A CALL FOR URGENT MEASURES TO SECURE THE JEOPARDIZED HEAT-ADAPTED CORALS OF THE GREAT BARRIER REEF

An Unsolicited Advisory Paper to the Great Barrier Marine Park Authority

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An Extension of Reefs of Hope, a UNESCO-endorsed Ocean Decade Action

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CORALS FOR CONSERVATION

Summary: *A Climate Emergency has emerged for Coral Reefs globally which potentially threatens ongoing Coral Breeding and Restoration programmes. Urgent and immediate action is required to secure brood-stock corals against sudden and widespread loss of bleaching resistant, heat adapted corals which these highly invested programmes depend on. An extinction-level coral bleaching event occurred in 2023 in Florida and the Caribbean, with nearshore temperatures as high as 38.4°C, resulting in the loss of uncountable numbers of corals and tens of millions of dollars in investment. With the recent surge in mean ocean temperature, https://climatereanalyzer.org/clim/sst_daily/ the Southern Hemisphere winter of 2024 could be the last few months of survival for millions of corals on the Great Barrier Reef and southern oceans, including tens of thousands of bleaching resistant corals that might be used in ongoing coral reef adaptation and restoration programs. A rescue and mass evacuation effort to save and secure as many of these bleaching resistant corals as possible is proposed, focused on moving coral colonies from areas of extreme heat stress to cooler water reefs nearby, where these pre-adapted corals can more easily survive. This effort would provide insurance to the future of coral breeding and restoration programmes, and to the reef itself in rapidly warning seas. Time is running out for the very corals which have the greatest potential of surviving into the future.*

Heat adapted coral populations of the extreme shallows are not well studied, being generally inaccessible during low tide. However, lack of data should not be used as an excuse for inaction. As the intensity of marine heat waves has increased, many heat adapted corals have undoubtedly already succumbed on many reefs, and what remains of these shallow water coral populations is largely unknown. An urgent response is justified and required.

A simple scoping exercise was done via Google Earth satellite photos, based on experience gained from working in sites in Fiji and the South Pacific region, and key strategic recommendations are included in this advisory paper. Ground truthing of these recommendations will be a relatively simple exercise, to confirm the presence of living corals of the genera of most interest (Acropora etc). Recommended collection and transport methods are also given, based on ongoing work in Fiji.

Heat Adapted Corals are Critically Jeopardized if left in Place.

The most heat adapted coral populations of extensive coral reef systems like the Great Barrier Reef are most often either found in nearshore environments, are associated with wide reef flats, or are located within restricted-flow lagoons. These "hot pocket" reefs are often dominated by shallow waters less than one meter deep at low tide. Corals of the hot pocket reefs are regularly exposed to extremely hot waters at low tide, and may also be exposed to the air during extreme low tides and thus impacted by heavy rainfall and drying by the sun and wind. Due to these multiple stressors, shallow hot pocket corals are often ephemeral, as few corals survive more than a few years, except for the most resilient species such as certain species and strains of *Porites*, *Diploastrea*, *Montipora, Pavona,* and a few other species. *Acropora*, the fastest growing, most genetically and morphologically diverse, and most vital habitat forming coral species group, which dominates most pristine reefs, tends to be the most vulnerable species group, and thus *Acropora* species are a major target when securing corals from localized extinction due to severe marine heat waves.

In Fiji shallow hot pocket temperatures often reach 34-36°C, which some *Acropora* corals can withstand without bleaching. Lethal temperatures exceeding 37°C sometimes occur within the thermal layer that forms at the surface at low tide on windless days, immersing coral colonies within this extremely warm "hot tub" layer. Yet despite this high thermal stress, some *Acropora* and other species of corals continue to thrive at the upper limit of coral survival. However, due to climate change and the associated increasingly intense and off-scale marine heart waves, all hot pocket coral populations should now be considered jeopardized over the longer-term, wherever they still exist.

The most urgent action to ensure that as much genetic diversity of as many species of corals as possible survives the approaching crisis, is a systematic collection of hot pocket corals before they succumb. These corals represent pre-adapted coral host and symbiont (holobiont) communities which exist at thermal conditions far above those predicted for coral reefs situated in cooler waters for many decades to come. Therefore, the time has come for a widespread scoping of shallow hot pocket reefs, to locate populations of heat-adapted corals, and then to launch a programme to systematically collect these precious pre-adapted corals before it is too late, relocating whole colonies (if possible) or fragments to cooler waters, incorporating them within genebank nurseries at cooler sites with good circulation, yet sheltered from cyclones.

RECOMMENDATIONS:

Scoping for Hot Pocket Coral Populations

1. Follow the general principle that wide reef shelves have a thermal gradient from warmer nearshore to cooler offshore waters.
2. Wide reef flats have greater potential to create and accumulate hot water during low tides than do narrow reef flats.
3. Restricted-flow bays and shallow lagoons which are located adjacent to wide reef flats may prevent mixing and may thus retain hot water.
4. Leeward sides of islands and reef flats sheltered from waves and winds will be warmer than their windward sides.
5. Experience indicates that the greatest heat stress will be located within 30-50cm of the surface at low tide, as the shallowest corals will be immersed within the thermal layer that forms at the surface during windless summer days. It may indeed be this "hot tub" layer that has driven adaptation of coral holobionts to extreme heat over countless centuries.

