they provide the same sorts of fish habitat; however, their presence might still help reboot recovery, as the small crabs and shrimp that live among *Pocillopora* in particular are very noisy, and sound attracts the larvae of both fish and corals [98,99].

4.1.2. Phase Two: Restoring Sexual Reproduction

When corals become rare, reproduction and larval recruitment fail due to the distance between colonies being too great, causing fertilization to fail: the "allele effect". At >10–15 m apart, virtually all fertilization and larval formation stop, greatly impacting coral reef recovery. A simple strategy to relocate isolated corals into proximity can restore sexual reproduction and is integral to the development of coral reef adaptation plans. Recovery plans focus on searching the reefs to find and secure rare and declining coral species and to gather heat-adapted survivors of bleaching together to restore sexual reproduction within nurseries and regeneration patches.

Natural coral reef recovery is reliant on a good supply of coral larvae, which requires reproductively viable populations of corals in the vicinity of and up-current of impacted reefs. Coral reefs with good connectivity to intact populations of diverse corals and abundant coral larvae recover from disturbance rapidly, within 5–10 years, while reefs with poor connectivity, which are thus cut off from abundant larval sources, take much longer to recover. Reefs with poor access to good larval sources sometimes recover as an alternative coral community—a phase shift dominated by brooding coral species that produce larvae able to settle immediately (certain species of *Porites*, *Pocillopora, and Montipora*) and thus more likely to settle locally near the parent corals. For broadcast spawners such as *Acropora*, the coral larvae require development while drifting in the larval state, and so the source reefs are best located 4–10 days up-current from the recovering reefs, so that the larvae can settle within that time. The relative distance this represents can be as high as several hundred km or as low as just a few km, should the larvae get caught within lagoons or caught within the eddies that can form down-current from islands.

4.1.3. Phase Three: Facilitating Natural Recovery Processes

A largely unrecognized problem when *Acropora* corals become rare is that the strong smell they emit, GLW-amide neuropeptide [101,102], is missing from the reef. This "reef" smell acts as a pheromone attractant and strongly induces larval settlement. Once *Acropora* corals are missing from the reef and the smell is gone, their larvae and potentially the larvae

of other corals, fish, and invertebrates have a more difficult time finding the proper place to settle. This is why a special focus is placed on large-branching staghorn corals, as they are particularly smelly, grow the fastest of any corals, and serve as important fish habitat. As most *Acropora* species have declined throughout the islands, it is important that they be secured within gene bank nurseries and propagated for later use in the creation of reef regeneration patches designed to attract coral and fish larvae to degraded reefs, which in turn accelerates natural adaptation and recovery.

Out-planting via regeneration patches proceeds using second-generation corals trimmed from nurseries and planted to reefs with good ecological balance and lower stress and thus with good prospects for long-term survival of heat-adapted corals. The goal is to create multi-genetic patches of each coral species close enough to each other to restore high rates of fertilization as well as to emit a strong smell to help the larvae find their way home. Established as discrete and concentrated patches, the corals can be more easily monitored and cared for, as opposed to haphazard planting of smaller fragments. Regular gardening activities can be more readily conducted to remove predators and excessive seaweed and to control disease.

Assuming that there are initially 10–20 gene bank nurseries of heat-adapted corals established, each of these nurseries should be producing surplus corals to create recovery patches in multiple sites of the surrounding reefs as the corals grow and are trimmed. With at least 50 species of branching corals in each nursery, by the third year, at least 50 densely planted recovery patches could be created per year per nursery, 500 to 1000 coral patches spread throughout the islands per year, facilitating both sexual reproduction and recruitment-based recovery, as well as facilitating heat adaptation, vastly increasing the stability and resilience of coral reefs of the nation regardless of warming seas.

4.1.4. Phase Four: Additional Measures to Support Coral Reef Health

1. Captive Breeding of Corals

While less community appropriate, more costly strategies, such as land-based flowing seawater facilities for the spawning and rearing of large numbers of juvenile bleaching-resistant corals, can be justified in an upscaled national strategy. However, these and all strategic efforts are dependent on securing an abundant collection of diverse heat-adapted coral broodstock in a timely manner. Captive breeding only makes sense between two or more genotypes of host-based heat-resilient corals; therefore, the coral genotypes used must be fully investigated as far as the source of resilience: host, algal symbionts, or probiotic symbionts. Ideally, the resulting juvenile corals should subsequently be inoculated with heat-resilient symbionts and probiotics, giving two resistant parents, resistant algal symbionts, plus resilient bacteria to maximize thermal resistance.

