Guam Coral Reef Restoration Action Plan

for Restoration Goal #1

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Reef restoration planning team:

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Project Description

Development of Guam's draft action plan for coral reef restoration was led by a core local team of six individuals representing a variety of relevant government entities and the University of Guam. Additional stakeholders were consulted and engaged throughout the process to incorporate additional areas of expertise. The restoration action plan will be a living document that is frequently updated to ensure effectiveness of ongoing restoration efforts and responsiveness to changes in ecological and management conditions. This plan complements the Guam Reef Resilience Strategy (2019), a document intended to guide coral reef management and conservation efforts on Guam from 2019-2025. Increased reef response and restoration is one of five target outcomes for coral reef management outlined in the Guam Reef Resilience Strategy.

Before developing this action plan, the local planning team - with input from other relevant experts and decision makers - established three priority goals for reef restoration on Guam:

Goal 1: The structure and function of coral reef communities are restored to enhance reef resilience to thermal stress. This goal addresses the need for coral reef restoration to address the structure and function of coral reef communities, including biodiversity (species richness and evenness, morphological diversity), structural complexity/rugosity, benthic composition, coral size structure, habitat provision, etc. Optimizing these traits of coral communities will enhance the resilience of coral

reef ecosystems to the impacts of thermal stress, i.e. coral bleaching and resulting mortality. Guam's reefs have been severely impacted by coral bleaching in recent years and annual severe bleaching events are predicted to occur by mid-century. In our restoration efforts, we will focus on thermally-tolerant coral taxa and resilient populations of species that have been impacted by past bleaching.

Goal 2: Reef fish habitat is restored to support sustainable subsistence and commercial fisheries. This goal addresses the needs of local stakeholders who harvest fish from Guam's reefs for food and livelihoods. Coral restoration will rehabilitate habitat for key fishery species, especially within marine preserves. By restoring habitat of key fishery species, we aim to support adequate populations that will allow for sustainable take of these species. When possible, we will focus on restoring habitat needed to support these species at all stages of their life histories.

Goal 3: Ecologically-important coral species that have experienced significant decline are recovered to sustain their specific functions. This goal aims to restore populations of species that are now uncommon due to perturbations such as coral bleaching, crown of thorns predation, low tide exposure, and disease. This goal focuses on species that provide specific functions within the environment, e.g. rugosity and symbioses. For many of these coral species, we do not fully understand the extent of their role in coral reef ecosystems, thus their extirpation could have unknown consequences. This goal is focused on maintaining biodiversity – a key aspect of reef resilience – and protecting coral taxa that may be endemic or contribute to the uniqueness of Guam's reefs.

Goal 1 was selected as the most important to target first, and is thus the focus of this action plan, given the severe impacts of coral bleaching on Guam in recent years and need to increase resilience to climate change, particularly thermal stress. The coral planning team has the most expertise to address this goal and begin the planning process before presenting the draft implementation plan to a wider stakeholder group after the workshop. Goal 1 supports the achievement of goals 2 and 3.

This draft action plan will be shared with all relevant stakeholders and decision makers during a community meeting in early 2021. The plan will be finalized following receipt of stakeholder input.

Priority Restoration Goal

Goal 1: The structure and function of coral reef communities are restored to enhance reef resilience to thermal stress.

The core planning team decided to focus this goal on reef flats due to budgetary and logistical considerations. All reef flats around the island have been severely impacted by coral bleaching and extreme low tides since 2013. Additionally, restoration efforts on reef flats are less likely to be negatively impacted by COTS predation. Most reef flats with high coral cover are on the west side of the island (leeward side). In the longer term, some work may focus on the reef front and on reef slopes to ~50'.

Sites Selected for Restoration

A total of 20 coral reef flat sites were considered by the restoration planning team and presented to stakeholders. Sites were evaluated in a semi-quantitative prioritization framework against 14 biological/ecological and socioeconomic indicators to determine their appropriateness for restoration interventions. Indicators were weighted according to their importance in influencing the success of

restoration efforts. Team members individually scored each site for all indicators and then the team discussed the values to reach consensus. Stakeholders were engaged through a workshop and given the opportunity to provide input on the indicators and sites. Based on feedback, indicators and sites were revised and additional technical experts were invited to score some indicators. The restoration team then selected a list of **six** sites that will be prioritized for restoration under Goal 1 (see Appendix 1).

Biological indicators and weights: Water quality (1.0), availability of suitable substrate (1.0), herbivore biomass (1.0), presence of nuisance species (1.0), prevalence of coral disease (0.75), coral cover (0.75), coral diversity (0.5)

Socioeconomic indicators and weights): Accessibility (1.0), potential for community support (1.0), cultural value (0.75), commercial value (0.75), level of management (0.75), data availability (0.75), already an existing or planned restoration site (0.5)

1. Tumon Bay Reef Flat (site coordinates: 13.511289, 144.797333)
Tumon Bay is the center of Guam's tourism industry, within a marine preserve, and an important site for traditional fishing and social activity among local residents. Compared to other sites, Tumon Bay has high herbivore biomass, coral cover, substrate availability, accessibility, cultural and commercial value, level of management, community support, and data availability. Within the site, specific areas for restoration will be carefully selected to avoid damage by the human users who frequent the bay. Coral cover is patchy and there are several areas with sufficient depth to allow for outplanting.

2. Tepungan East Reef Flat (site coordinates: 13.473749, 144.702697)
Tepungan is an important site for tourism activities, located within the Piti Bomb Holes Marine Preserve, and is an important site for traditional fishing and social activity among local residents. Compared to other sites, Tepungan East has high herbivore biomass, coral cover and diversity, substrate availability, cultural and commercial value, level of management, community support, and data availability. This site includes Guam's largest existing outplanting area, consisting of 464 transplanted colonies of staghorn Acropora covering ~1 hectare. This site is located near the Piti coral nursery, however, some parts of this site have accessibility challenges due to strong currents and wave action.

3. Tepungan West Reef Flat and Channel (site coordinates: 13.466326, 144.689211)
Tepungan is an important site for tourism activities, located within the Piti Bomb Holes Marine Preserve, and is an important site for traditional fishing and social activity among local residents. Tepungan West both scored high for herbivore biomass, accessibility, cultural value, and level of management. Tepungan West is located near the Piti coral nursery.

