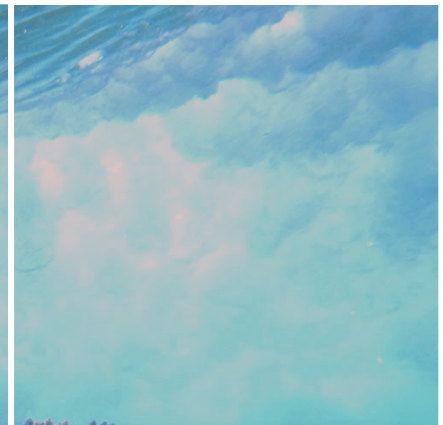
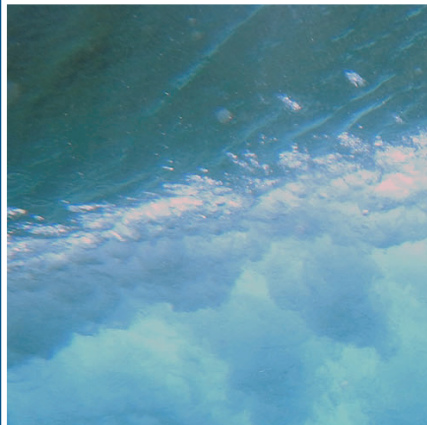
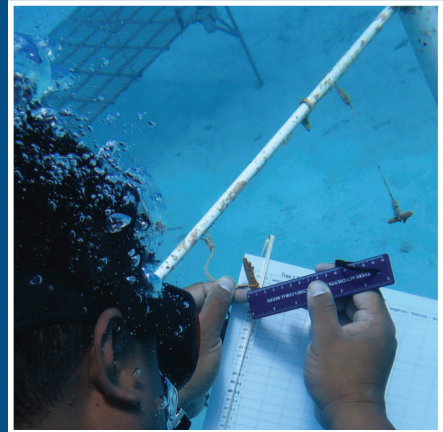


Action Plan for Restoration of Coral Reef Coastal Protection Services: Case study example and workbook

Supplement to *A Manager's Guide to Coral
Reef Restoration Planning & Design*



Office of Research and Development
Center for Public Health and
Environmental Assessment

ACTION PLAN FOR RESTORATION OF CORAL REEF COASTAL PROTECTION SERVICES: CASE STUDY EXAMPLE AND WORKBOOK

Supplement to

A Manager's Guide to Coral Reef Restoration Planning & Design

Center for Public Health and Environmental Assessment
Office of Research and Development
U.S. Environmental Protection Agency
Washington, DC 20460

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QUALITY ASSURANCE SUMMARY AND DISCLAIMER

This work was conducted under the U.S. Environmental Protection Agency's Quality Assurance (QA) program for environmental information, with an approved Quality Assurance Project Plan, L-HEEAD-0031309-QP-1-2. Independent QA audits were not deemed necessary; the product was reviewed by QA, three internal technical reviewers, and three external peer reviewers.

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. Contractor's role did not include establishing Agency policy.

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ACRONYMS AND ABBREVIATIONS

GIS	Geographic Information System
LiDAR	Light Detection and Ranging
NOAA	National Oceanic and Atmospheric Administration
SLR	Sea level rise
SMART	Specific, Measurable, Achievable, Relevant, Time-bound
SWAN	Simulating Waves Nearshore
TNC	The Nature Conservancy
UAV	Unmanned Aerial Vehicle
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WAU	Wave Attenuation Unit

PREFACE

This report was prepared by the U.S. Environmental Protection Agency (USEPA), Office of Research and Development, as part of the Air, Climate and Energy (ACE) research program, with support from Tetra Tech, Inc., and in collaboration with the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, and The Nature Conservancy. The ACE research program provides scientific information and tools to support USEPA's commitment to clean air, clean water and sustainable natural resources, even as environmental conditions change. A key component of this is the development of sound science to support adaptation. Adaptation involves preparing for and adjusting to the effects of climate change and its interactions with other global and local stressors. Because these effects are diverse, interactive, and difficult to predict, adapting management of natural resources in this context can be very challenging.

Coral reefs—which provide valued ecosystem services such as fisheries, coastal protection, and tourism—are threatened by the effects of increased sea surface temperatures, sea level rise, and intensifying storms. These large-scale stressors are interacting with local stressors such as pollution, overfishing, and recreational misuse to drive ongoing and accelerating declines in coral reef ecosystems. Thus, there is a rising urgency to design and implement climate change adaptation measures that will enable reef resilience in the face of these changes. This includes accounting for, and adjusting to, the combined effects of climate change and local stressors in coral reef protection and restoration efforts.

The action plan, example case study, and workbook found in this report demonstrate a structured process for integrating climate-smart design considerations into restoration planning using *A Manager's Guide to Coral Reef Restoration Planning and Design*. The focus is a hypothetical coral reef restoration project that has a goal of recovering nature-based coastal protection services using restoration interventions. The intent is to provide readers with a completed example of how to use the *Guide* workbook to inform a draft action plan, centering on the topic of coastal protection as a burgeoning area of interest in coral reef science and management communities. The information in this hypothetical case study is not intended for direct use; rather, it provides a starting point for more detailed planning that would occur in specific places. And while a full review of the current literature on reef restoration methods is outside the scope of this report, readers are encouraged to use the examples herein as well as in the *Guide* as a jumping-off point for exploring the rapidly growing body of information on methods, techniques, successes, failures, monitoring challenges and future directions of coral reef restoration in a changing world. The workbook, together with the action plan, can serve as a valuable record of the planning thought process as well as a living document for adaptive management, to be updated through time as improved information becomes available.



Waves break over a reef in American Samoa.
Credit: Valentine Vaeoso, American Samoa.

AUTHORS, CONTRIBUTORS, AND REVIEWERS

The Air, Climate and Energy research program of EPA's Office of Research and Development was responsible for producing this report. The report was prepared by Tetra Tech, Inc., under EPA Contract No. EP-C-17-031. Jordan M. West served as the Task Order Project Officer, providing overall direction and technical assistance, and was a contributing author.

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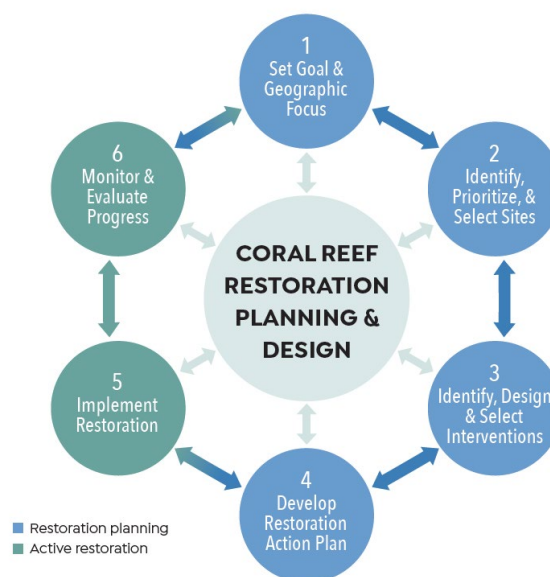
1 BACKGROUND

Introduction to the Guide and Workbook

A Manager's Guide to Coral Reef Restoration Planning and Design (the Guide) [1] supports coral reef managers--together with their partners and stakeholders--in developing restoration projects for coral reefs in their locations. It describes four key steps to create a Restoration Action Plan that is tailored to the reef area and management context.¹ These steps are illustrated by the sequential cycle at right, but it should be noted that the steps are iterative and can inform each other from any starting point. The four planning steps include:

- **Step 1:** Set Goal & Geographic Focus
- **Step 2:** Identify, Prioritize, & Select Sites
- **Step 3:** Identify, Design, & Select Interventions
- **Step 4:** Develop Restoration Action Plan

The Manager's Guide Workbook (the Workbook) is a user-friendly companion to the Guide. It provides a template to document the information used and decisions made during the four steps of the planning process in developing a Restoration Action Plan. In the "Suggested Process" sections within each Guide step, prompts indicate when to turn to the Workbook to complete activities with the planning team. The Workbook serves as a reference document for evaluating and adapting the Restoration Action Plan over time. It provides a comprehensive record of the information and assumptions made in developing the Restoration Action Plan and may provide valuable insights as new information becomes available or underlying assumptions change, allowing for adaptive responses at any point in the process from goal setting through project implementation.