Strategies for Collecting and Moving Corals

1. For coral breeding programmes, whole coral colonies should be targeted, so that the programme will not have delays waiting for corals to grow to the appropriate reproductive adult size.
2. To save as much genetic diversity as quickly as possible, a strategy focused on collecting as many 15-20cm long fragments as possible might be used. This is the best strategy for restoration efforts that can afford to wait 1-2 years for the rescued hot pocket corals to grow large enough to generate fragments.
3. Duplicate fragments of each coral might be collected at the same time, with the intention of creating multiple recipient genebank nurseries at multiple sites for greater security into the future.
4. A systematic approach to collections on the various hot pocket reefs should be made, to avoid re-collecting the same genotypes, if the work continues into a second year.
5. Collecting the few unbleached corals at the tail end of a mass bleaching event as the waters begin to cool can be done, which will ensure that the corals are truly bleaching resistant. However, if this is done, whole colonies do better than fragments, which bleach in the high UV, unless the fragments are planted under shade.
6. When transporting corals, care must be taken to avoid oxidative stress, which can result in non-aerated containers, or when fragments bunch up together in a container. In Fiji we get 100% survival from transporting coral colonies for hours on deck out of water, as long as the corals are shaded and constantly sprayed.

Establishing Cooler Water Gene Bank Nursery Sites

1. Follow the principle that outer reefs are generally cooler than inner reefs.
2. Smaller reefs with less shallow water area will be cooler than larger reefs with extensive shallow areas.
3. Even short distance translocation a few hundred meters, if taken from <1M deep and moved to >2m deep, can make a huge difference in reducing temperatures, as it moves corals from the upper hot thermal layer into the cooler water layer below.
4. Gene bank nurseries should be located behind a narrow reef flat, which breaks the waves and protects the nursery.
5. As winds and wave directions can be expected to change during storms, the nursery should be located where reefs protect it on all sides, not just the prevailing wave direction.
6. Nurseries situated in in less deep waters (2-3 meters deep), to optimize growth and to allow for more community involvement, should be situated at least 1-2 meters deeper than the reef flat and situated 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.
7. 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. Tree nurseries are not recommended due to the high cost of hand cleaning, as well as vulnerability during cyclones.
8. MARRS reef stars can be used as easily deployed gene bank nurseries in shallow water sites, with either one genotype per star, if the coral is a fast-growing species, or up to six genotypes of a single species per star, if coral growth is slower, such as with tight branched digitate or corymbose coral species.

9. If while coral colonies are intended to be taken for use in selective breeding work, a table nursery will serve best, with each colony cemented onto a cement “cookie” disc so that it can be removed from and then returned to the nursery (Figures 1 and 2).
10. If the primary goal is to produce fragments for out-planting, rope nurseries can be established on 3m x 3m iron frame tables linked together over sand or rubble substrates, with each rope representing a single genotype of a particular coral species (Figure 3). The corals are trimmed annually, or one colony is fragmented to replant a replacement rope, and the rest is used for out-planting purposes.
11. Out-planting for restoration is best focused on cooler water reef areas, and done as mixed genetic patches, to restore reproductive potential to declining species. If reef stars or A-frames (Figure 4) are used, 2-3 distinct genotypes should be planted to each star, with each genotype planted to a specific section, to encourage fusion of branches, resulting in merging into adult colonies over a shorter time frame.

Figure1. Table nursery with corals attached to large cement disc “cookies”. Holes in the disc 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 help keep the corals healthy and clean.

Figure 2. Corals cemented to "cookies" and grown on table nurseries allows for easy removal and replacement for coral breeding.

Figure 3. Rope nursery over sand. Each rope represents a singe genotype of a species. A narrow table nursery with coral colonies helps provide fish habitat, as fish clean the ropes.

Figure 4. A-frame nurseries on sand, made of heavy welded floor mesh coated with epoxy. Best for fast-growing staghorn *Acropora* corals. Reef Stars can be used in this manner as well.

Desktop Scoping for Hot Pocket Coral Populations and Genebank Nursery Sites

The below figures show potential hot water collection and cooler water nursery sites, as part of the scoping process required before any plan of action to rescue heat adapted corals can be carried out. The specific cooler water sites for translocation must also be selected in advance. If shallow water temperature data exists, that would also be useful. These recommendations of course require on the ground verification.

Ideally gene bank nurseries would be created for every extensive hot pocket coral population, located nearby in cooler water. However, as the warming advances, the most promising offshore reef sites might incorporate corals from multiple satellite nurseries and might be located every hundred kilometres or so along the entire length of the GBR. Duplication of heat adapted corals between local rescue nurseries and sectoral genebank nurseries would provide some duplication to help ensure against loss from cyclones. Local scale rescue nurseries would most likely be in moderately heat stressed reef areas, which might help ensure that resilience does not fade over time. These detailed strategies can be developed and adjusted over time, but for now the situation requires urgent action, as the winter of 2024 could potentially be our last chance to access populations of corals that will not likely survive a NOAA condition 4 or 5 bleaching event, which is more likely with each passing year.

Due to logistics and cost, plus the need to move as many corals as possible as quickly as possible from the hot pocket areas, local-scale movement of corals just a few hundred meters away, to reefs nearby on the same reef may prove to be the most efficient way to save the most corals if a severe heat emergency develops for 2025. This strategy (Figure 6) would allow more heat adapted corals to be rescued with the resources at hand, before the arrival of the summer. Close-ups of the hot pockets are given in Figures 7 and 8. And a promising prospect for creating a long-term gene bank nursery is shown in Figure 9.