4. Babi Island Reef Flat (site coordinates: 13.243881, 144.680403)
This site is a combination of two sites, Cocos East Staghorn Patch (previously called Achang Reef Flat) and Babi Island Reef Flat. The Cocos East Staghorn Patch site was the fifth highest scoring site under both the original and revised frameworks and was categorized as medium-high priority under both frameworks. Cocos East scored high for coral cover and diversity, substrate availability, coral disease, and data availability. Cocos East received low scores for accessibility (only accessible by boat) and level of management. Babi Island Reef Flat was the ninth highest scoring site under the original framework (medium-high priority) and the eleventh highest site under the revised framework (low-medium priority). Babi Island scored high for substrate availability and coral disease, and received a low score for level of management. These two sites were combined because they were small compared to other sites being considered and adjacent to each other. Malesso East is close to the Malesso coral nursery. The team is also prioritizing this site due to the community support that has grown over the

past five years in Malesso, and the need to continue fostering relationships with residents. Water quality issues will be carefully considered in restoration planning at this site.

5. Litekyan Reef Flat (site coordinates: 13.651492, 144.854247)
This site is located within the Guam National Wildlife Refuge and the USFWS is expected to be a valuable partner for restoration efforts here. Compared to other sites, Litekyan scored high for water quality, coral diversity, coral disease, commercial value, and community support. This site scored low for accessibility and data availability. Litekyan was prioritized over the Ritidian Closed Reef Flat site as that side of the refuge is closed to the public; future military development may also hinder access. Although this site is not ideal for restoration with staghorns, it may be a good recipient for corymbose and cespitose Acroporids and Isopora, which is not found elsewhere on Guam.

6. Malesso Pier Reef Flat and Rim (site coordinates: 13.265498, 144.662213)
Malesso Pier is close to the Malesso coral nursery. The team also prioritized this site due to the community support that has grown over the past five years, and the need to continue fostering relationships with residents. Compared to other sites, Malesso Pier received high scores for accessibility, cultural value, and community support. This site scored low for water quality, coral diversity, and level of management. Water quality issues will be carefully considered in restoration planning at this site and alternate interventions (e.g., algae removal) will be investigated.

Rationale for Site Selection

The local planning team met in March 2020 to identify candidate sites for restoration under **Goal 1: The structure and function of coral reef communities are restored to enhance reef resilience to thermal stress.** The objectives of this meeting were to 1) brainstorm all potential sites for restoration and 2) identify any important factors for decision making that were not highlighted in the step 2 guide. In addition to making progress on step 2A, the team finalized revisions to goals and geographic focus areas under step 1 based on feedback from RRN staff and considered input from DOAG (Director Muna-Brecht) and NOAA (Gerry Davis). For goal 1, reef flats around the island were divided into four geographic focus areas delineated based on human use intensity, extent of LBSP impacts, coral cover, and accessibility (see map submitted with step 1 workbook).

After discussing the objectives, outputs, and timeline of step 2A and overviewing the tasks to be completed for steps 2B and 2C, the team reviewed the site identification parameters provided in the restoration guide (e.g., management in effect, reef value, data availability). The team then reviewed a list of potential sites provided by D. Burdick, who coordinates Guam's Long-term Coral Reef Monitoring Program, and worked on a spreadsheet with all sites listed. In addition to the site parameters described in the guide, the team discussed other potential factors for site selection: site accessibility; presence of rare and/or ecologically important coral taxa; relevance to multiple goals; potential site users and threats; and potential for partnerships. The team built a list of 38 potential sites for restoration under all goals, which included 20 reef sites that are applicable under goal 1.

We decided to complete a semi-quantitative framework for assessment of potential restoration sites. This allowed us to consider sites and indicators for which we did not have full quantitative data available. Although this method is potentially less rigorous, it provided us with a wider range of options.

High priority sites (4):
- Tumon Bay reef flat (mean score = 2.09)
- Asan Piti reef flat (2.08)

- Piti Bomb Holes west reef flat (2.01)
- Tepungan Channel (1.91)

Medium-high priority sites (5):

- Cocos East staghorn patch (1.87)
- Ritidian closed reef flat (1.78)
- Malesso Pier reef flat/rim (1.68)
- Ritidian open reef flat (1.68)
- Babi Island reef flat (1.64)

Medium-low priority sites (8):

- Family Beach reef flat (1.60)
- Tanguisson reef flat (1.54)
- Urunao reef flat (1.51)
- West Hagatna reef flat (1.49)
- Agat Cemetery reef flat (1.46)
- Luminao reef flat (1.44)
- Ipan reef flat (1.41)
- Sharks Hole reef flat (1.39)

Low priority sites (3):

- Sasa Bay reef flat (1.28)
- Alutom south reef flat (1.26)
- Dadi Beach reef flat (1.22)

The restoration planning team (W. Hoot, J. Cruz, M. Auyong, F. Roberto, D. Burdick, and L. Raymundo) hosted a stakeholder webinar via Zoom on May 21, 2020. The webinar, which was attended by 29 participants in addition to the six team members, consisted of a 30 minute presentation followed by approximately one hour of discussion.

The webinar was attended by the following entities and individuals:
Guam Department of Agriculture (Chelsa Muna-Brecht, Brent Tibbatts, Jay Gutierrez, Cara Lin)
Guam Environmental Protection Agency (Walter Leon Guerrero, Margaret Aguilar, Taryn Mesa)
Guam Bureau of Statistics and Plans (Mallory Morgan)
Guam Coastal Management Program (Audrey Meno)
Guam Visitors Bureau (Taylor Pangelinan, Lyann Dydasco)
University of Guam Marine Lab (Tom Schils, Colin Lock)
University of Guam Sea Grant (Fran Castro)
Guam Community College (Joni Kerr)
The Nature Conservancy (Farron Taijeron)
Guam Preservation Trust (Joe Quinata)
Micronesia Conservation Coalition (Julie Hartup)
Micronesia Challenge (Vangie Lujan)
National Park Service (Ashton Williams)
US Fish and Wildlife Service (Tammy Summers, Marybelle Quinata)
Department of Defense (Adrienne Loerzel)
Western Pacific Fisheries Management Council (Felix Reyes)
Underwater World (Rafael Calderon)
Fish Eye Guam (Tani Akihiro)
Micronesian Divers Association (Lee Webber)
Other (Mike Gawel, retired from National Park Service; Kitty Courtney, Tetra Tech)

The following entities were also invited to attend but did not send representatives to the meeting:
Guam Port Authority, Guam Department of Parks and Recreation, Guam Hotel and Restaurant

Association, UOG Center for Island Sustainability, UOG Pacific Islands Climate Science Center, Naval Facilities Engineering Command, Mayors Council of Guam, Ayuda Foundation, Axe Murderer Tours Guam, Urunao landowners

During the facilitated discussion session, participants provided input on indicators and sites. Participants were asked to respond to the following questions:

- Are any additional indicators needed to better address Goal 1?
- Should any indicator weights be adjusted to better address Goal 1?
- Should any additional reef flat sites, beyond the 20 evaluated in the framework, be considered?
- Of the nine high and medium-high priority sites, are any especially important?
- Of the nine high and medium-high priority sites, are any non-viable?
- Which 3-6 sites are the greatest priority now to achieve Goal 1?
- Was this a fair, transparent process? Was this an effective way to get stakeholder input? In what ways would you change it?