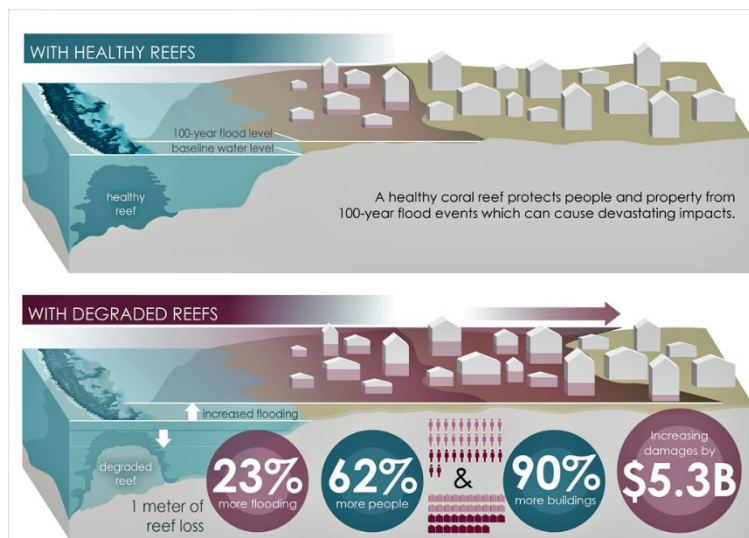
A key step in the planning process is setting goals for coral reef restoration. Coral reef managers may identify priority goals such as improving biodiversity or fish habitat. In this case study, the pre-selected goal is improving coastal protection. Hence, this document presents an example Workbook and Action Plan for a hypothetical coral reef restoration project, located in the Pacific region, which focuses on the goal of improving the ecosystem service of coastal protection.

¹ Note: Steps 5 and 6 are implementation steps to carry out the Restoration Action Plan and not part of the planning process covered in the Guide or Workbook.

Coastal Protection Services

The degradation of coastal habitats, particularly coral reef ecosystems, increases the exposure of coastal communities to erosion and flooding [2, 3]. Structural complexity in coral reef environments plays a crucial role in dissipating wave energy and protecting coastlines [4, 5]. High structural complexity results in high hydraulic roughness and greater frictional dissipation of wave energy when compared to other coastal settings. Lower frictional dissipation results in larger wave heights in back-reef environments and erosion of the near-shore zones of tropical reef islands and beaches. Reef crests can dissipate, on average, 86% of the incident wave energy [6]. Reef flats can then dissipate 65% of the remaining wave energy, for a total wave energy reduction of up to 97% [6].

The bathymetric profile (including during tidal cycles and during high water events such as storm surges) and rugosity of a reef are critical factors in determining wave attenuation benefits. For this reason, the three-



If one meter of reef is lost, flooding may increase by 23%, impact 62% more people and 90% more property, and increase damages by \$5.3 billion across the U.S. Credit: Adapted from Reguero et al. (2021) by J. Kendall-Bar, ©UCSC.

dimensional complexity, structural integrity, and health of a reef are paramount in providing coastal protection services. Coral reef degradation from land-based runoff, disease, ship-groundings, and other stressors results in coral mortality and subsequent physical and bio-erosion and flattening of the reef structure [7, 8], whereas healthy reefs support biogenic production of sediments to the reef and shoreline [9]. In addition, if vertical reef accretion is unable to keep pace with the rate of sea level rise, then there will be even less wave dissipation at the reef crest, and larger waves will be able to propagate into reef flat environments [4, 10]. As sea level rise and other climate change threats make tropical coastal communities more vulnerable to

shoreline erosion and flooding [5, 11], reef managers are increasingly considering coral reef restoration as an additional tool for preserving and enhancing coastal protection.

Coral reef restoration for coastal protection is an area of active multi-disciplinary research and development that will require an array of subject matter experts and the performance of numerous studies and pilot projects to demonstrate feasibility and proof of concept [12-15]. Interdisciplinary technical expertise in ecology, coastal geology, oceanography, engineering, and social science can be combined to design a coral reef restoration project that addresses the goal of reducing wave energy and associated coastal erosion by restoring the structural complexity of a coral reef environment [16-18]. In the face of climate change, sufficient reef accretion to keep pace with sea level rise and other challenges may be unlikely in some geographies. Thus, some communities may want to consider including an engineered option [2] to provide near- and longer-term coastal protection benefits. While hybrid gray/artificial reef restoration efforts have documented wave attenuation benefits [19], few projects aimed at restoring natural reefs have done so [19-21].

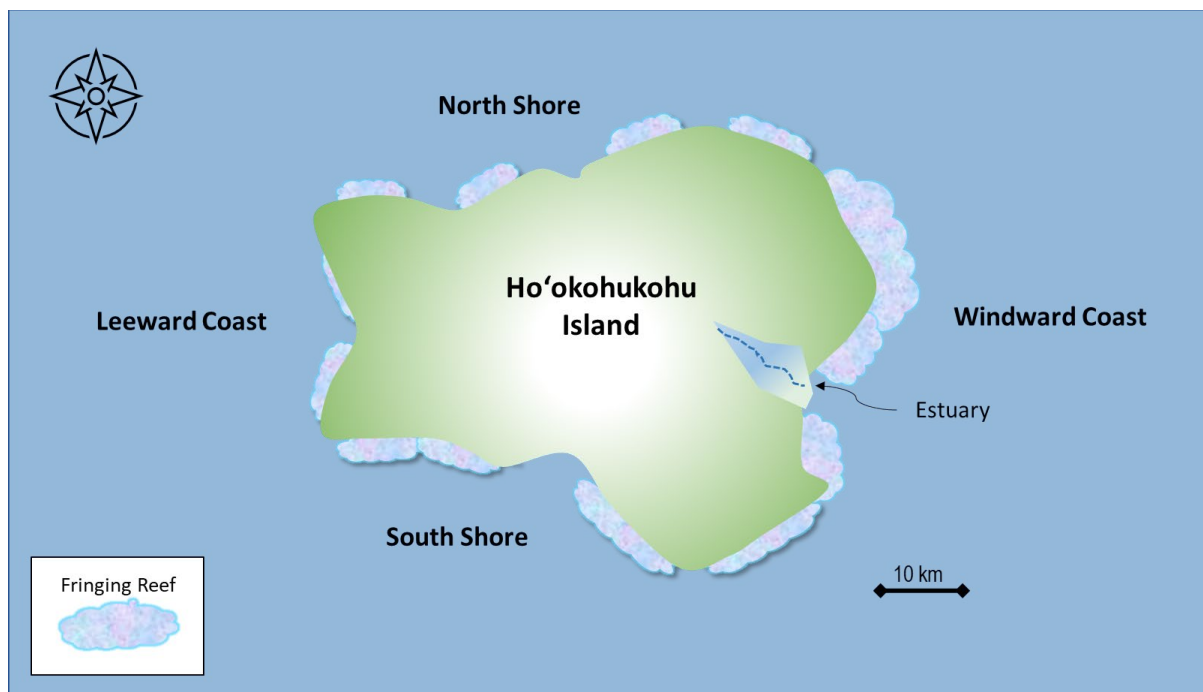
This case study example explores coastal protection as a restoration planning goal. It is based on a hypothetical island; as such, it provides a starting point for the more detailed planning and technical knowledge that would be needed to design a restoration plan for a specific place. Restoration planning can include a multidisciplinary team of relevant subject-matter experts to critically assess the extent of place-based information and data that may be needed to more comprehensively design a restoration project for coastal protection services in a specific geographic location.



A reef protects a populated coast.
Credit: U.S. Geological Survey. Public Domain.

Context for the Hypothetical Case Study

This case study example is based on the hypothetical Island of Ho'okohukohu, pictured below. The island is about 50 km in diameter with about 200 km of shoreline. Ho'okohukohu is a volcanic high island located in the central North Pacific. The island's terrestrial landscape is dominated by mountain ranges and comprised of many watersheds, large and small. Northeast trade winds deliver moisture to the northeastern side of the island, making it the wettest side of the island. Rivers and streams empty into nearshore coastal waters, although many have been channelized and paved to protect properties from stormwater runoff.