Heat Adapted Coral Rescue in the Townsville Sector of the GBR

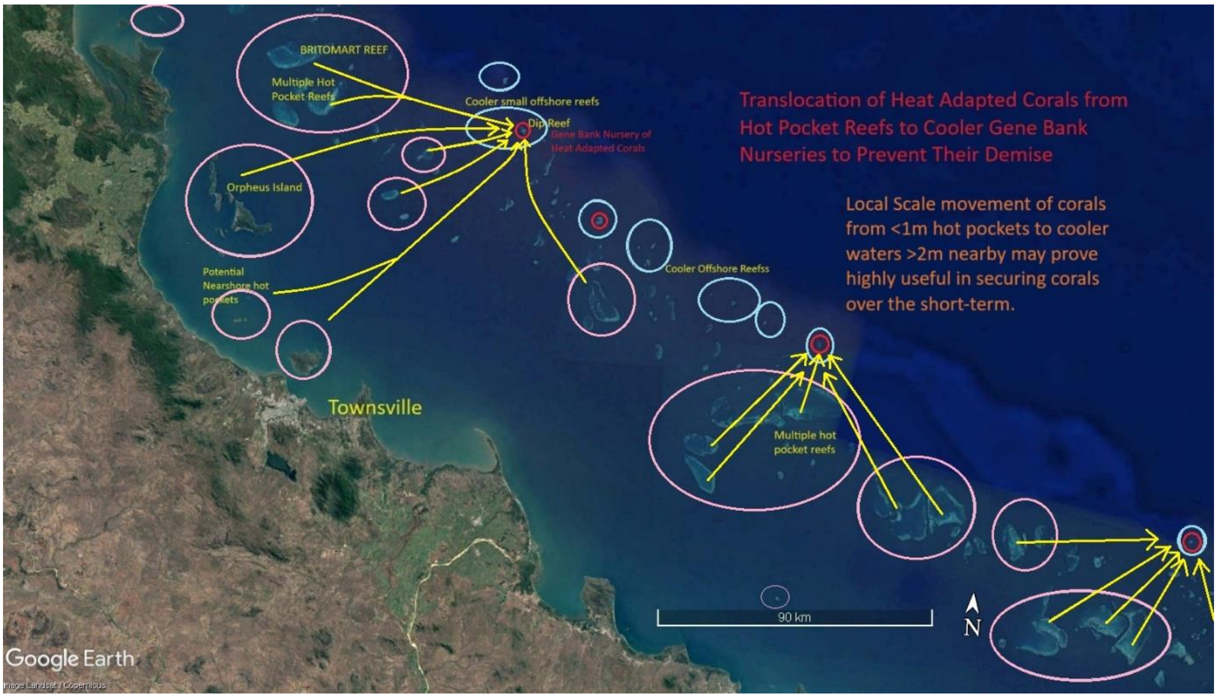

Figure 5: Townsville sector of the GBR, with multiple reefs having extensive shallow waters. Potential hot-pocket coral populations are circled in pink as potential collecting sites. Presumably cooler-water reefs, where heat adapted corals might escape lethal levels of heat stress in the coming decades are circled in blue. Proposed gene bank nurseries are presented with red circles, ideally located every 100km or so down the entire GBR system.

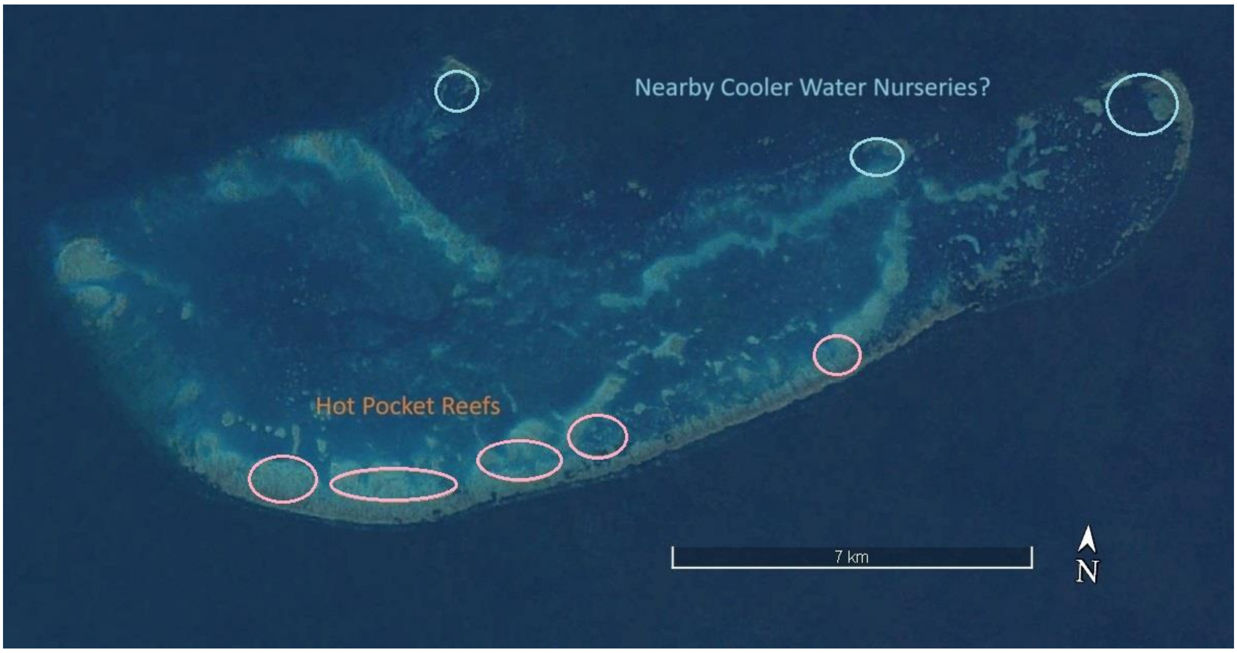

Figure 6. Britomart Reef, located directly north of Townsville, is one of many examples of a shallow reef system with extensive hot pocket areas of restricted water flow in the Townsville area. Cooler water and sheltered areas with potential to serve as ideal nursery sites are located within the same reef system.