Following the webinar, stakeholders were able to submit additional comments via email before final site selection decisions were made. Stakeholders also had the opportunity to review and revise the meeting notes.

Based on stakeholder input and additional discussions among team members, the following changes were made:

- The reef value indicator was separated into two separate socioeconomic indicators (cultural value and commercial value).
- The proximity to nursery indicator was removed and proximity to nursery was incorporated as a factor in the accessibility indicator.
- A total of 11 additional experts were engaged to score the herbivore biomass (one additional score) and cultural value indicators (nine additional scores, including one joint score).
- The potential for partnerships indicator was changed to potential for community support (the indicator description/definition was not altered).
- All team members reviewed and revised weights for all 14 indicators (see below).

Changes to indicator weights after stakeholder input and re-weighting by restoration planning team:

- Weight for potential for community support indicator (formerly called "potential for partnerships") increased from 0.75 to 1.0
- Weight for level of management indicator decreased from 1.0 to 0.75
- Both cultural value and commercial value indicators (formerly grouped as reef value) were given a weight of 0.75

The team re-ran the prioritization framework with the updated site scores and revised indicator weights. Given the large number of stakeholders who provided input on the cultural value indicator, the team did not revise the raw means for this indicator. For all other indicators that were revised, the team repeated the process described in step 2B and reviewed and adjusted scores with range >1. The updated framework resulted in the following site rankings:

High priority sites (3):

- Tumon Bay reef flat (mean score = 2.16)
- Asan Piti reef flat (2.03)
- Piti Bomb Holes west reef flat (1.99)

Medium-high priority sites (6):

- Tepungan Channel (1.86)
- Cocos East staghorn patch (formerly described as Achang Reef Flat) (1.85)
- Ritidian open reef flat (1.77)
- Ritidian closed reef flat (1.74)
- Malesso Pier reef flat/rim (1.69)
- Family Beach reef flat (1.63)

Medium-low priority sites (8):

- Urunao reef flat (1.60)
- Babi Island reef flat (1.59)
- Tanguisson reef flat (1.58)
- Luminao reef flat (1.52)
- West Hagatna reef flat (1.50)
- Agat Cemetery reef flat (1.47)
- Ipan reef flat (1.45)
- Sharks Hole reef flat (1.41)

Low priority sites (3):

- Alutom south reef flat (1.32)
- Sasa Bay reef flat (1.26)
- Dadi Beach reef flat (1.24)

Team members then discussed the revised rankings and selected the six highest priority sites for restoration under goal 1. Some sites were combined and/or renamed based on input from team members and outside stakeholders.

Ongoing Management

Tumon Bay Reef Flat:

- Within the Tumon Bay Marine Preserve
- Scuba-based spear fishing is banned

Tepungan East Reef Flat:

- Within the Piti Bomb Holes Marine Preserve
- Piti-Asan Watershed Management Plan
- Scuba-based spear fishing is banned

Tepungan West Reef Flat and Channel:

- Within the Piti Bomb Holes Marine Preserve
- Piti-Asan Watershed Management Plan
- Scuba-based spear fishing is banned

Babi Island Reef Flat:

- Part of the NOAA Manell-Geus Habitat Blueprint Focus Area
- Manell-Geus Conservation Action Plan
- Scuba-based spear fishing is banned

Litekyan Reef Flat:

- Within the Guam National Wildlife Refuge
- Scuba-based spear fishing is banned

Malesso Pier Reef Flat and Rim:

- Part of the NOAA Manell-Geus Habitat Blueprint Focus Area
- Manell-Geus Conservation Action Plan
- Scuba-based spear fishing is banned

Restoration Interventions

The team categorized all interventions as PRIMARY (four interventions) and SUPPLEMENTAL (six interventions). *Primary intervention options* are stand-alone interventions that directly contribute to the restoration goal. *Supplemental intervention options* are conducted in conjunction with one or more primary interventions to further the restoration goal and/or facilitate the primary intervention. Supplemental interventions may also be conducted independently of primary interventions at sites where the primary interventions are either not necessary or not feasible.

Primary intervention options:

- Option 1: Direct transplantation without nursery phase
    - SITES: (6) Malesso Pier Reef Flat and Rim
- Option 2: Asexual propagation with nursery phase
    - SITES: (1) Tumon Bay Reef Flat, (2) Tepungan East Reef Flat, (3) Tepungan West Reef Flat and Channel, (4) Babi Island Reef Flat, (5) Litekyan Reef Flat, (6) Malesso Pier Reef Flat and Rim
- Option 3: Sexual propagation
    - SITES: (1) Tumon Bay Reef Flat, (2) Tepungan East Reef Flat, (3) Tepungan West Reef Flat and Channel, (4) Babi Island Reef Flat, (5) Litekyan Reef Flat, (6) Malesso Pier Reef Flat and Rim
- Option 4: Restabilization/repair after physical damage
    - SITES: (2) Tepungan East Reef Flat, (3) Tepungan West Reef Flat and Channel, (6) Malesso Pier Reef Flat and Rim

Supplemental intervention options:

- Option 5: Coral predator management
    - SITES: (1) Tumon Bay Reef Flat, (2) Tepungan East Reef Flat, (3) Tepungan West Reef Flat and Channel, (4) Babi Island Reef Flat, (5) Litekyan Reef Flat, (6) Malesso Pier Reef Flat and Rim
- Option 6: Macroalgae and cyanobacteria removal/management
    - SITES: (1) Tumon Bay Reef Flat, (3) Tepungan West Reef Flat and Channel, (4) Babi Island Reef Flat, (6) Malesso Pier Reef Flat and Rim
- Option 7: Disease management
    - SITES: (1) Tumon Bay Reef Flat, (2) Tepungan East Reef Flat, (3) Tepungan West Reef Flat and Channel, (4) Babi Island Reef Flat, (5) Litekyan Reef Flat, (6) Malesso Pier Reef Flat and Rim
- Option 8: Substrate augmentation to enhance coral growth and outplant establishment
    - SITES: (2) Tepungan East Reef Flat, (3) Tepungan West Reef Flat and Channel, (4) Babi Island Reef Flat
- Option 9: Seagrass restoration
    - SITES: (2) Tepungan East Reef Flat, (3) Tepungan West Reef Flat and Channel, (4) Babi Island Reef Flat
- Option 10: Mangrove restoration
    - SITES: (4) Babi Island Reef Flat

OPTION 1: Direct transplantation of corals without a nursery phase (6)
This PRIMARY intervention was selected specifically for site 6 (Malesso Pier Reef Flat and Rim), where we previously removed corals that had grown on the village boat ramp and relocated them to an adjacent suitable reef site following a request from the local community. Re-growth of these coral colonies, which are primarily *Porites* massive spp., on the ramp may necessitate another transplanting effort. These taxa are generally resistant to thermal stress compared to faster growing species. Large colonies will be removed, fragmented, and outplanted using cement or epoxy. This intervention may also be applied for compensatory mitigation projects or after physical damage from storms or vessel groundings. Outplanting methods will be designed to withstand wave action and storm impacts.

OPTION 2: Coral gardening/asexual propagation with corals reared in an in situ nursery (1-6)
This PRIMARY intervention has been selected for all six priority sites. Guam's two coral nurseries currently hold six species of staghorn *Acropora*, with plans to incorporate additional taxa, including *Heliopora coerulea*, Pocilloporids, and other Acroporids. Furthermore, we have noticed significant, rapid plasticity of coral morphology after outplanting; they seem to adapt well to shallow high wave energy sites even after being cultured in a deeper, more sheltered nursery. Our nursery-reared corals, which have been cultured through fragmentation (asexual propagation), were collected from donor colonies that are presumed to have some thermal tolerance, as they survived past bleaching events. Outplanting methods will depend on taxa and substrate type and will include cement/epoxy and nails and zip ties; methods will be designed to withstand wave action and be suitable for both colony morphology and substrate characteristics. Colonies will be outplanted to deeper areas of reef flat habitats to decrease the risk of mortality from ENSO-driven extreme low tides. Restored corals that die due to bleaching, disease, storm damage, etc. will be replaced whenever possible. Before outplanting, we will prepare the substrate by removing algae and sediment with scrub brushes. Regular algae removal may be required at some sites to maintain outplants; algal removal may have to be increased if rising ocean temperatures and/or increased nutrients stimulate algal growth. This intervention may include managed relocation and/or assisted gene flow for taxa with low genetic diversity.

OPTION 3: Gamete and larval capture and seeding/sexual propagation (1-6)
This PRIMARY intervention has been selected for all six priority sites, however it is not currently a high priority compared to other restoration interventions given the significant resource requirements and challenges surrounding the lack of knowledge of the reproductive timing of many of Guam's coral species. Application of this intervention would likely utilize staghorn *Acropora* spp., *Heliopora coerulea*, and other Acroporids, such as *A. azurea* and *A. abrotanoides*. Due to accessibility limitations, gametes would likely be collected from site 1 (Tumon Bay Reef Flat) and/or site 3 (Tepungan West Reef Flat and Channel). Larvae will be settled on conditioned tiles and reared ex-situ or in in-situ settlement pools before propagation in one of Guam's two field-based nurseries. When outplanted, tiles with live recruits will be affixed to clean prepared substrate using cement or epoxy; attachment protocols will be designed to ensure that tiles remain intact even if impacted by storms and wave action. Tiles will be outplanted to deeper areas of reef flat habitats to decrease the risk of mortality from ENSO-associated extreme low tides. Regular algae removal may be required at some sites to maintain outplants and algal removal may have to be increased if rising ocean temperatures and/or increased nutrient inputs increase algal growth. Any intervention that requires ex situ rearing and/or mechanical aquaria equipment will include some kind of contingency plan in the event that severe storms cause power interruptions and fuel shortages. This intervention may include managed relocation and/or assisted gene flow for taxa with low genetic diversity.

OPTION 4: Restabilization/repair after physical damage (2, 3, 6)
This PRIMARY intervention was selected for three sites: site 2 (Tepungan East Reef Flat), site 3 (Tepungan West Reef Flat and Channel), and site 6 (Malesso Pier Reef Flat and Rim). This intervention, which will be conducted as needed, encompasses restabilization and repair of coral

colonies following physical damage due to storms, vessel groundings, anchor damage, etc. Implementation of this intervention will be based on resource availability, scale and significance of impact, and site value. This intervention can restore function, fish habitat, etc. quickly after damage, prevent phase shifts by preventing mortality of damaged/toppled corals, and prevent secondary damage from movement of loose corals. Best practices will be applied to ensure that the intervention is resilient to climate change, including more severe storms/wave action in the future.

OPTION 5: Coral predator management (1-6)
This SUPPLEMENTAL intervention has been selected for all six priority sites. As needed, coral predators - such as *Drupella* sp. and *Coralliophila* sp. - will be manually removed from coral outplants if significant predation of restored corals occurs. Warming ocean temperatures may increase disease outbreaks, and diseased colonies are more vulnerable to gastropod predation; thus predator management may need to be increased in the future. We will also opportunistically cull *Acanthaster planci* (COTS) using vinegar injections, as needed, during outplant maintenance and monitoring activities. However, COTS are rarely seen in reef flat habitats. Warming ocean temperatures and increased runoff from more severe storms may elevate the severity and frequency of COTS outbreaks over time.