A more low-tech version of the gamete harvesting and captive larval rearing strategy is also possible once the source of resilience of the coral broodstock in a gene bank nursery is known. Resilient-host-based coral strains can then be used to create single-species regeneration patches of multiple coral genotypes. The resulting gametes released from these patches will all be from heat-resistant parents, which can be captured via nets placed directly above patches during spawning. The resulting larvae can then be reared to the point of settlement within temporary tanks and allowed to settle onto specially designed (movable) substrates in an environment dominated by heat-resistant symbionts. An alternate strategy would be to release ready-to-settle larvae directly onto coral reefs near well-established regeneration patches planted with heat-resilient holobionts, giving the juvenile corals a high probability of accessing heat-resilient symbionts as they settle around the patches.

2. Including Tridacnid Clams in the Coral Reef Adaptation Work

In addition to corals, giant clams of the genus *Tridacna* are another photosynthetic coral reef animal that is vulnerable to bleaching and subsequent death due to hot waters. Just as with corals, heat-adapted clams can be moved from hot to cooler and from extreme shallows to deeper waters as an adaptation strategy. This would help prevent giant clam death during marine heat waves in extremely hot and shallow environments.

Tridacnid clams contain the same species and strains of symbiotic algae within their tissues as do corals, and the clams shed live symbionts in copious amounts in their feces, which have been shown to be picked up by newly settled corals [106]. Therefore, a potential strategy focusing on using heat-adapted clams to facilitate adaptation is possible. The strategy could simply involve moving heat-adapted clams from hot pocket reefs to cooler waters to give the clams a better chance at survival, with the clams shedding copious amounts of heat-adapted algae throughout the reef to become "teachers of the reef", with the resistant algae picked up by newly settled juvenile corals and clams.

The present clam hatchery at Makogai Island and other such hatcheries throughout the region have the potential to become centers of coral reef adaptation, supporting national coral reef adaptation plans by intentionally introducing heat-resistant symbiotic algae to the juvenile clams they produce. The large numbers of heat-adapted clams they produce would be sent out to communities and resorts, helping spread heat-resistant symbionts throughout the country, increasing the adaptation potential of coral reefs.

3. Coral-focused Measures to Adapt to Ocean Acidification

While not an important factor presently, measures to combat the impacts of ocean acidification may, in the future, need to be incorporated into gene bank nurseries, assuming that corals can make it through the continually worsening ocean warming crisis. Such measures might involve farming seaweed on ropes alternating with ropes of corals or perhaps locating nurseries above healthy seagrass beds to combat declining pH levels. However, the present practice of locating nurseries above coralline lagoon sand may serve to buffer the impacts of acidification as well. Corals adapted to acidified waters may also be sought for incorporation into the program, such as corals found to be associated with mangrove areas low in freshwater influences. Numerous potential sites for the development of low-pH-adapted corals are found on the leeward low-rainfall reefs of Fiji (Figure 21).



Figure 21. Mangrove islands on restricted-flow lagoons off the northern low rainfall coast of Bua, Vanua Levu. Such closed-lagoon mangrove environments remote from freshwater runoff present a potential source of both low-pH-adapted and heat-adapted corals.

5. Recommendations Based on Lessons Learned

5.1. Repurposing Restoration Methods for Adaptation

While most coral reef conservation and restoration efforts have been severely impacted by recent mass bleaching events, lessons can be learned from these failures and setbacks. It is becoming clear that restoration must be re-focused away from the random selection and planting of corals and toward coral-focused adaptation, using strategies such as selection for thermal resilience, local-scale gene banking, and translocation in order to secure coral genetic diversity and with restored reproduction as a primary goal. However, past progress made in developing effective coral propagation and out-planting methods will not go to waste, as these techniques can be re-purposed to support facilitated adaptation. Active coral-focused adaptation, in turn, can be channeled to support wider coral reef conservation strategies and MPA functionality by increasing living coral habitats and by insuring against further coral diversity loss in the face of increasingly severe marine heat waves.

5.2. Predator Removal and Control as a Facilitated Adaptation Strategy

The most basic coral-focused adaptation measure that is already in place in some conservation areas of Fiji and the region is COTS removal and control. If predator impacts are not part of existing management strategies, this is where to start for many reef systems. However, with few exceptions, corals of Fiji and the Pacific Islands are being left to die from predators (e.g., crown-of-thorns starfish (COTS) and *Drupella* snails), before, during, and after severe marine heat waves. Heat-adapted corals, which are so important to coral reef adaptation, are subsequently eliminated by these predators in the face of vastly skewed predator-to-prey ratios, which undermines adaptation potential [107,108]. In such cases, rather than focusing on the numbers of corals planted, a more effective use of resources would be to focus on COTS removal and securing declining corals within elevated COTS-free nurseries.