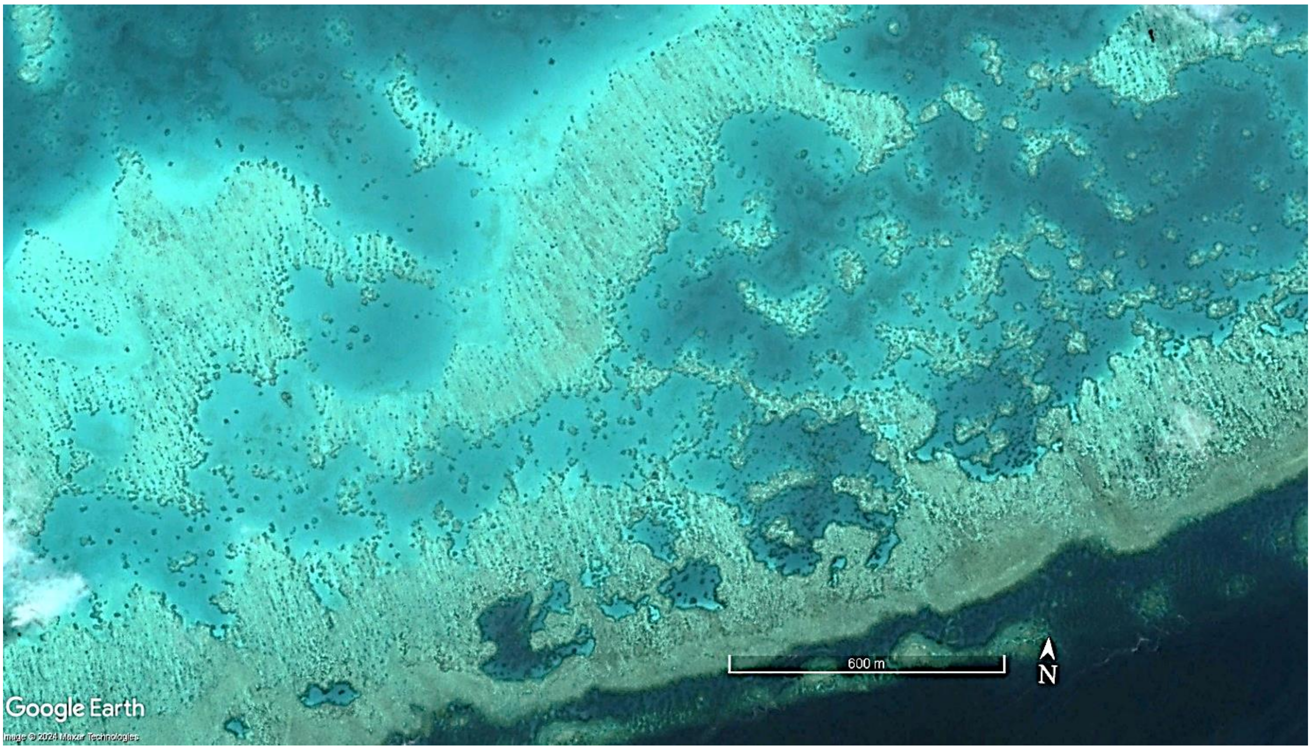

Figure 7. Overview of a small section of the promising Britomart Reef hot pocket coral population.

Figure 8. Close-up of Britomart Reef a representative hot pocket coral population.

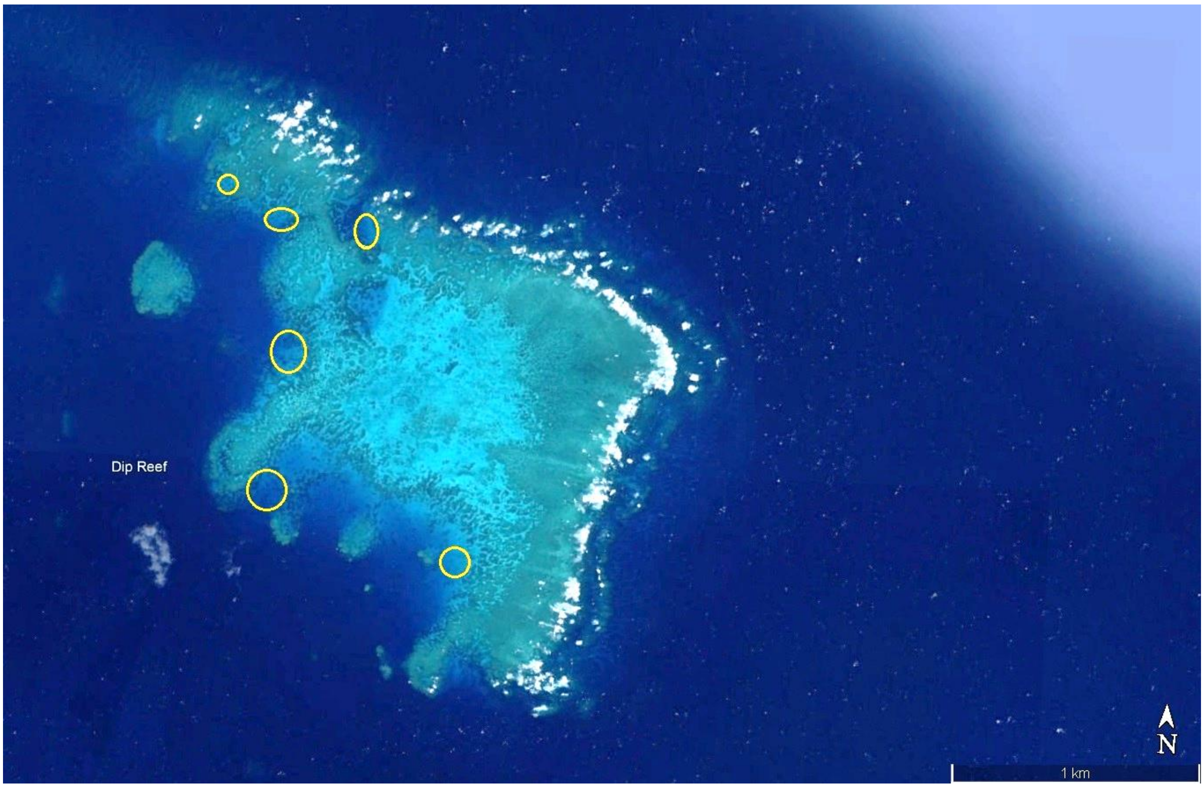

Figure 9. An ideal gene banking site for the Townsville area would be Dip Reef. The reef is surrounded by cooler oceanic waters and thus offers excellent potential for locating longer-term gene bank nurseries intended to remain in place for many decades to come. This could be done the second or third year as a series of MARRS stars, planted with second generation branches trimmed from initial on-site nurseries located closer to the hot pocket reefs. Some prospective nursery sites are circled.