OPTION 6: Macroalgae and cyanobacteria removal and management (1, 3, 4, 6)
This SUPPLEMENTAL intervention was selected for site 1 (Tumon Bay Reef Flat), site 3 (Tepungan West Reef Flat and Channel), site 4 (Babi Island Reef Flat), and site 6 (Malesso Pier Reef Flat and Rim). As needed, we will manually remove nuisance algae (e.g., *Chaetomorpha* sp., *Padina* sp.) and cyanobacteria from coral outplants and surrounding substrate when its abundance threatens the health and survival of restored corals. The need for algal removal will vary seasonally and usually peaks during warm summer months; we will track algal abundance and removal to learn when algae is most likely to impact our restoration sites. This effort includes both small-scale algae removal as a site maintenance activity and larger scale removal as a community engagement effort. Algal removal may have to be increased if rising ocean temperatures and/or increased nutrient inputs increase algal growth.

OPTION 7: Disease management (1-6)
This SUPPLEMENTAL intervention has been selected for all six priority sites. We will address disease outbreaks by removing diseased colonies or portions of colonies (with epoxy applied to the edges of the live tissue on remaining colonies) and attempt to test the efficacy of applying an Amoxicillin paste to treat white syndromes (the most common suite of coral diseases). Warming ocean temperatures and increased nutrient runoff may increase the severity and frequency of disease outbreaks, requiring enhanced disease management to safeguard restored corals in the future. We plan to conduct further research to determine the best methods to mitigate coral diseases on Guam's reefs.

OPTION 8: Substrate augmentation to enhance coral growth and outplant establishment (2-4)
This SUPPLEMENTAL intervention was selected for site 2 (Tepungan East Reef Flat), site 3 (Tepungan West Reef Flat and Channel), and site 4 (Babi Island Reef Flat). This intervention includes both artificial (engineered) reef structures and rubble stabilization. Artificial reef structures - which may be C-frames (rebar and metal wire), coral spiders (rebar), or another type of structure - will be outplanted with asexually fragmented corals sourced from our coral nurseries. Mesh will be attached to rubble areas using anchors (rebar or angle bars) to stabilize the substrate and may be outplanted with asexually fragmented corals (primarily staghorn *Acropora* spp.) sourced from our coral nurseries. Our nursery-reared corals are presumed to have some thermal tolerance, as they were collected from donor colonies that survived past bleaching events. Restored corals that die due to bleaching, disease, storm damage, etc. will be replaced whenever possible. Multiple taxa will be outplanted to the artificial reefs and mesh, primarily branching and foliose species, as they grow well on these structures. Structures and mesh will be designed, positioned, and securely installed with anchors - and checked and

maintained regularly - to ensure that they can withstand storms and wave action. However, we will avoid installing structures and mesh in exposed areas that are likely to experience extreme storm impacts. Structures will be installed in deeper parts of reef flat habitats to decrease the risk of mortality from ENSO-associated extreme low tides. Regular algae removal may be required at some sites to maintain outplants and algal removal may have to be increased if rising ocean temperatures and/or increased nutrient inputs increase algal growth.

OPTION 9: Seagrass restoration along adjacent coastline (2-4)
This SUPPLEMENTAL intervention was selected for site 2 (Tepungan East Reef Flat), site 3 (Tepungan West Reef Flat and Channel), and site 4 (Babi Island Reef Flat). Of our six high priority restoration sites, these are the only three with adjacent seagrass beds. This intervention consists of propagation, transplantation, and monitoring of seagrass propagules along nearshore areas adjacent to these restoration sites. Selection of seagrass species for restoration will be based on both their ecological function and their expected resilience to future climate change impacts, including ocean warming and sea level rise. Guam is predicted to have less frequent but more severe storms in the future, increasing the importance of coastal vegetation to reduce the impacts of nutrient and sediment inputs on our coral reefs. In addition to capturing nutrients, sediment, pathogens, and toxins that run off the land, intact seagrass habitats absorb CO2, prevent erosion, and create nursery habitat for many reef-associated species.

OPTION 10: Mangrove restoration along adjacent coastline (4)
This intervention has been selected for site 4 (Babi Island Reef Flat), the only one of our six priority sites that is adjacent to a mangrove area. This intervention consists of propagation, transplantation, and monitoring of mangrove propagules along nearshore areas adjacent to this restoration site. Selection of mangrove species for restoration will be based on both their ecological function and their expected resilience to future climate change impacts, including ocean warming and sea level rise. Guam is predicted to have less frequent but more severe storms in the future, increasing the importance of coastal vegetation to reduce the impacts of nutrient and sediment inputs on our coral reefs. In addition to capturing nutrients, sediment, pathogens, and toxins that run off the land, intact mangrove habitats absorb CO2, prevent erosion, and create nursery habitat for many reef-associated species.

The local restoration planning team reviewed all ten potential intervention options and scored them based on five criteria with a total of 13 sub-criteria:

1. EFFECTIVENESS
    a. Intervention has been tested on Guam and been technically successful
    b. Intervention will be climate-smart in addressing changing conditions and uncertainties
2. FEASIBILITY
    a. Costs of implementation and maintenance are feasible
    b. Technical capacity needed for implementation will be in place
    c. Physical structure needed for implementation is available
    d. Required permits are obtainable within the implementation timeline (3-5 years)
    e. Strong community, political, and private sector support exists for this intervention
3. URGENCY
    a. Threat to reef structure and function is high if intervention is not implemented immediately
    b. There is an immediate opportunity for partnerships, funding, and/or leveraging existing efforts
    c. This intervention is needed before other restoration efforts will be feasible or successful
    d. Results can be achieved in a timeframe aligned with urgency of threat

4. FLEXIBILITY
    a. Intervention can be adapted if biophysical conditions (not related to climate change) change and is responsive to new data
5. EXTERNALITIES
    a. Intervention minimizes unintended negative consequences and is reversible if needed

For each sub-criteria, each intervention received a score of 5 (strongly agree), 4 (agree), 3 (neutral), 2 (disagree), or 1 (strongly disagree). The restoration planning team then calculated a total score for each of our ten potential intervention options. Then, we reviewed the application of each option at each of the six priority sites for which an option was selected. At this stage, we did not eliminate any of the options. Rather, we discussed the relative priority and potential benefits of each option. We are keeping all options available so that if conditions (available funding, technical capacity, etc.) change in the near future, we have maximum flexibility for restoration intervention options within our strategy.