Coral reefs are the dominant nearshore habitat around the island. These reefs take different forms depending on their degree of exposure to large open-ocean swells and trade winds that influence the structure and nature of the ecosystem. Along the windward (east, trade-wind dominated) coast, reef crest and reef flat environments are important habitats that reduce wave energy reaching the shoreline. Reef flat environments serve as

nurseries for reef fish and support subsistence and recreational fishing. Coral reefs around the south shore of the island grow on an extensive submarine shelf that extends offshore to depths of about 30 m before dropping off steeply to the seafloor. These reefs provide some level of coastal protection, as well as recreational uses. On the leeward coast, fringing reefs close to shore extend to depths of 30 m, dropping off rapidly close to shore. The north shore is a high wave-energy environment resulting from seasonal extratropical storms. The coral reefs along the north shore are composed of encrusting and lobate corals typical of high wave-energy environments. The south shore is particularly exposed to high waves and coastal flooding from periodic tropical cyclones. Estuaries and bays exist along the windward and south shores of the island.



A road affected by coastal flooding.

Credit: Peter Swarzenski, U.S. Geological Survey. Public domain.

Human uses of the coastal environment vary around the island. The windward coast is mostly rural, dominated by residential, agricultural, subsistence fishing, and ocean recreational uses, such as surfing, swimming, and fishing. The coastal highway connecting the south and north shores is an important scenic drive for tourists as well as a lifeline for residents to travel to employment and medical facilities located on the south shore. The south shore is highly urbanized and dominated by tourism development and use. The leeward coast is characterized by sparse residential and agricultural land uses. The north shore is predominantly rural with some agriculture, tourism, and surfing.

Land-based runoff contributes significant sediment, nutrient, and contaminant runoff to coastal waters, although ongoing management efforts are reducing this threat. The island's dense population and commercial infrastructure along the south coast contribute to the runoff. Agriculture and the prevalence of invasive plant and animal species in forested upland areas results in increased erosion and soil loss, especially along the windward (east) coast of the island. Sedimentation, nutrient and pollutant loadings promote coral disease and bleaching, resulting in degraded coral reefs [22, 23]. A review of coral reefs in turbid water environments suggests that coral reefs exposed to moderate levels of turbidity may be more resilient to climate change impacts [24, 25].

Management efforts to preserve the various ecosystem services provided by coral reefs are increasing, especially for land-based sources of stress. Extensive efforts to remove terrestrial invasive species, especially ungulates, and replant native species in forested areas are helping to decrease soil erosion and improve nearshore water quality. Greater emphasis is needed, however, on nearshore fisheries management. New rules are needed to reduce overfishing, especially of herbivorous fish. Enforcement is underfunded and lacks human resource capacity.

Climate change has diminished the strength of the prevailing trade winds, and as a result has decreased the amount of annual rainfall needed to maintain the drinking water aquifer and support riverine and estuarine systems. Island-wide bleaching events have occurred, especially along the windward coast and south shore, resulting in localized coral mortalities. Incidences of coral recovery have been documented, but only along the windward coast. Coastal erosion is occurring over approximately 80 percent of the shoreline. Flooding events caused by large waves, King Tides, and/or severe storms occur annually, impacting beaches, properties, and

infrastructure. These and other coastal hazards are exacerbated by sea level rise. Climate change adaptation plans are being developed for coastal roads. New rules are being put into place to restrict shoreline armoring and increase coastal construction setbacks. Without reducing such sources of coral stress and mortality at sites slated for restoration, coral reef restoration efforts will generally fail [26].

In this hypothetical example of a restoration planning and design process, a Core Planning Team composed of government and nongovernmental reef managers, scientists, and practitioners was established to work through the four planning steps of *A Manager's Guide to Coral Reef Restoration Planning and Design*. Due to the highly technical nature of the restoration goal and interventions, a Technical Advisory Group composed of subject matter experts in watershed management, social science, economics, reef ecology, coastal geology, coastal engineering, and physical and chemical oceanography was also formed to support the Core Planning Team's specific needs during the planning process. Outreach to community stakeholders was conducted during planning and design, specifically to gauge community interest in restoration and to identify potential restoration sites. Six months were allocated to complete the Workbook planning process and create a Restoration Action Plan. The Restoration Action Plan was designed to be submitted as part of a grant proposal to the government for funding.

The completed Restoration Action Plan is presented in Section 2 below. This is followed in Section 3 by the full Workbook that was used to record the step-by-step, detailed thought process and assembled information used to generate the Restoration Action Plan.

2 ACTION PLAN FOR CORAL REEF RESTORATION ON HO'OKOHUKOHU ISLAND

Note: The following Restoration Action Plan is structured according to the Action Plan Template provided in *A Manager's Guide to Coral Reef Restoration Planning and Design* [1]. A fillable version of the template is available for download at:

https://www.coris.noaa.gov/activities/restoration_guide/welcome.html.

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### Project Description

October 2021

This project will focus on restoring coastal protection services provided by coral reefs on the reef flat and upper reef crest at Fisher's Reef along the windward coast of the Island of Ho'okohukohu. The reef crest, fore reef, and reef flat play significant roles in reducing wave energy and coastal erosion in island environments. Coral reef restoration will address the impacts of coral bleaching and storms that have reduced the hydrodynamic roughness of the site, which is a critical factor in wave attenuation. In addition to providing added protection to the coastal highway and properties in the area, the project will improve fish habitat in an area where recreational and subsistence fishing are important.



Corals will be propagated *in situ* at North Bay Reef and outplanted on Fisher's Reef on both existing substrate and wave attenuation units (WAUs). The installation of WAUs is deemed necessary to achieve the goal of wave energy reduction within a timeframe of 15 years and to keep up with rising sea level. The nursery at North Bay Reef provides variable water conditions including temperature, salinity, and water quality that are ideal for acclimatizing corals to coral bleaching and other stressors.

This Action Plan was developed by a Core Planning Team together with significant input from a Technical Advisory Group and stakeholders at the project sites.

## Restoration Goal

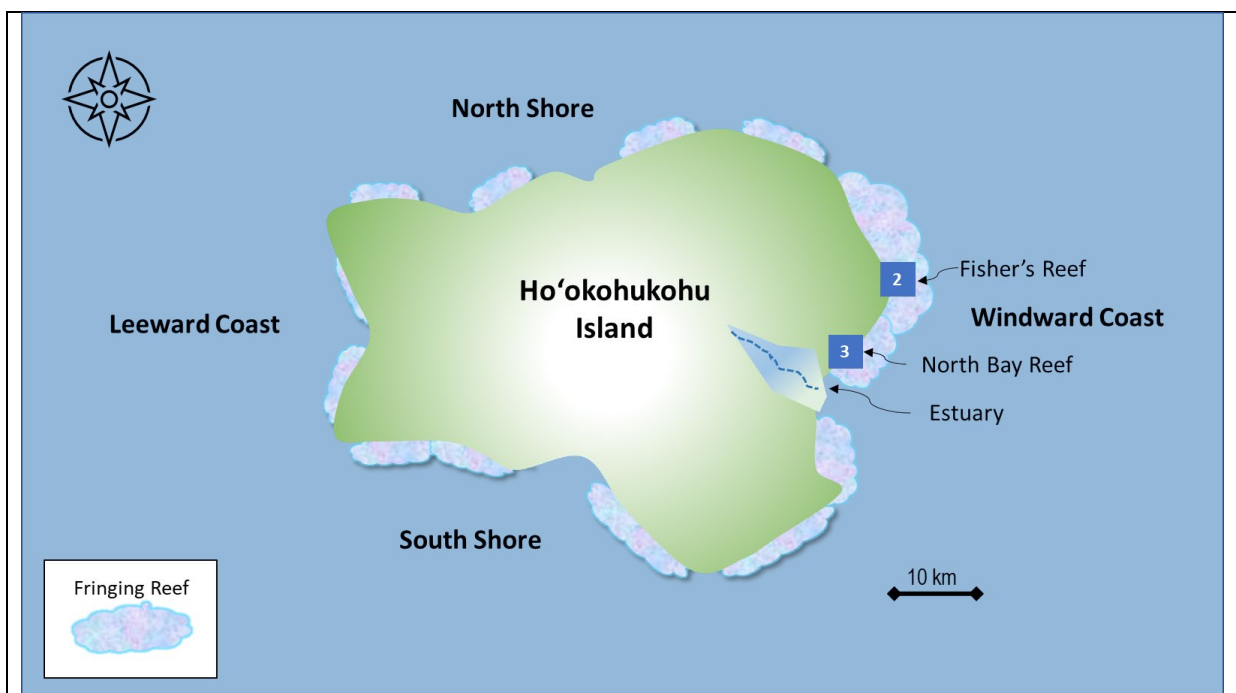
The goal selected for this restoration action plan is: **Within 15 years, restored reef structure reduces wave energy that contributes to coastal erosion, thereby strengthening the resilience of coastal communities to sea level rise and increasingly intense storms.**



A crashing wave in Hawaii.  
Credit: Michele Reynolds, U.S. Geological Survey.  
Public domain.