Coral Rescue of the Cairns Sector of the Great Barrier Reef

A similar strategy was developed for the Cairns sector (Figure 10). The larger shallow reefs, such as Arlington and Sudbury reefs (Figure 11), may prove excellent as coral collecting sites, and cooler areas of these same reefs might also be found in which to establish coral gene banks relatively nearby.

For the Cairns sector of the GBR, the presence of large floating pontoons as major tourism industry investments, as well as existing partnerships with ongoing restoration efforts, gives an added potential for moving quickly to address the need to secure heat adapted corals to cooler waters. This could potential help ensure the survival and genetic diversity of many coral species, as well as the survival of the tourism industry itself, in an era of rapid ocean warming. Moore Reef, a focal point of pontoon development, has excellent potential to serve as an easily accessible centralized genebank nursery site, as part of the ongoing multi-stakeholder partnership which is established there (Figures 12 and 13).

The involvement of indigenous youth as tourism staff in the Moore Reef site gives added value as a training venue for potential expansion of these interventionist translocation strategies into areas with less tourism involvement.

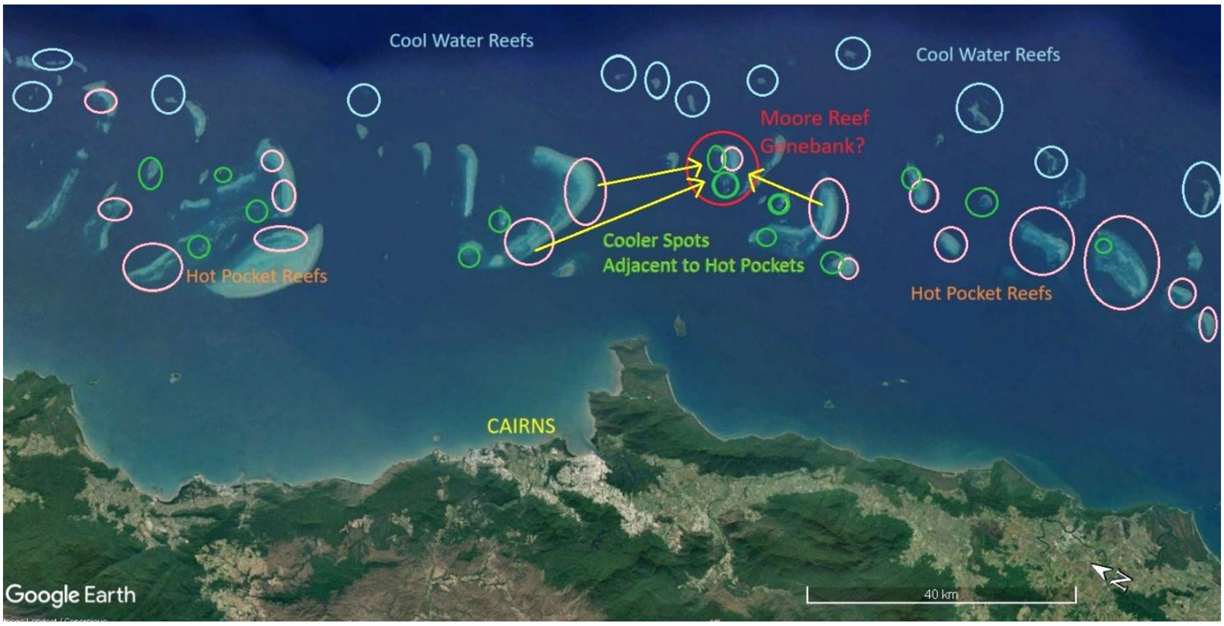

Figure 10. Cairns Sector showing potential hot water and cool water reef areas.