SITE 1: Tumon Bay Reef Flat

Intervention options for this site and their scores:

- Primary interventions:
    - Option 2: Asexual propagation with nursery phase (51)
    - Option 4: Restabilization/repair after physical damage (45)
    - Option 3: Sexual propagation (32)
- Supplemental interventions:
    - Option 5: Coral predator management (52)
    - Option 6: Macroalgae and cyanobacteria removal/management (52)
    - Option 7: Disease management (42)

We have identified six potential restoration intervention options for Tumon Bay Reef Flat. Three primary interventions (asexual propagation with nursery phase, restabilization/repair after physical damage, and sexual propagation) will be complemented by three supplemental interventions (coral predator management, disease management, and macroalgae and cyanobacteria removal and management). These supplemental interventions may be necessary before other restoration efforts, such as asexual propagation, can be successful. Coral predator management may include opportunistic removal of COTS and Drupella. Although COTS are rarely found in reef flat zones, we aim to use vinegar injections to cull any that are reported. Water quality is a serious issue in Tumon Bay, largely due to stormwater runoff, and the restoration team is concerned about outplanting corals in this area until water quality improves. Several macroalgal removal efforts have been conducted in the bay and it is likely that the need for this intervention may increase as the ocean warms. However, there are certain parts of the bay where corals are thriving, and these areas may be good candidate sites for outplanting of asexually propagated colonies of certain species that have become rare due to mortality from bleaching, extreme low tides, etc. Disease prevalence in Tumon is generally low, but outbreaks do occur and thus disease management may become a necessary intervention option. If physical damage occurs due to impacts from recreational vessels or severe storms, we will implement option 4, restabilization and repair of damaged colonies. Sexual propagation is the lowest priority of these intervention options due to the high resource requirements and limited success with this technique on Guam in the past. However, we did not eliminate this as a potential option in case there is more capacity for this approach in the near future.

SITE 2: Tepungan East Reef Flat

Intervention options for this site and their scores:

- Primary interventions:

    - Option 2: Asexual propagation with nursery phase (51)
    - Option 4: Restabilization/repair after physical damage (45)
    - Option 3: Sexual propagation (32)
- Supplemental interventions:
    - Option 5: Coral predator management (52)
    - Option 8: Substrate augmentation to enhance outplant establishment (46)
    - Option 7: Disease management (42)
    - Option 9: Seagrass restoration (40)

We have identified seven potential restoration intervention options for Tepungan East Reef Flat. Three primary interventions (asexual propagation with nursery phase, restabilization/repair after physical damage, and sexual propagation) will be complemented by four supplemental interventions (coral predator management, disease management, substrate augmentation to enhance outplant establishment, and seagrass restoration). Coral predator management, disease management, and substrate augmentation may be necessary before other restoration efforts, such as asexual propagation, can be successful. Coral predator management may include opportunistic removal of COTS and Drupella. Although COTS are rarely found in reef flat zones, we aim to use vinegar injections to cull any that are reported. Disease prevalence in Tepungan Bay is generally low, but outbreaks do occur and thus disease management may become a necessary intervention option. If physical damage occurs due to impacts from recreational vessels or severe storms, we will implement option 4, restabilization and repair of damaged colonies. At this site, option 8 will include artificial structures, such as C-frames and coral spiders; after installation, artificial structures will be outplanted with asexually propagated corals from our in situ nursery. With this option, our greatest concern is that any structures are climate-smart and resilient to strong storms and wave action. Tepungan Bay has extensive seagrass beds, thus option 9 is included as a potential restoration intervention. The current Guam Coral Fellow is conducting research on seagrass restoration and will conduct at least one seagrass restoration project before the end of her fellowship in 2022. However, with this option we are cognizant of the difficulties of tying seagrass health directly to changes in coral reef health, and have given higher priority to direct reef-based interventions. Sexual propagation is the lowest priority of these intervention options due to the high resource requirements and limited success with this technique on Guam in the past. However, we did not eliminate this as a potential option in case there is more capacity for this approach in the near future.

SITE 3: Tepungan West Reef Flat and Channel

Intervention options for this site and their scores:

- Primary interventions:
    - Option 2: Asexual propagation with nursery phase (51)
    - Option 4: Restabilization/repair after physical damage (45)
    - Option 3: Sexual propagation (32)
- Supplemental interventions:
    - Option 5: Coral predator management (52)
    - Option 6: Macroalgae and cyanobacteria removal/management (52)
    - Option 8: Substrate augmentation to enhance outplant establishment (46)
    - Option 7: Disease management (42)
    - Option 9: Seagrass restoration (40)

We have identified eight potential restoration intervention options for Tepungan West Reef Flat and Channel. Three primary interventions (asexual propagation with nursery phase, restabilization/repair after physical damage, and sexual propagation) will be complemented by five supplemental interventions (coral predator management, disease management, substrate augmentation to enhance

outplant establishment, macroalgae and cyanobacteria removal/management, and seagrass restoration). Coral predator management, macroalgal and cyanobacteria removal/management, substrate augmentation, and disease management may be necessary before other restoration efforts, such as asexual propagation, can be successful. Coral predator management may include opportunistic removal of COTS and Drupella. Although COTS are rarely found in reef flat zones, we aim to cull any that are reported to vinegar injections. Disease prevalence in Tepungan Bay is generally low, but outbreaks do occur and thus disease management may become a necessary intervention option. If physical damage occurs due to impacts from recreational vessels or severe storms, we will implement option 4, restabilization and repair of damaged colonies. At this site, option 8 will include artificial structures, such as C-frames and coral spiders; after installation, artificial structures will be outplanted with asexually propagated corals from our in situ nursery. With this option, our greatest concern is that any structures are climate-smart and resilient to strong storms and wave action. Tepungan Bay has extensive seagrass beds, thus option 9 is included as a potential restoration intervention. The current Guam Coral Fellow is conducting research on seagrass restoration and will conduct at least one seagrass restoration project before the end of her fellowship in 2022. However, with this option we are cognizant of the difficulties of tying seagrass health directly to changes in coral reef health, and have given higher priority to direct reef-based interventions. Sexual propagation is the lowest priority of these intervention options due to the high resource requirements and limited success with this technique on Guam in the past. However, we did not eliminate this as a potential option in case there is more capacity for this approach in the near future.