Fish predators can also impact remnant *Acropora* corals greatly after severe bleaching mortality reduces coral abundance. This is problematic for reefs with abundant parrot fish and butterfly fish, which can sometimes eliminate surviving *Acropora* corals within months post-bleaching [29]. Butterfly fish may also spread disease in the nursery, as we experienced with Bula Nursery. Gathering what remains together with other corals into a nursery can sometimes help solve this problem, but it can also make matters much worse. This is because *Stegastes* farmer damselfish can be important in preventing fish and invertebrate predation on *Acropora* corals within their territories, and corals collected from this protection and planted in nurseries can subsequently be attacked and damaged or even killed. Placing small mesh covers over the corals in the nursery is perhaps the only solution to prevent this damage.

5.3. Strategies for Collecting and Moving Corals

Collecting unbleached corals at the end of a mass bleaching event as the waters begin to cool is an effective way to ensure that the corals are truly bleaching-resistant.

Always move corals from hot to cooler and from shallow to deeper waters. Even during highly stressful mass bleaching periods, this strategy has proven highly effective, as it relieves thermal stress and helps the corals survive. However, avoid unnecessary fragmentation during hot, high-UV seasons, unless shading is subsequently provided within the nursery.

Wherever shallow water coral populations are jeopardized, whole coral colonies should be targeted for inclusion within gene bank nurseries. As this is a coral rescue, experience indicates that whatever is left behind will likely die in a severe marine heat wave at some point in the future. The strategy also prevents delays waiting for corals

to grow to the appropriate reproductive adult size. But most importantly, fragmentation opens exposure to high UV levels, which can cause bleaching for both the source colony and transplants, often lethal when carried out during high-UV-stress periods.

When transporting corals, care must be taken to avoid oxidative stress, which can result when using non-aerated containers or when fragments bunch up together in a container. Over multiple years in multiple sites, we have typically obtained 100% survival by transporting coral colonies on deck and out of water while constantly spraying them with cool seawater and, if possible, also keeping them shaded and out of the wind.

5.4. Guidance for Selecting Cooler Water Gene Bank Nursery Sites

Just as with locating ideal coral collecting sites, desktop scoping for potential gene bank nursery sites is carried out using Google Earth satellite photos, followed by ground-truthing to verify assumptions. This desktop and field scoping process is required before any plan of action to rescue heat-adapted corals can be devised and carried out.

Follow the principle that outer reefs are generally cooler than inner reefs and smaller reefs with a less-shallow water area will be cooler than larger reefs with extensive shallow areas. If temperature data exists, that would be useful.

Gene bank nurseries ideally should be secure from wave damage, being located behind a shallow reef facing the incoming wave direction. And as wind and wave directions can be expected to change during shifting monsoons and storms, the nursery should be located where reefs protect it on all sides, not just the prevailing seasonal or fair-weather wave direction.

Nurseries are ideally situated in waters with 2 m of water on top of the nursery at low tide, to optimize growth and to allow for easy SCUBA-free access and more community involvement. They should be situated at least 1–2 m deeper than the nearby reef flats or coral heads and, if possible, close up against the reef, so that breaking waves will roll right over and above the nursery during storms. In this way, the nursery will have both good flow and excellent protection, and reef fish will visit the nursery to clean the structures.

Nurseries located near populations of surgeonfish and juvenile parrotfish are cleaned naturally by the fish. However, if the fish are too afraid to cross barren sand or rubble to the nursery, habitat bridges can be created.

With Reefs of Hope strategies, ideally, corals are not translocated into highly different thermal or light regimes, to prevent acclimation pressures away from their original highly resistant state. The goal is to keep heat-adapted corals within the natural stress regimes where they evolved, which requires local-scale translocation, as thermal conditions are shifting due to warming oceans. As global warming progresses, the location of the gene bank nurseries may thus need to shift into cooler waters in the years to come, and shading might be required should temperatures climb higher than expected. In the present crisis, even short-distance relocation by just tens of meters from situations of extreme stress and exposure can make all the difference in reducing the probability of death due to lethal temperatures or lethal levels of exposure during extreme low tides.

6. Support for Implementation

6.1. Government Incentives and Policies Are Needed to Support Coral Reef Adaptation

The mainstreaming of coral-focused adaptation at the tourism industry level could be incentivized by establishing government enabling mechanisms through the creation of new policies and tax incentives. Enabling mechanisms for communities would be through the creation of new laws supporting full legal recognition of community no-take areas, with the ability to enforce local MPAs. In addition, support for economic incentives such as alternative livelihoods, a bounty on COTS removal, continued support for giant clam

restocking into permanent MPAs, support for sea cucumber restoration, and support for youth involvement in coral-focused work are needed. Increased coordination and capacity building at village, district, and provincial levels should focus on maintaining local initiative and drive to continue carrying out the lion's share of the work at the local level.