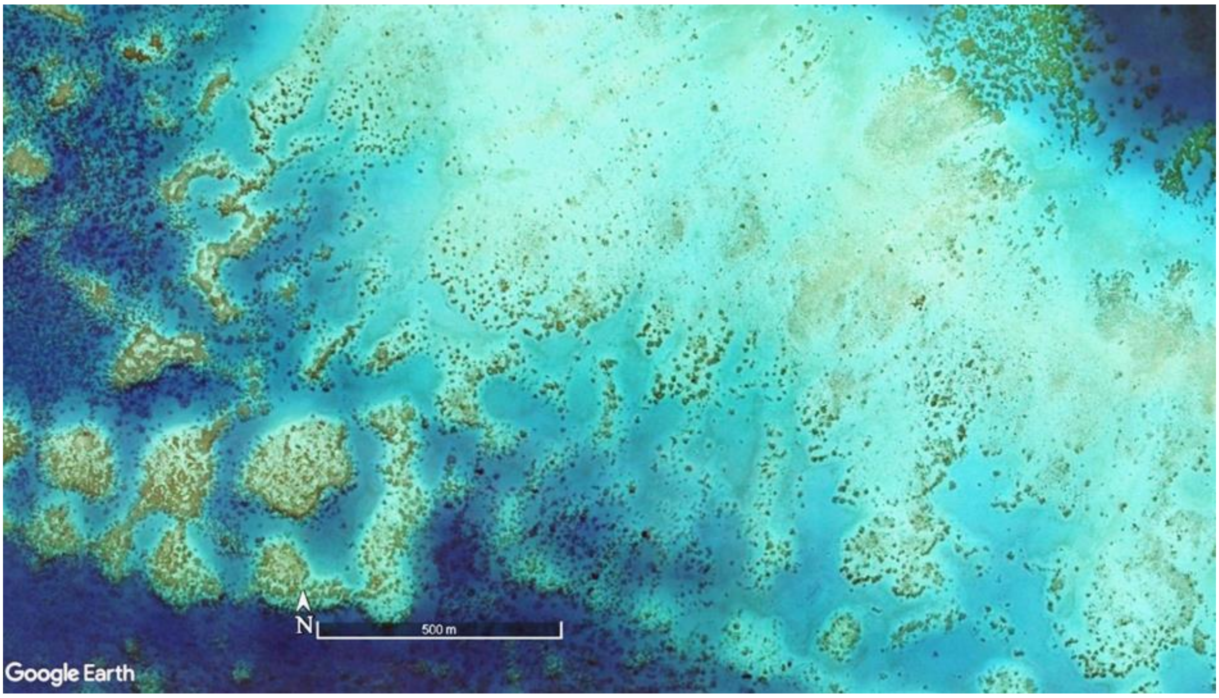

Figure 11. Extensive hot pocket areas exist at Arlington Reef.

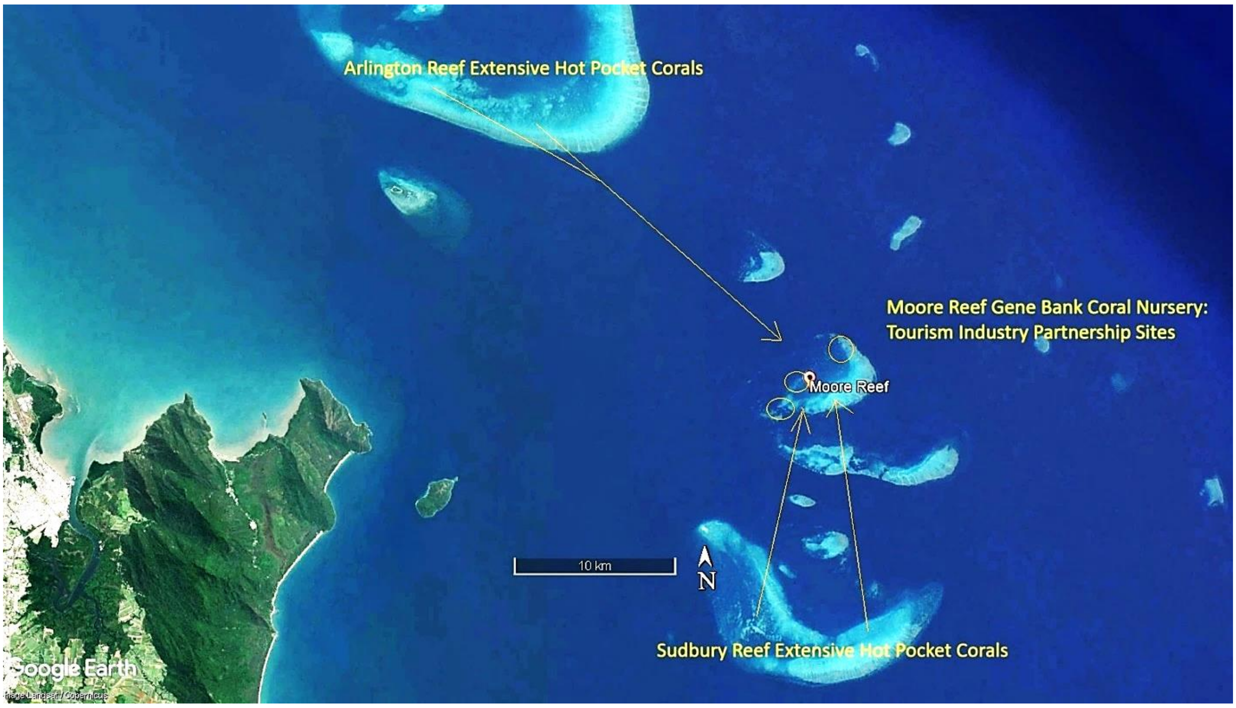

Figure 12. Plan for a centralized heat adapted coral gene bank station at Moore Reef.