SITE 4: Babi Island Reef Flat

Intervention options for this site and their scores:

- Primary interventions:
    - Option 2: Asexual propagation with nursery phase (51)
    - Option 4: Restabilization/repair after physical damage (45)
    - Option 3: Sexual propagation (32)
- Supplemental interventions:
    - Option 5: Coral predator management (52)
    - Option 6: Macroalgae and cyanobacteria removal/management (52)
    - Option 8: Substrate augmentation to enhance outplant establishment (46)
    - Option 7: Disease management (42)
    - Option 10: Mangrove restoration (41)
    - Option 9: Seagrass restoration (40)

We have identified nine potential restoration intervention options for Babi Island Reef Flat. Three primary interventions (asexual propagation with nursery phase, restabilization/repair after physical damage, and sexual propagation) will be complemented by six supplemental interventions (coral predator management, disease management, substrate augmentation to enhance outplant establishment, macroalgae and cyanobacteria removal/management, seagrass restoration, and mangrove restoration). Coral predator management, macroalgal and cyanobacteria removal/management, substrate augmentation, and disease management may be necessary before other restoration efforts, such as asexual propagation, can be successful. Coral predator management may include opportunistic removal of COTS and Drupella. Although COTS are rarely found in reef flat zones, we aim to use vinegar injections to cull any that are reported. Disease prevalence at this site is generally low, but outbreaks do occur and thus disease management may become a necessary intervention option. If physical damage occurs due to impacts from recreational vessels or severe storms, we will implement option 4, restabilization and repair of damaged colonies. At this site, option 8 will include artificial structures, such as C-frames and coral spiders; after installation, artificial structures will be outplanted with asexually propagated corals from our in situ nursery. With this option, our greatest concern is that any

structures are climate-smart and resilient to strong storms and wave action. The Babi Island site has both seagrass beds and mangrove areas, thus options 9 and 10 are included as potential restoration interventions. The current Guam Coral Fellow is conducting research on seagrass and mangrove restoration and will conduct at least one seagrass restoration project and one mangrove restoration project before the end of her fellowship in 2022. However, with this option we are cognizant of the difficulties of tying seagrass and mangrove health directly to changes in coral reef health, and have given higher priority to direct reef-based interventions. Sexual propagation is the lowest priority of these intervention options due to the high resource requirements and limited success with this technique on Guam in the past. However, we did not eliminate this as a potential option in case there is more capacity for this approach in the near future.

SITE 5: Litekyan Reef Flat

Intervention options for this site and their scores:

- Primary interventions:
    - Option 2: Asexual propagation with nursery phase (51)
    - Option 4: Restabilization/repair after physical damage (45)
    - Option 3: Sexual propagation (32)
- Supplemental interventions:
    - Option 5: Coral predator management (52)
    - Option 7: Disease management (42)

We have identified five potential restoration intervention options for Litekyan Reef Flat. Three primary interventions (asexual propagation with nursery phase, restabilization/repair after physical damage, and sexual propagation) will be complemented by two supplemental interventions (coral predator management and disease management). These supplemental interventions may be necessary before other restoration efforts, such as asexual propagation, can be successful. Coral predator management may include opportunistic removal of COTS and Drupella. Although COTS are rarely found in reef flat zones, we aim to use vinegar injections to cull any that are reported. This site also has high abundance of the Terpios sponge, which may need to be managed before outplanting is implemented. Disease prevalence at Litekyan is generally low, but outbreaks do occur and thus disease management may become a necessary intervention option. If physical damage occurs due to impacts from recreational vessels or severe storms, we will implement option 4, restabilization and repair of damaged colonies. Sexual propagation is the lowest priority of these intervention options due to the high resource requirements and limited success with this technique on Guam in the past. However, we did not eliminate this as a potential option in case there is more capacity for this approach in the near future.

SITE 6: Malesso Pier Reef Flat and Rim

Intervention options for this site and their scores:

- Primary interventions:
    - Option 2: Asexual propagation with nursery phase (51)
    - Option 1: Direct transplantation without nursery phase (49)
    - Option 4: Restabilization/repair after physical damage (45)
    - Option 3: Sexual propagation (32)
- Supplemental interventions:
    - Option 5: Coral predator management (52)
    - Option 6: Macroalgae and cyanobacteria removal/management (52)
    - Option 7: Disease management (42)

We have identified seven potential restoration intervention options for Malesso Pier Reef Flat and Rim. Four primary interventions (asexual propagation with nursery phase, direct transplantation, restabilization/repair after physical damage, and sexual propagation) will be complemented by three supplemental interventions (coral predator management, disease management, and macroalgae and cyanobacteria removal/management). These supplemental interventions may be necessary before other restoration efforts, such as asexual propagation, can be successful. Coral predator management may include opportunistic removal of COTS and Drupella. Although COTS are rarely found in reef flat zones, we aim to use vinegar injections to cull any that are reported. Disease prevalence at this site is generally low, but outbreaks do occur and thus disease management may become a necessary intervention option. This is the only site where option 2, direct transplantation without a nursery phase, is included as a potential intervention. This intervention is directly related to two site-specific projects, 1) the removal of coral colonies that have grown on the Malesso boat ramp and 2) the removal of colonies that have grown on the tire reef in the Malesso Lagoon. These colonies will be transplanted from these man made structures to adjacent natural reef areas at this site. If physical damage occurs due to impacts from recreational vessels or severe storms, we will implement option 4, restabilization and repair of damaged colonies. Sexual propagation is the lowest priority of these intervention options due to the high resource requirements and limited success with this technique on Guam in the past. However, we did not eliminate this as a potential option in case there is more capacity for this approach in the near future.

Objectives and Performance Metrics

The specific objectives and performance metrics that will be used to assess project progress are as follows. A summary is provided in Appendix 2 of this Action Plan detailing the site(s), lead personnel and agencies, partners, and timeframe to complete each of these activities.

Objective 1.1: By the end of 2023, Guam's two field-based nurseries have the capacity to culture sufficient stock to outplant 6,000 fragments of six species of staghorn Acropora corals *(A. cf pulchra; A. aspera, A. muricata, A. acuminata, A. teres, and A. microphthalma)*, with outplants covering at least 4 acres of shallow reef area with a survival rate of at least 75%.

Performance Metrics:

- # of corals propagated
- # coral fragments outplanted
- Fragment survival in nurseries
- Change in size/health of colonies transplanted/ moved
- Survival of outplanted corals, especially after adverse events
- Change in area receiving outplants. The specific indicators are reef fish, invertebrate abundance and diversity, and rugosity.

Activities:

1. Complete permit(s) acquisition for new outplanting sites (Tumon, Tepungan East and West, Babi Island, Malesso, Litekyan/Ritidian). The Raymundo Lab will lead and complete this step on an as-needed basis. Other partners who need to be consulted include Guam Department of Agriculture (Guam DoAg), Guam Environmental Protection Agency(EPA), US Army Corps of Engineers (USACE), NOAA, and US Fish and Wildlife.
2. Expand nurseries and test new types of structures in Malesso and Piti nurseries. The Raymundo Lab will lead this step from 2021-2023. Other partners include Guam EPA, USACE, and NOAA.