## Sites Selected for Restoration

Below is a brief description of the priority site(s) selected for restoration intervention based on each site's relevance to the restoration goal, potential for condition improvement, projected future exposures to large wave events, ecological resilience and processes, and human impacts. Out of six sites originally considered, the final priority sites selected were Site #2, Fisher's Reef and Site #3, North Bay Reef, windward coast (see map below).



#### **Fisher's Reef: Windward Coast – Restoration Site**

- **Relevance to Restoration Goal:** Intact reef crest and wide reef flat provide highly effective protection to the adjacent shoreline
- **Potential for Condition Improvement:** High potential for restoration to stabilize/improve coral cover and structure that was lost primarily from recent bleaching events
- **Future Exposure:** Experiences large waves, but intact reef crest and wide reef flat dampen wave energy
- **Ecological Resilience and Processes:** Documented cases of some coral species recovering from anomalously high temperatures and thermal bleaching
- **Human Impacts:** Area is heavily fished using pole and line and spearguns

#### **North Bay Reef, Windward Coast – *In situ* Nursery Site**

- **Relevance to Restoration Goal:** Reef crest and reef flat provide coastal protection for nursery site that will supply corals for outplanting to restoration site
- **Potential to Improve Condition:** Not applicable: site will serve as a nursery that supplies corals for improvement of condition at the restoration site
- **Future Exposure:** Experiences large waves, but intact reef crest and wide reef flat dampen wave energy that wraps around the reef and enters the bay



- **Ecological Resilience and Processes:** Corals experience high variability in temperature, turbidity, and sometimes salinity due to watershed and adjacent estuarine environments, which helps acclimatize corals and make them more resilient to perturbations; corals at this site have had limited bleaching, and corals that were bleached recovered



A diver monitors coral bleaching. Credit: Margaux Hein.

- **Human Impacts:** There are some recreational uses including picnicking and fishing at the beach park adjacent to reef; a primary impact to the reef is intermittent soil runoff and sedimentation from the adjacent watershed, which is exacerbated by invasive plants and ungulates

### ***Rationale for Site Selection***

The rationale behind selecting these sites as the highest priority includes:

Fisher's Reef has the highest potential for restoration to stabilize/improve coral cover and structure that has been lost primarily from recent bleaching events. The reef area is important for recreational and subsistence fishing, as well as coastal protection.

North Bay Reef was identified as an *in situ* nursery site. Corals at this site have had limited bleaching, and corals that were bleached recovered. The reef area is important because it is adjacent to an embayment with estuarine habitat that serves as a nursery ground for fish, as well as coastal protection. Corals experience variable environmental conditions, which helps acclimatize corals and make them more resilient to perturbations.

### ***Ongoing Management***

The management actions and regulations already in place at these sites are:

While some overfishing occurs at Fisher's Reef, especially of herbivores, new herbivore regulations are being established.

North Bay Reef has some soil runoff to nearshore waters, but the runoff is mostly transported south and dissipated. Watershed management to reduce soil erosion is being implemented.

## Restoration Interventions

Below is a description of the planned climate-smart restoration interventions at each priority restoration site:

Site #2, Fisher's Reef – Restoration Site

Site #3, North Bay Reef – Nursery Site

**Selected Intervention(s):** After evaluating a full array of options, it was determined that a hybrid green-gray restoration intervention would be needed to achieve the goal within 15 years. This intervention includes asexual propagation of structure-building corals in a field nursery and outplanting onto existing reef structure and wave attenuation units (WAUs). Sea urchins raised in a land-based nursery will be outplanted to both prepare and maintain the site against algal overgrowth. In addition, due to the potential for overfishing, especially of herbivorous fish, the project will pursue other herbivore management interventions such as place-based protection (e.g., herbivore replenishment areas), fishing gear restrictions and size limits, and other new regulations. This green-gray restoration intervention will focus on Fisher's Reef. The North Bay Reef site will be used as a nursery for *in situ* coral propagation.

**Propagation.** Structure-building corals will be propagated in the field nursery. Branching coral *Pocillopora meandrina* and boulder coral *Porites lobata* will be used because they will create the most friction on the reef flat while also being more resistant to bleaching and robust against high wave energy. Coral fragments will be obtained from sites outside the restoration site that have sufficient numbers for collection. Corals will be collected from sites that have experienced past bleaching events such that corals are more likely acclimatized or have genes for increased stress tolerance. A nursery site suitability study identified North Bay Reef as not only a source of corals but also a suitable site for a field nursery. Coral fragments will be collected from “corals of opportunity” that are already broken, or as small fragments harvested from intact donor colonies. Fragments will be collected from at least 5 m apart to maximize the likelihood of including as many genotypes as possible. Corals showing indications of disease or stress will be avoided. Asexual fragmentation will be followed by grow-out in two field nurseries along the windward coast. In addition to North Bay Reef, another field nursery will be planned and established to reduce the risk of loss from unanticipated events at a single site. Branching coral fragments will be attached directly to coral trees for propagation using CoralClips [27]. Fragments of boulder corals will be epoxied to plates and attached to the coral tree. The coral tree propagation method will enable corals to be vertically adjusted or shaded as needed for acclimatization and lowered in case of storms. The field nursery is exposed to a range of temperatures, water quality conditions, and wave energy, which is expected to engender more resilient corals for outplanting.



A coral tree nursery in the Commonwealth of the Northern Mariana Islands. Credit: Pheona David, Division of Coastal Resources Management, CNMI.

**Outplanting Techniques.** Propagated branching and boulder coral fragments will be outplanted on existing reef structure and WAUs using the best available techniques (e.g., CoralClips and epoxy) for which multiple options will be field-tested during the pilot phase. Adjustments will be made in the event



A diver works with outplanted corals in Guam. Credit: Whitney Hoot, Guam Coral Reef Initiative.

of high failure rates to ensure that the outplanted corals withstand existing and future wave conditions and sea level rise.

WAUs will incorporate biologically friendly materials, such as pH-neutral concrete or lightweight concrete with an organic matter matrix to accelerate biological colonization. WAU stabilization will be enhanced with the installation of scour blankets to reduce potential scouring effects. Multiple technical guidance documents [21, 28] and expertise will be consulted to identify WAU prototypes for pilot testing to evaluate their propensity to support natural recruitment, withstand severe wave events, and improve fish habitat as a co-benefit of the restoration intervention.

**Outplanting Configuration.** The number and configuration of WAUs will be based on the results of wave modeling using programs such as XBeach, SWAN, and Delft3D [5, 11, 29]. These programs are typically appropriate for the scale of most reef projects to determine optimal siting and alignment of WAUs along the width and length of the site in areas with the greatest potential to minimize erosion along the shoreline under existing and future conditions, including sea level rise and increasingly severe storm events. The configuration of corals outplanted to existing reef areas will be based on both the configuration of WAUs determined through wave modeling and baseline studies of coral



An artificial reef structure colonized by corals. Credit: Boze Hancock.

demography and reef structure. Corals will be outplanted on the reef flat in areas of the site where additional structural complexity could prove beneficial to wave energy reduction and in multiple locations and at different depths within the site to account for sea level rise and spread the risk of impacts from potential bleaching events. A rapid response plan will be created for repair or replacement of structures after storms.

**Site Preparation and Maintenance.** Removal of macroalgae by hand or mechanical means may be required at the nursery site to protect propagated corals and at the restoration site to protect coral outplants and recruits. Algae removal frequency may have to be increased if rising ocean temperatures and/or increased nutrient

inputs increase algal growth in the future. Sea urchins will be outplanted at appropriate densities to the restoration site from an existing land-based laboratory that is resistant to hurricane force winds and has a back-up power generator. Natural urchin species and densities will first be assessed on other reefs to determine how many urchins are needed to support algae removal at the restoration site. A rapid response plan will be put into place for replenishment of urchins lost at high rates due to factors such as disease, predation, and temperature extremes. Other herbivore management efforts, such as place-based protection, gear restrictions, and size limits, will be pursued to diversify herbivore biomass at the restoration site; this will help address uncertainty in impacts of climate change on urchins and other herbivores and the macroalgae they consume. Different functional groups of herbivorous fish (e.g., scarids, acanthurids, kyphosids) will be needed to support reef growth and recruitment.