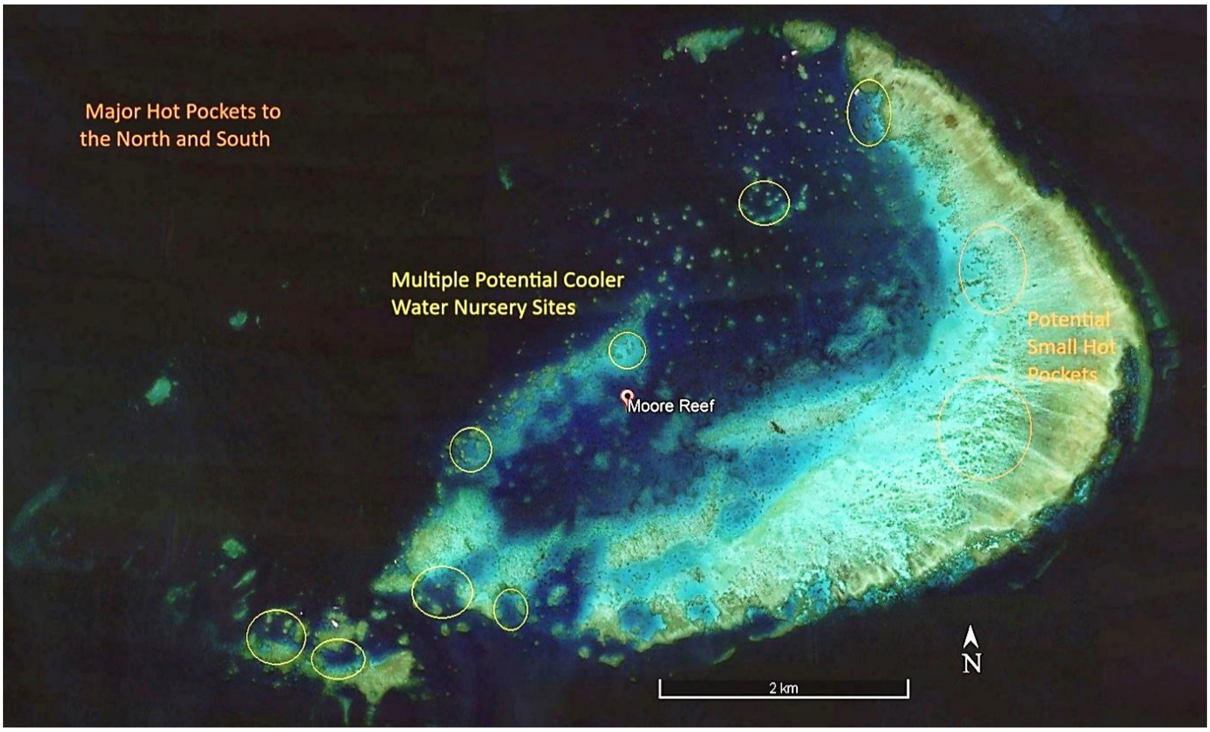

Figure 13. Moore Reef has some hot pocket potential, but it has excellent potential as a cooler water nursery site due to its accessibility and regular transport to the tourism pontoons.

NOAA reports that we are presently in the fourth global bleaching event, which has the potential to become the worst in history. 2025 may be worse for the GBR than 2024, because the ocean thermal anomaly has become fixed at a high level (Figure 14). There is a distinct possibility that this winter could be our last chance to act before a mass die-off of corals on much of the GBR. While such a mass die-off might have a low probability <10%, we insure our homes and businesses for much less risk. The time has come for insurance against the potential die-off of heat adapted coral parent stock that we must rely upon for the adaptation work. The probability of an extinction level event will only increase with each passing year.

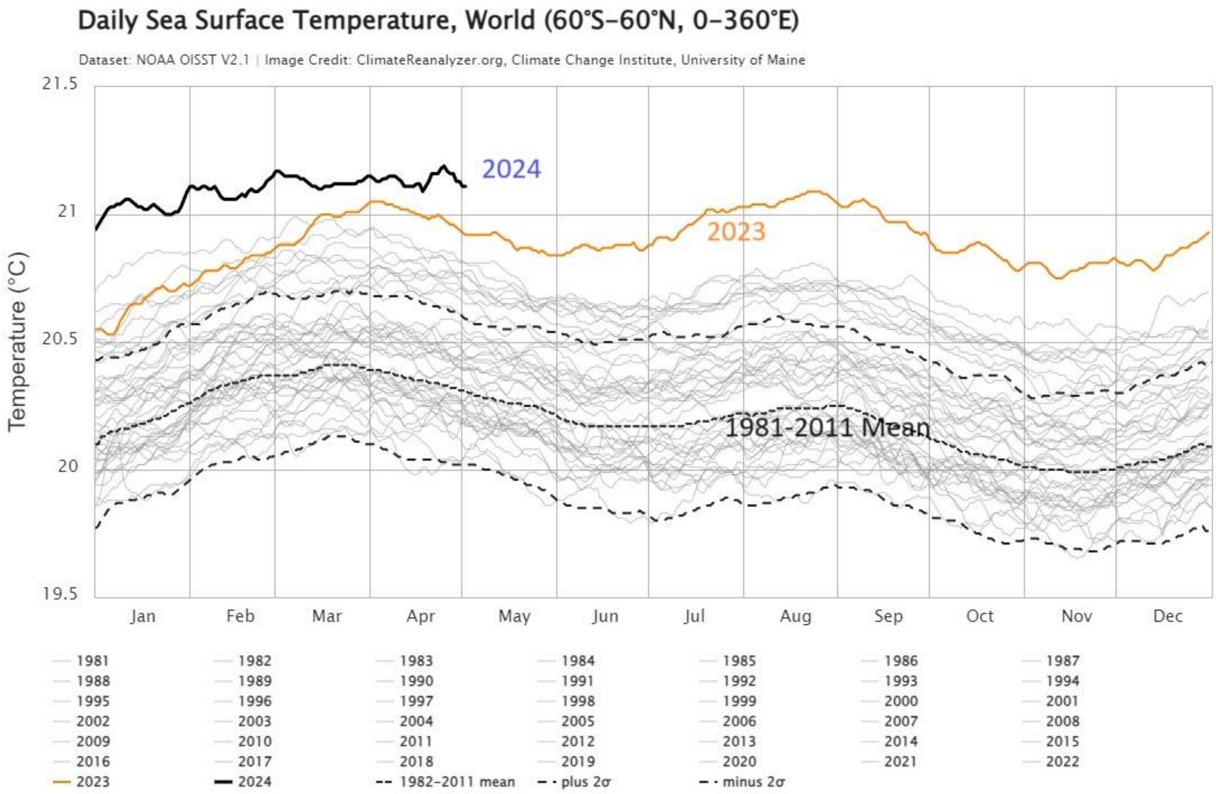

Figure 14. An unexplained and sudden rise in mean sea temperature has created a situation whereby annual summer bleaching temperatures may now become the norm, and where extinction-level bleaching events will become commonplace. Time is quickly running out.

The extensive coral breeding and out-planting programs at AIMS would face a crisis if a major die-off of corals were to occur in the Townsville sector of the GBR. This coral breeding and larval out-planting program would be severely impacted and in danger of failing, with huge implications for both the corals and the University. The present AIMS strategy, which returns resistant parent stock to the same warm-water reef areas where they were originally found, leaves the corals vulnerable. If these parent corals were returned to a gene bank nursery, strategically located in cooler waters sheltered from cyclones, the program would be made considerably more secure. Gene banking of heat adapted coral colonies is urgently needed as insurance against potential mass die-off of coral broodstock.