With a more proactive approach being taken by the government, the various local and international NGOs can better align behind and support government initiatives. In the past, NGOs had to develop their own priorities and took on the primary leadership role, which was appropriate during Fiji's several coups and in post-coup realities. However, a stronger leadership role is now being taken by the government as times become stable and government capacity increases. Government capacity is an essential aspect of funding for a national climate change adaptation program, as only governments can tap into the billions of UN dollars set aside to fund climate change adaptation.

A promising development in proactive management and leadership by the Ministry of Environment and Climate Change was launched in August 2024—the Fiji National Hub for Coral Reef Conservation—with the goal of becoming the central coordination body to work with NGOs, Ministries, and UN agencies to develop Fiji's Coral Reef Action Plan. The ongoing work aims for completion by late 2025 and is being facilitated in partnership with WCS and UNDP/UNEP and with input from all stakeholders.

6.2. Representative Estimated Budget

While the true costs of national implementation will require more fine-scale analysis, the budget given below for Fiji (Table 1) roughly estimates the costs of a comprehensive ten-year coral reef adaptation plan. Fiji has expansive coral reefs, and so the plans are costly; however, nations with much smaller reef areas, such as Samoa or Vanuatu, would require only a fraction of this amount. However, only national governments backed by the coral reef conservation community can hope to access the untapped billions of dollars earmarked in multiple funds by various UN agencies for coral reef adaptation: Global Fund for Coral Reefs, Adaptation Fund, Green Climate Fund, Global Environment Facility, and Coral Reefs Breakthrough. Rather than individual countries attempting to access these funds directly, SPREP could establish a more orderly and comprehensive regional approach tied to its existing Pacific Coral Reef Action Plan, avoiding considerable administrative duplication and associated costs. It also makes sense from the standpoint of program management, the procurement of materials and scientific equipment, capacity building, project monitoring, and a regional approach to early warning systems and emergency response teams to address the arrival of impending severe marine heat waves.

Table 1. A ten-year representative budget for a National Coral Reef Adaptation Plan for Fiji.

ITEM	Per Year Site Cost	20 Sites/Year	Ten Years
Personnel	€100,000	€2,000,000	€20,000,000
Boats, Fuel, Travel	50,000	1,000,000	10,000,000
Nursery Materials	10,000	200,000	2,000,000
Out-planting Materials	10,000	200,000	2,000,000
Community Workshops	10,000	200,000	2,000,000
Subtotals	€180,000	€3,600,000	€36,000,000
Additional support for coral spawning systems to double as giant clam hatcheries	100,000	Five sites/year 500,000	Ten Years €5,000,000
Totals	€275,000	€4,100,000	€41,000,000

Funding sources such as the Global Fund for Coral Reefs are tied to investment funds and expect a profit on investment, preventing the implementation of coral reef

adaptation and conservation in the poorest nations. Reefs of Hope can best be considered as insurance against permanent and irretrievable loss, and funds should therefore come with no strings attached.

The July 2025 International Court of Justice ruling that climate-change-impacted nations have the right to "invoke" the responsible states for "an internationally wrongful act resulting in damage to the climate system and other parts of the environment" could result in more direct funding to actively save coral reefs, which is recognized as the most climate-impacted of all marine ecosystems [109].

7. Conclusions

There are no quick-fix solutions, and so the best we can hope for is to buy more time for coral reefs and coral species. Reefs of Hope solutions will not solve the overarching problem of coral reef decline due to climate change. Rather, our goal is to assist those already involved in coral reef conservation to adopt best-practice coral-focused strategies to insure against coral diversity loss and for those working with coral restoration to do it in such a way that it reinforces bleaching resistance and genetic diversity rather than imposing large numbers of corals planted randomly onto reef systems. What better solution than to prevent the die-off of the most heat-adapted corals and to work with these genetic treasures to reboot natural adaptation and recovery processes?

Global warming is causing the nearshore and hot reef flats to become lethal environments during marine heat waves, and the heat-adapted corals living there cannot move themselves, so we must urgently move these corals to maintain them within the shifting thermal environment as the waters warm. Perhaps one day, when sea level rises 30–50 cm, the thermal environment of these warmer waters will cool again, and we can put these corals back where they came from. But for now, we must act swiftly to keep them alive!

Ultimately, the long-term success of any intervention requires a transformation of energy production away from fossil fuels and toward sustainable alternatives. However, with carbon emissions and temperatures increasing unhindered, nature may impose her own solutions, such as massive ice loss resulting in sea level rise and the collapse of ocean overturning circulation [5,110,111]. While these events pose major risks globally, some models suggest that they could temporarily ameliorate reef heat stress by slowing global warming rates or cooling surface waters regionally [112,113]. Even a moderate amount of sea level rise could help cool shallow reef areas and lagoons due to increased circulation and increased depth of reef flats, lowering heat stress on the corals that remain [114–116]. These "silver lining" types of changes are unpredictable, but they would come with enormous costs to humanity, and, as such, they might finally help to galvanize effective action.

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