Hatchery-raised urchins on a reef in Hawaii. Credit: Kyle Rothenborg, Hawaii.



## Objectives and Performance Metrics

The specific objectives and performance metrics that will be used to assess project progress are as follows.

**Objective 1:** Within 5 years, 250 fragments each of branching coral *Pocillopora meandrina* and boulder coral *Porites lobata* have been preconditioned in a field nursery and outplanted with 50% survival on existing reef structure and WAU prototypes to demonstrate proof of concept.

- Number of WAU prototypes created and deployed at Fisher's Reef (Site 2)
- Number and % survival of corals propagated in nurseries (Site 3) and outplanted on WAU prototypes (Site 2)
- Number and density of urchins outplanted at Fisher's Reef
- Number of corals recruited on WAU prototypes
- Universal metrics [12]:
  - Monthly minimum, maximum, and mean temperature (nursery and outplanting sites)
  - Restored reef areal dimension: outplant plot and ecological footprint (baseline)
  - Population metrics: mean coral size, abundance, size-frequency distribution (baseline)
- Monthly minimum, maximum, and mean total suspended solids, salinity, and temperature (Site 3) [12]



An outplanted coral in Guam. Credit: Whitney Hoot, Guam Coral Reef Initiative.

**Objective 2:** Within 3 years, the wave energy reduction goal and outplanting configuration needed to achieve that goal are determined via models, and the results peer-reviewed.

- Baseline physical characteristics of the restoration site established, including wave energy, bathymetry, geology, geotechnical conditions, and wave climate
- Modeling of the existing and proposed reef configuration for different wave energy reduction goals completed
- Wave energy reduction goal and WAU configuration established for the restoration site

**Objective 3:** Within 10 years, wave energy is reduced by 50%, and restored reef areal dimension expands naturally by an additional 30% after reef restoration.

Long-term monitoring and evaluation plan will include universal metrics and goal-specific metrics [12]:

- Restored reef areal dimension: outplant plot and ecological footprint
- Population metrics: mean coral size, height, abundance, size-frequency distribution
- Reef structure and complexity: Mean height of corals and reef structure at a restoration site
- Reduced wave energy



Waves break on an artificial reef structure. Credit: Steve Schill, The Nature Conservancy.

*The percent reduction in wave energy, measured as a function of wave height, will be determined as the ratio of the wave energy landward of the restored reef to the wave energy on the seaward side. Bottom mounted pressure sensors or wave buoys will be used for short periods of time to measure the wave height and period. Estimated wave energy reduction goals for the restored reef will be reviewed and validated based on modeling:*

- 25% reduction in wave energy 5 years after reef restoration
- 50% reduction in wave energy 10 years after reef restoration

**Objective 4:** Within 15 years, wave energy is reduced by 90%, the restored reef areal dimension is maintained, and natural reef build-up continues after reef restoration.

Long-term monitoring and evaluation plan will include universal metrics and goal-specific metrics [12]:

- Restored reef areal dimension: outplant plot and ecological footprint
- Population metrics: mean coral size, height, abundance, size-frequency distribution
- Reef structure and complexity: Mean height of corals and reef structure at a restoration site
- Reduced wave energy

*The percent reduction in wave energy, measured as a function of wave height, will be determined as the ratio of the wave energy landward of the restored reef to the wave energy on the seaward side. Bottom mounted pressure sensors or wave buoys will be used for short periods of time to measure the wave height and period. Estimated wave energy reduction goals will be reviewed and validated based on modeling:*

- 90% reduction in wave energy within 15 years of reef restoration

## Activities and Implementation Timeframe

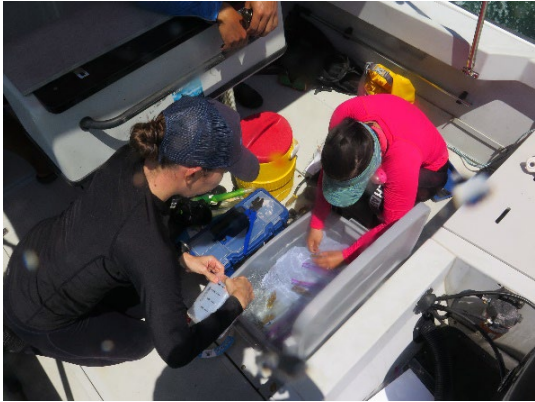
**Restoration Goal:** Within 15 years, restored reef structure reduces wave energy that contributes to coastal erosion, thereby strengthening the resilience of coastal communities to sea level rise and increasingly intense storms.

**Objective 1:** Within 5 years, 250 fragments each of branching coral *Pocillopora meandrina* and boulder coral *Porites lobata* have been preconditioned in a field nursery and outplanted with 50% survival on existing reef structure and WAU prototypes to demonstrate proof of concept.

### Performance Metrics:

- Number of WAU prototypes created and deployed at Fisher's Reef (Site 2)
- Number and % survival of corals propagated in nurseries (Site 3) and outplanted on WAU prototypes and existing reef structure (Site 2)
- Number and density of urchins outplanted at Fisher's Reef
- Number of corals recruited on WAU prototypes
- Universal Metrics [12]:
  - Monthly minimum, maximum, and mean temperature (nursery and outplanting sites)
  - Restored reef areal dimension: outplant plot and ecological footprint (baseline)
  - Population metrics: mean coral size, abundance, size-frequency distribution (baseline)
- Monthly minimum, maximum, and mean total suspended solids, salinity, and temperature (nursery site)

| Activities |                                                                                                                                                                                                                                                                                                      | Timeframe  |
|------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| 1.1        | Establish a Coral Propagation and Outplanting Pilot Study Working Group with a lead and experts in coral ecology, biology, and artificial reef structures, such as coastal engineers, to develop a detailed design and work plan for the pilot phase that includes implementation of the pilot phase | Year 1 – 5 |
| 1.2        | For restoration sites, conduct baseline survey of population metrics (mean coral size, abundance, size-frequency distribution)                                                                                                                                                                       | Year 1     |
| 1.3        | Establish location, number, configuration, and size of outplant plots for pilot studies                                                                                                                                                                                                              | Year 1     |
| 1.4        | Monitor temperature and water quality at the restoration site as well as the field nursery to document the pre-conditioning environment                                                                                                                                                              | Year 1 – 5 |
| 1.5        | Develop propagation and outplanting protocols                                                                                                                                                                                                                                                        | Year 1     |
| 1.6        | Obtain permits for field activities                                                                                                                                                                                                                                                                  | Year 1     |
| 1.7        | Outplant sea urchins from land-based nursery and monitor survival                                                                                                                                                                                                                                    | Year 2     |

|                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                            |                  |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|
| 1.8                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Establish <i>in situ</i> nursery and develop and test propagation protocol                                                                                                                                                                                                                                                                                                                                 | Year 1 – 2       |
| 1.9                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Develop and test WAU prototypes with and without outplanted corals                                                                                                                                                                                                                                                                                                                                         | Year 2 – 3       |
| 1.10                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Outplant corals and monitor coral outplant survival                                                                                                                                                                                                                                                                                                                                                        | Year 3 – 5       |
| 1.11                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <p>Conduct peer review of the pilot study and make any adjustments in coral species, propagation and outplanting techniques, and WAU designs based on Activity 2.7</p> <p>Scientists prepare coral fragments for attachment to nursery trees. Credit: Pheona David, Division of Coastal Resources Management, CNMI.</p>  | Year 5           |
| <b>Objective 2:</b> Within 3 years, the wave energy reduction goal and outplanting configuration needed to achieve that goal are determined via models, and the results peer-reviewed.                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                            |                  |
| <b>Performance Metrics:</b> <ul style="list-style-type: none"> <li>Baseline physical characteristics of the restoration site documented including wave energy, bathymetry, geology, geotechnical conditions, and wave climate</li> <li>Modeling of the existing and proposed reef configuration for different wave energy reduction goals completed</li> <li>Wave energy reduction goal and WAU configuration established for the restoration site</li> </ul> |                                                                                                                                                                                                                                                                                                                                                                                                            |                  |
| <b>Activities</b>                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                            | <b>Timeframe</b> |
| 2.1                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Establish a Coastal Processes Pilot Study Working Group with relevant experts to create a detailed work plan                                                                                                                                                                                                                                                                                               | Year 1 – 3       |
| 2.2                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Prepare detailed work plan to develop model wave energy reduction scenarios for outplanting corals on existing structures and WAUs                                                                                                                                                                                                                                                                         | Year 2           |
| 2.3                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Conduct baseline mapping of reef geometry at the restoration site (e.g., height, structural complexity) using the best available technology such as high resolution airborne topo/bathymetric LiDAR or UAV imagery                                                                                                                                                                                         | Year 1 – 2       |
| 2.4                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Conduct baseline monitoring of wave energy across the restoration site using instrumentation (e.g., bottom-mounted pressure sensors or wave buoys) and methods that can be repeated over time                                                                                                                                                                                                              | Year 1 – 2       |
| 2.5                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Conduct hydrodynamic modeling to simulate different configurations and combinations of coral outplants and WAUs to establish feasible wave energy reduction goals for restoration                                                                                                                                                                                                                          | Year 2           |
| 2.6                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Develop and test WAU prototypes with and without outplanted corals                                                                                                                                                                                                                                                                                                                                         | Year 2 – 3       |
| 2.7                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Conduct peer review of the results of the modeling and make any adjustments to outplanting configurations and WAU designs                                                                                                                                                                                                                                                                                  | Year 4           |
| <b>Objective 3:</b> Within 10 years, wave energy is reduced by 50%, and restored reef areal dimension expands naturally by an additional 30% after reef restoration.                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                            |                  |
| <b>Performance Metrics:</b> Long-term monitoring and evaluation plan will include universal metrics and goal-specific metrics [12]: <ul style="list-style-type: none"> <li>Restored reef areal dimension: outplant plot and ecological footprint</li> </ul>                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                            |                  |