3. Test various outplanting methods; assess variation in outplanting success by attachment method, by taxa, and by site. The Raymundo Lab and Guam Restoration and Intervention Partnership (GRRIP) will lead this step, slated primarily for 2021.
4. Outplant at least 6,000 colonies, targeting a 75% survival rate, covering at least 4 acres. The Raymundo Lab and GRRIP will lead this step from 2021-2023.
5. **Supporting community engagement activities occurring in conjunction with restoration**:
    a. TNC and the Guam Watershed Coordinator will continue to design and implement in-water and land-based reef restoration efforts in Malesso, expanding to other sites, through at least 2022.
    b. Coral Reef Fellow will develop and implement mangrove and seagrass products and activities from 2020-2022.
    c. NOAA's Friends of Reefs Guam Coordinator will implement complementary restoration activities, such as algae removal, and other coral-related outreach, from 2020-2022.
    d. The Park Ranger at the U.S. Fish and Wildlife Refuge will develop new marine-oriented community outreach at Litekyan/Ritidian starting in 2021.
    e. BSP will oversee installation of new signage at Malesso Pier, Tumon, and Tepungan (Fish Eye) in 2021-2022. Signage includes information about the coral nursery (Malesso) and MPA rules.

Additionally, in order to evaluate progress in meeting Objective 1.1's performance metrics, the following indicators will be monitored starting from Activity 2 onward:

- Coral fragment growth, differential bleaching resistance, and survival in nursery
- Nursery-specific threats that hinder coral fragment survival
- Time and costs associated with nursery maintenance
- Outplant growth, health, and survival at recipient sites

Objective 1.2: By 2025, diversity enhancement is incorporated into all restoration activities, including the coral nurseries. All outplanting activities will incorporate at least two staghorn species and at least three source populations.

Performance Metrics:
- # staghorn species at recipient site
- # source populations at recipient site

Activities:
1. Genotype all corals in nurseries at Tepungan East and Malesso; develop a database to track genotypes that are fragmented and outplanted. The Combosch Lab will lead this activity from 2021-2023.
2. Develop a strategy and plan that identifies species and populations to be outplanted at each site. The Raymundo Lab and the Bureau of Statistics and Pans will complete this activity in 2021.
3. Test and develop fish habitat structures to augment outplant and nursery areas in early stages of growth. The activity lead is the Raymundo Lab, with partners DAWR and TNC from 2021-2023.
4. Monitor for spawning *in situ* during established spawning times at the Tumon and Tepungan sites. The Raymundo Lab will lead this activity from 2021-2025.
5. Test efficacy/practicality of sexual propagation of *A.* cf. *pulchra* in the Tumon and Tepungan sites. The Raymundo Lab will lead this task from 2022-2025.

Objective 1.3: By 2025, nursery maintenance and outplanting methods are standardized; a long-term monitoring program is developed for restored sites, which includes monitoring for recruitment of coral-associated invertebrates and fish to outplanted communities; and a threat response plan to address acute mortality events is completed.

Performance Metrics:

- Completion of nursery expansion and maintenance plan
- Outplanting methodology finalized and documented
- Completion of long-term outplant monitoring plan
- Completion of acute threat response plan

Activities:

1. Monitor fragment growth and survival in the nursery, adjusting methods as necessary. Monitor outplant growth and survival at recipient sites, adjusting methods as necessary. The Raymundo Lab will lead this task, in partnership with GRRIP from 2021-onward.
2. Begin monitoring for fish and invertebrate recruits. The Raymundo Lab will lead this task, with support from DAWR from 2021-onward.
3. The Raymundo Lab and BSP will draft nursery maintenance, outplanting standard operating procedures, a threat response plan, and a long term monitoring plan for outplants in 2021.
4. Review plans with appropriate stakeholders. The Raymundo Lab and BSP will lead this task in partnership with GRRIP in 2021.
5. Incorporate feedback into plans; finalize protocols and plans. The Raymundo Lab and BSP will lead this task, with a target completion date of 2025.
6. **Supporting management activities occurring in conjunction with restoration**:
    a. Guam's Reef Response Team will participate in The Nature Conservancy (TNC) Reef Brigades training sessions, so as to improve capacity to respond to emergency restoration efforts, from 2020-2022.
    b. Guam's Coastal Fellow will develop the Seashore Reserve Plan from 2020-2022. Guam's Coastal Management Program will push for adoption and passage of the plan through 2025.
    c. The Coral Reef Initiative will continue to develop and advocate for legal and fiscal mechanisms to support reef repair and restoration efforts, especially in response to vessel groundings.
    d. The Department of Agriculture's Division of Aquatics and Wildlife (DAWR) will conduct visual stock assessment surveys of MPAs and control sites: Achang Reef Flat Marine Preserve, Piti Bomb Holes Marine Preserve, Tumon Bay Preserve, Asan Bay, Pago Bay, and Cocos Lagoon, in 2021.
    e. The Department of Agriculture's Law Enforcement Unit implements the Volunteer Conservation Officer Reservist program, with its accompanying increased outreach and enforcement efforts, starting in 2021.

Additionally, in order to evaluate progress in meeting Objective 1.3's performance metrics, the following indicators will be monitored starting from **Activity 1** onward:

- Fragment growth and survival in nurser, including how they vary by species and populations
- Outplant growth, health, survival at recipient sites, including how they vary by species and populations
- Budgets, staffing, nursery construction methods, nursery maintenance problems and solutions. Efficacy will be assessed at funding cycle conclusion in order to develop lessons learned.

Stakeholder Engagement and Outreach

Once finalized, Guam's Coral Reef Restoration Action Plan will be disseminated to local stakeholders (e.g., decision makers, natural resource managers, researchers, interested community members) through one or more presentations. These sessions will likely be virtual due to COVID-19 public health regulations. A one page executive summary will be developed and shared with high level decision makers (e.g., Office of the Governor, members of the legislature and their staff). The document will be made publicly available online through www.guamcoralreefs.com.

Appendix 1. Map of Priority Sites (ATTACHED)

Appendix 2. Action Plan Summary Matrix (ATTACHED)