Permitting for Emergency Actions to Rescue Corals

The Great Barrier Reef Authority has recently changed a long-standing hands-off policy, by encouraging those with standing permits for coral restoration work to intervene with emergency measures to rescue and stabilize corals dislodged from the recent cyclones. The Authority, based on the NOAA warnings as to what is potentially coming, might now allow for permit holders to intervene to rescue corals threatened with extreme heat stress and in danger of dying based on their location in the reef system, encouraging those with standing permits to intervene to collect colonies of heat adapted corals from hot pocket reefs and move them to safety in cooler waters. This permission would include corals exposed at low tide, as they are clearly jeopardized and have zero chance of surviving more than a few years. The most heat adapted of all corals are exposed to the top layer of extremely hot water when low tide occurs from around midday to the afternoon during low wind days. This "hot tub layer" reaches 34-36C and above. These corals and symbionts are at the upper limit of possible coral survival, and so they are no more secure than the heat sensitive corals due to their location and the increased heat stress.

If restoration practitioners with permits could urgently begin to rescue a diversity of genotypes of each coral species from the hot pocket reef areas and move them to approved and pre-selected sites, they could become part of a series of gene banks along the entire length of the GBR. These heat-adapted "super corals" could then become the mother stock for future coral breeding and restoration work.

Additional Background Information:

During discussions at the Reef Resilience Symposium, 14-19th April 2024 in Cairns, it became clear that no emergency plans are in place to save coral species from local extinction should a severe, NOAA condition 4 or 5, extinction-level bleaching event threaten the Great Barrier Reef.

Each of the three scientists present at the symposium who work in the Caribbean, which in 2023 experienced a severe extinction-level coral bleaching event, repeated the message that the time to prepare for an extreme (>20 Degree Heating Week) bleaching event on the Great Barrier Reef has arrived. In the Pacific, Kiribati experienced such a mass die-off event in 2014-15, and the GBR is increasingly in danger. Severe bleaching may come sooner than expected.

The present focus on the GBR is on resiliency, which is good, however measures to promote resiliency have proven inadequate during extreme heat stress events when they occur. The time has come to learn from other areas of the planet and to dispel the misconception that there is nothing more that can be done.

Operational Assumptions: Ensuring that we are all on the same page.

1. Climate change has accelerated, with mean ocean temperatures suddenly off-scale, time appears to have run out for many coral reefs. The question remains: have we now entered the endgame for coral reefs, where bleaching temperatures will become an annual summer event?
2. Even in the worse case scenario, open ocean waters will remain under 33-34°C. Even if shallow nearshore waters experience >38C°.
3. Some outer coral reef areas will continue to remain under 34-35°C into the future during marine heat waves.
4. Some heat-adapted corals can withstand multiple days of 34-36°C unbleached.
5. Logic indicates that heat adapted corals, if translocated from the hottest reefs into cooler waters of the outer reefs, will have a high probability of surviving warming seas.
6. Hot pocket reefs, most often located on wide shallow reef flats and closed shallow lagoons, are ideal places for heat adaptation and bleaching resistance to evolve, and in many cases where heat adapted corals still survive.
7. If heat adapted corals are left within hot pocket reefs, these areas will increasingly be in danger of exceeding lethal temperatures of 37-38°C. Time is quickly running out.
8. Thermal resilience is complex, involving host, symbiotic algae, and probiotic bacteria. A good place to secure these multiple factors is in jeopardized hot pocket coral

populations. And adapted corals found in cooler waters may not have all elements of the resistant holobiont.

9. Coral breeding programs urgently need to secure the most resilient broodstock by moving resilient corals into genebank nurseries located in cooler waters.
10. We must learn as we go, as we can not afford to wait until more factual and detailed information is in and published, or we risk losing most of the genetic diversity what we presently still have, as is already the case for Kiribati since 2015, and the Caribbean since 2023.
11. It is better to over-prepare than to under-prepare, as too much is at stake. If 2025 is not the mass die-off year that it might become, then we have yet another year to prepare.

Summary of UNESCO Reefs of Hope Decade Action Strategies

Reefs of Hope Ocean Decade: https://oceandecade.org/actions/reefs-of-hope/

1. First secure heat-adapted corals by moving whole colonies from heat stressed waters into cooler water gene bank nurseries.
2. Duplicate the nurseries of heat adapted corals as soon as practical using fragments, planted to either rope nurseries or to reef stars.
3. Rope nurseries should contain 8-10 colonies per coral genotype, with the intention of producing fragments for out planting. Welded bar “reef star” nurseries should be planted with one coral genotype per star, with the reef stars of a single species deployed as clusters to encourage fertilization during spawning in the nursery.
4. Out-planted coral patches should contain multiple genotypes of a single species in a cluster or on a single frame or star, to restore sexual reproduction and reboot production of coral larvae via effective spawning as the corals mature.
5. An ideal deployment of A-frames or reef stars as an out-planting method might have seven reef stars planted with a single species tied together in a cluster (six stars surrounding a central star), each of the seven stars planted with a unique genotype of the same coral species. Each coral species would receive its own cluster of reef stars. A hundred clusters of reef stars would secure and restore reproduction to a hundred coral species.
6. When biomass is sufficient, and when the waters are cool and UV levels low, second-generation fragments are trimmed from gene bank nurseries and used to create dense “nucleation patches” within damaged reef systems, targeting the cooler degraded reefs in favour over the warmer degraded reefs.
7. Nucleation patches are designed to serve as fish habitat and so larger coral colonies are used. If fragments are used, they are planted densely and elevated above the substrate on reef stars or A-frames for maximum impact. These coral patches are designed to reboot natural recovery processes through attraction of coral and fish larvae via smell, sight, and sound. The second objective of the nucleation patches is to reboot sexual reproduction to declining coral species. The dense coral patches, if composed of heat adapted corals, also potentially facilitate adaptation of coral reefs to warming seas by sharing heat resistant symbionts with incoming coral recruits.