- Population metrics: mean coral size, height, abundance, size-frequency distribution
- Reef structure and complexity: mean height of corals and reef structure at a restoration site
- Reduced wave energy: *The percent reduction in wave energy, measured as a function of wave height, will be determined as the ratio of the wave energy landward of the restored reef to the wave energy on the seaward side. Bottom mounted pressure sensors or wave buoys will be used for short periods of time to measure the wave heights. Wave energy is measured by wave height and period. Estimated wave energy reduction goals will be reviewed and validated based on baseline assessment and modeling conducted under Objective 2:*
  - 25% reduction in wave energy 5 years after reef restoration
  - 50% reduction in wave energy 10 years after reef restoration



A researcher collects monitoring data on a reef in American Samoa. Credit: Valentine Vaeoso, American Samoa.

| Activities                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                | Timeframe         |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|
| 3.1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Review and refine the Restoration Action Plan, adjusting SMART objectives and metrics and activities as needed based on results of pilot phases                                                | Year 5            |
| 3.2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Refine propagation and outplanting protocol and schedule                                                                                                                                       | Year 5            |
| 3.3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Develop long-term restoration monitoring and evaluation plan                                                                                                                                   | Year 5            |
| 3.4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Update existing or obtain new permits for field activities                                                                                                                                     | Year 5            |
| 3.5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Scale-up nursery operations                                                                                                                                                                    | Year 6 – ongoing  |
| 3.6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Scale-up outplanting operations                                                                                                                                                                | Year 6 – ongoing  |
| 3.7                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Monitor reef geometry at the restoration site (e.g., height, structural complexity) using baseline assessment methodology (see Activity 2.3) to compare to baseline images collected in Year 1 | Year 6, 8, and 10 |
| 3.8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Implement long-term restoration monitoring and evaluation plan                                                                                                                                 | Year 6 – ongoing  |
| 3.9                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Conduct peer review of restoration operations and results                                                                                                                                      | Bi-Annual         |
| <b>Objective 4:</b> Within 15 years, wave energy is reduced by 90%, the restored reef areal dimension is maintained, and natural reef build-up continues after reef restoration.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                |                   |
| <b>Performance Metrics:</b> Long-term monitoring and evaluation plan will include universal metrics and goal-specific metrics [12]: <ul style="list-style-type: none"> <li>• Restored reef areal dimension: outplant plot and ecological footprint</li> <li>• Population metrics: mean coral size, height, abundance, size-frequency distribution</li> <li>• Reef structure and complexity: mean height of corals and reef structure at a restoration site</li> <li>• Reduced wave energy: <i>The percent reduction in wave energy, measured as a function of wave height, will be determined as the ratio of the wave energy landward of the restored reef to the wave energy on the seaward side. Bottom mounted pressure sensors or wave buoys will be used for short periods of time to measure the wave height and period. Estimated wave energy reduction goals will be reviewed and validated based on baseline assessment and modeling conducted under Objective 2:</i> <ul style="list-style-type: none"> <li>○ 90% reduction in wave energy within 15 years of reef restoration</li> </ul> </li> </ul> |                                                                                                                                                                                                |                   |
| Activities                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                | Timeframe         |
| 4.1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Implement long-term restoration monitoring and evaluation plan                                                                                                                                 | Years 11 – 15     |
| 4.2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Maintain and replace damaged WAUs as needed after severe storm events                                                                                                                          | Years 11 – 15     |
| 4.3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Maintain outplanting activities to replace corals lost from severe storm events and bleaching                                                                                                  | Years 11 – 15     |
| 4.4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Maintain algae removal and urchin outplanting as needed                                                                                                                                        | Years 11 – 15     |



## Stakeholder Engagement and Outreach

The Ho'okohukohu 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 a combination of in-person and virtual. 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. In addition, two Pilot Study Working Groups will be established to conduct literature review and develop a detailed design of the pilot studies and modeling for Objectives 1 and 2. These groups will regularly meet and share information, progress, and insights on restoration design and implementation that will be used to update the Action Plan. The results of the pilot phase and modeling studies will be presented to communities and key stakeholder groups. Education and outreach activities will be conducted to foster and maintain support for coral restoration and herbivore management. Educational presentations and materials on the restoration project will be prepared and communicated to students, particularly in target communities.



A snorkeler dives under a breaking wave on the reef crest at Palmyra Atoll. Credit: Tim Calver.

# 3 GUIDE WORKBOOK FOR ACTION PLANNING

Note: The following completed Workbook is structured according to the Workbook Template provided in *A Manager’s Guide to Coral Reef Restoration Planning and Design* [1]. A fillable version of the template is available for download at: [https://www.coris.noaa.gov/activities/restoration\\_guide/welcome.html](https://www.coris.noaa.gov/activities/restoration_guide/welcome.html). Footnotes are used where explanation of case study context is needed. Some repetition of information occurs in the Workbook because it is an instrument for breaking a complex thought process into manageable pieces; as such, each step refines and builds upon information drawn from the previous step.

## STEP 1: SET GOAL AND GEOGRAPHIC FOCUS

### 1A. Identify and Prioritize Goals

*List and describe the priority goals for your management area. Summarize the process and decisions made in generating the list of goals.<sup>2</sup>*

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Priority restoration goals (in order of priority):</b></p> <ol style="list-style-type: none"><li>1. Recover coastal protection services (e.g., reduce coastal erosion, protect coastal infrastructure)</li><li>2. Recover fisheries productivity and habitat connectivity (e.g., restore fish habitat at different locations/depths)</li><li>3. Build capacity of technical and human resources (e.g., response protocols, nursery capacity, nursery manager, response team) to respond to acute disturbances (e.g., storms, ship strikes)</li><li>4. Support local tourism (e.g., economies, aesthetics)</li><li>5. Reestablish a self-sustaining reef system (e.g., focus on foundational species)</li><li>6. Recover or manage endangered species (e.g., restore rare coral species or corals on which endangered species depend)</li><li>7. Engage local communities to build reef stewardship (e.g., education, capacity building)</li></ol> |
| <p><b>Summary of Process:</b> The Core Planning Team initiated the goal setting process and developed an initial list of priority restoration goals. The Core Planning Team then conducted a virtual webinar with the Technical Advisory Group of experts and other stakeholders to vet the list and discuss prioritization. Through this process, the seven general goals were identified and prioritized.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

<sup>2</sup> During this brainstorming Step 1A, some jurisdictions detailed the rationale for each goal and began to indicate sites where each goal was most appropriate. This information can be helpful in Step 1B to identify the geographic focus for each goal and to define the management and biophysical context of these geographies. However, the identification of specific sites should not be determined too early in the process, and all potential sites should be evaluated in Step 2.

Rewrite your priority goals using the SMART (Specific, Measurable, Achievable, Relevant, Time-bound) approach. Summarize the key problems addressed by each goal and the process used to generate the details of these goals. We suggest working with up to three priority goals as a starting point.<sup>3</sup>

| SMART GOALS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Key problems addressed by this goal                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Goal 1:</b> Within 15 years, restored reef structure reduces wave energy that contributes to coastal erosion, thereby strengthening the resilience of coastal communities to sea level rise and increasingly intense storms.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | <ul style="list-style-type: none"> <li>• Coral reef structure has been lost due to coral bleaching and severe storm events, resulting in reduced wave attenuation that provides coastal protection services</li> <li>• Loss of coral reef structure results in coastal erosion and exposure to coastal flooding during storms, threatening critical infrastructure and residential properties and causing loss of beaches</li> <li>• Coastal erosion is exacerbated by shoreline armoring, sea level rise, and extreme storm events</li> </ul> |
| <b>Summary of Process:</b> Each priority restoration goal was refined to reflect specific, place-based problems that the goal is intended to address and medium to long-term desired ecological or social condition, including the level of recovery sought. The Core Planning Team and Technical Advisory Group met to identify three priority goals, and one goal was selected to move forward with planning. Priority goal 1 was selected and refined to address SMART criteria. The goal of coastal protection was made more specific by identifying the various issues that needed to be addressed by coral reef restoration. The goal is relevant to reef restoration priorities, focuses on a measurable parameter (reducing wave energy), and establishes a 15-year time horizon. This 15-year period was based on the current technical capacity for implementing pilot projects and likely need for studies to design the restoration intervention recognized by the Core Planning Team and Technical Advisory Group. The Core Planning Team acknowledged that the goal might be further refined later in the planning process or even through early stages of implementation when gaps in knowledge, such as the degree to which wave energy can be reduced, are filled. |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

## 1B. Identify Geographic Focus for Priority Goal

Describe and provide a labeled map of the geographic focus area(s) for each priority goal. Provide notes about the functionality and benefits, and management and biophysical context. Then, summarize the process used or experts consulted for this work.<sup>4</sup>

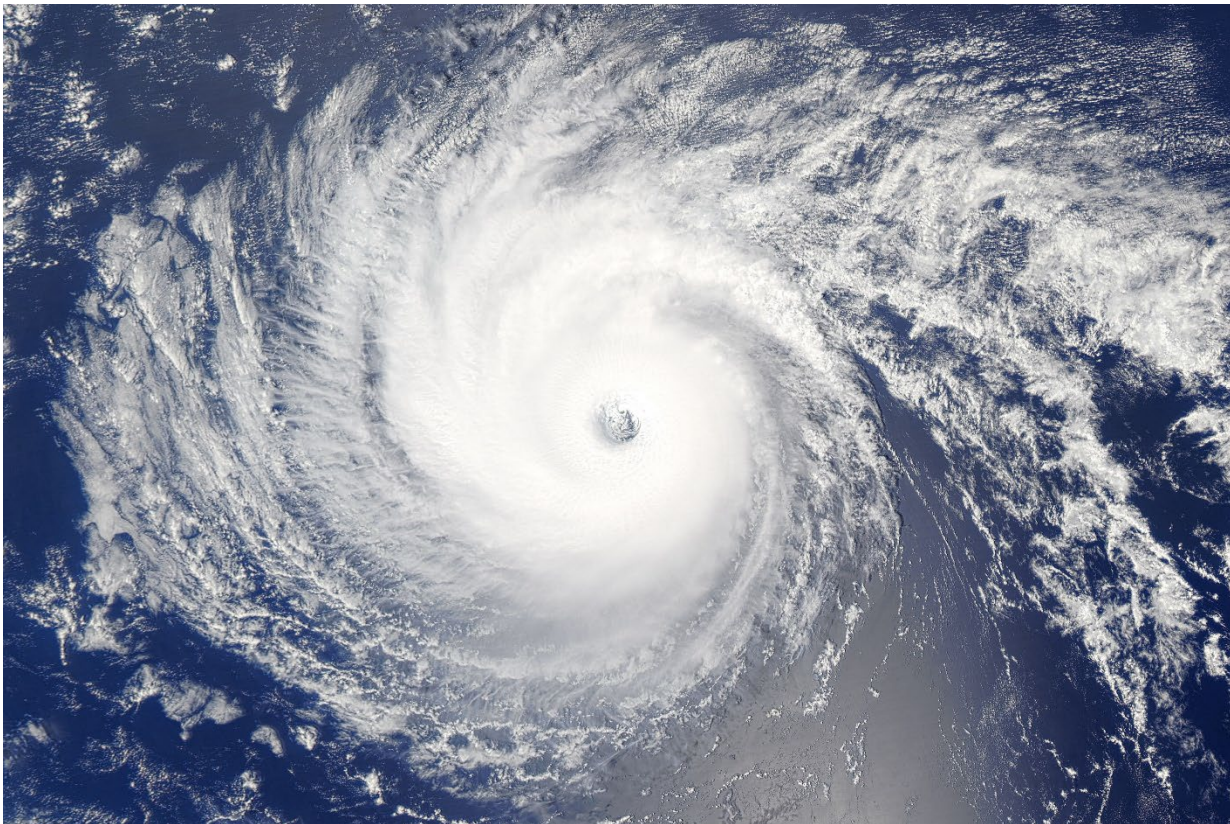
|                                                                                                                                                                                                                                                                                                                                                                                                                        |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Goal 1:</b> Within 15 years, restored reef structure reduces wave energy that contributes to coastal erosion, thereby strengthening the resilience of coastal communities to sea level rise and increasingly intense storms.                                                                                                                                                                                        |
| <b>Geographic Focus: Round 1 – Functionality and Benefits</b> <ul style="list-style-type: none"> <li>• What areas currently or in the recent past have performed functions that are relevant to the goal?</li> <li>• What areas are currently experiencing the problems that the goal seeks to address?</li> <li>• Within these areas, where could reef restoration provide social and ecological benefits?</li> </ul> |

<sup>3</sup> The Guide instructs the reader to retain approximately three goals until the selection of one priority goal in Step 1C. Goal 1- restoration of coastal protection services - was selected for this Workbook example; thus, for brevity, only the description of this priority goal (which usually would be selected in Step 1C) is shown here. Developing SMART Goals was one of the initial challenging tasks encountered by jurisdictional partners. As described in the Guide, a goal is a medium- to long-term statement that details the desired impact to achieve by conducting a restoration intervention. A common pitfall is to develop a goal statement that defines success as a pilot project or building capacity to conduct restoration. As you will see in this example in Step 4, objectives are crafted under the goal to define the specific outcomes of these types of activities.

<sup>4</sup> Geographic focus areas are large areas where multiple potential restoration sites may be located. It is important at this stage to identify geographic focus areas for each goal and describe the management and biophysical context from a larger landscape and seascape perspective. Also note that only one priority goal has been fully developed for this Workbook Example. You would repeat this process for each of your priority goals (up to 3).



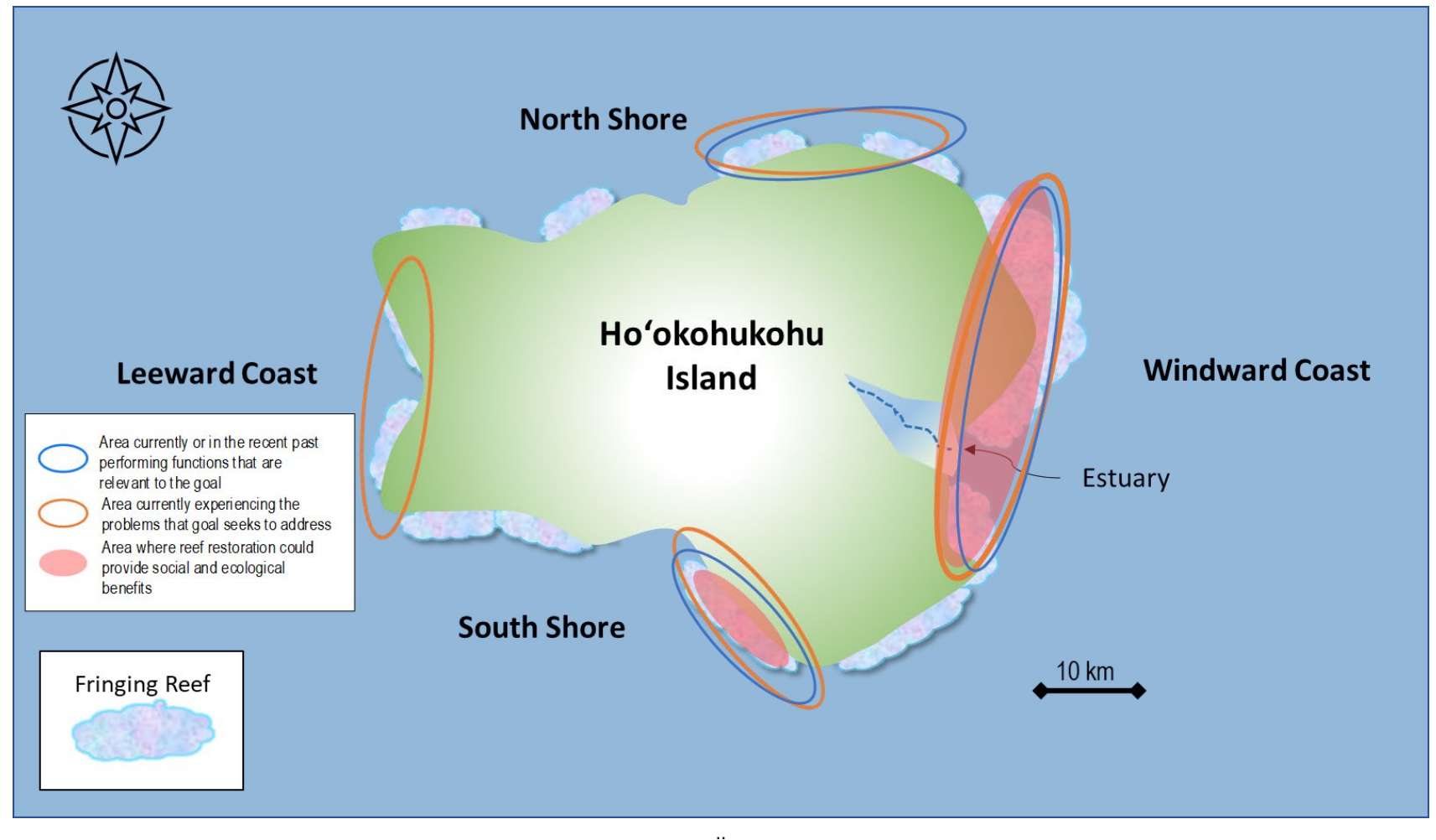
|                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|--------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>1) What areas currently or in the recent past have performed functions that are relevant to the goal?</b> | The windward coast and south shore have historically provided the greatest coastal protection services around the island. The reef crest and wide reef flat along the windward coast provide protection from annual high wave events and storms. The leeward coast is characterized by a narrower reef flat that is closer to the shoreline and an extensive forereef that gradually extends to depth of 30 m before dropping off to great depths.                                                                                         |
| <b>2) What areas are currently experiencing the problems that the goal seeks to address?</b>                 | All shorelines around the island are experiencing coastal erosion during annual large wave events, King Tide events, and tropical storms exacerbated by sea level rise. Projected future erosion rates are accelerating, with an intermediate-high scenario of four feet of sea level rise by 2075. The south shore is particularly exposed to large waves and coastal flooding from tropical cyclones. The north shore is a high wave energy environment resulting from seasonal extratropical storms.                                    |
| <b>3) Within these areas, where could reef restoration provide social and ecological benefits?</b>           | The windward coast has a coastal highway that connects the northern and southern portions of the island, which is used by both residents and tourists alike. Recreational and subsistence fishing provide important benefits to the community. Reefs and adjacent estuarine environments provide fish habitat and serve as nursery grounds for fish species that are important for recreational and subsistence use. The south shore is the economic engine for the island and is where the majority of tourism infrastructure is located. |



Tropical cyclones affect coral reefs throughout the Pacific. Credit: National Aeronautics and Space Administration.

## GEOGRAPHIC FOCUS AREAS

**Description and Map.** Two geographic focus areas along the eastern and southern shorelines of the island were identified as most relevant to the goal. These areas were identified because coral reefs have historically provided coastal protection services to key public and private infrastructure in these areas. Both areas are experiencing coastal erosion that is threatening the coastal highway and residential areas (windward coast) and tourism infrastructure (south shore). Bleaching and storm events have resulted in coral loss in recent years. Increased storm activity and sea level rise are growing concerns as portions of shoreline are eroding, especially along the eastern shoreline.




*Geographic Focus: Round 2 - Management and Biophysical Context*

- *What are the greatest management challenges in each area for achieving the restoration goal?*
- *What is the biophysical context in which these challenges will need to be addressed?*
- *What is the likelihood of overcoming these challenges? What are unique opportunities?*

| Context                                                                                                                                                                  | Windward Coast                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | South Shore                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Management Context</b>                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>• Land-based pollution</li> <li>• Overfishing</li> <li>• Tourism Overuse</li> <li>• Government Policies &amp; Programs</li> </ul> | <p>The windward (east) coast is mostly rural and dominated by residential and recreational uses; the coastal highway is an important scenic drive for tourists as well as a lifeline for residents.</p> <p>Sediment runoff during heavy rainfall events in upland areas contributes to degraded water quality in some locations along the coast. Invasive plant and animal species in upland areas contribute to soil erosion. Watershed management plans for the area are being implemented to reduce soil runoff to nearshore waters. The local government is leading the implementation of the watershed management plan together with nongovernmental partners. Funding is a key challenge for addressing these impacts.</p> <p>Subsistence and recreational pole and line fishing occurs from the shoreline. Overfishing of herbivorous fish species on the reef flat from spearfishing has resulted in algal overgrowth in many reef areas. Nighttime spearfishing targets overfished scarids (parrotfish) that are important for maintaining reef substrate free of macroalgal overgrowth for natural coral recruitment. Regulations to protect herbivorous fish species from overfishing are weak, and enforcement is absent. Government is proposing new rules to protect herbivorous fish; however, greater education and outreach are needed to gain support from fishers. The establishment of community watch groups is needed to encourage voluntary compliance with existing and new regulations.</p> <p>The impacts of tourism on reef structure are minimal along this coast, except in one location along the southern portion of the coast in an area heavily frequented by snorkelers. More education and outreach are needed to reduce impacts of snorkelers on coral reefs.</p> | <p>The south shore is highly urbanized and dominated by tourism development and use.</p> <p>Land-based runoff from roads and other impermeable surfaces enters nearshore waters from storm drains. Shoreline hardening, such as the construction of seawalls and revetments, is increasing due to increasing coastal erosion and limited government policies and regulations. Coastal erosion exacerbated by sea level rise is putting greater pressure on regulators to maintain or expand shoreline hardening in urbanized areas. Government recently amended coastal zone management rules, prohibiting any future use of seawalls and revetments.</p> <p>Place-based restrictions on fishing are in place through a marine managed area, but the small size and open and closed seasons have been found to be largely ineffective at protecting corals or enabling spillover of fish to adjacent waters. Fishers are not in favor of changing to permanent fishing restrictions for this marine managed area.</p> <p>Tourism impacts on reef structure are somewhat mitigated due to the presence of a marine managed area; however, greater education and outreach are needed to minimize the impacts of snorkelers.</p> |



| Context                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Windward Coast                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | South Shore                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Biophysical Context</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <ul style="list-style-type: none"> <li>• Oceanographic processes</li> <li>• Geomorphology</li> <li>• Ecological connectivity</li> <li>• Watersheds and hydrology</li> <li>• Ocean temperature, bleaching &amp; disease</li> <li>• Ocean acidification</li> <li>• Sea level rise</li> <li>• Storm surge &amp; runoff</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                         | <p>The windward (east) coast is dominated by trade wind conditions. Annual high waves generate substantial wave energy that is largely attenuated by the reef crest and reef flat.</p> <p>Sand dunes and marine deposits that accumulated on land during previous geologic periods could support landward beach migration with sea level rise.</p> <p>The reef crest and wide reef flats provide protection for the coastal road and homes along the shoreline despite the emergence of hardened structures, such as highway and residential areas, which impede the adaptive capacity of the area for natural shoreline retreat with sea level rise.</p> <p>Reef flats serve as nurseries for fish that also populate adjacent reef flats and deeper reefs outside the reef crest.</p> <p>Multiple watersheds exist along the coast, contributing to runoff to the ocean. One watershed has an estuarine environment that empties into a bay.</p> <p>Bleaching events have occurred. Some species have recovered. No area-specific information on the long-term regional increase in ocean acidification is available.</p> | <p>The south shore has more variable winds. Annual high waves generate wave energy that is attenuated somewhat by the fore reef. This side of the island is subject to large wave events from tropical cyclones.</p> <p>Narrow reef flats provide some coastal protection from wave events. The fore reef extends to depths of 30 m on a gradually sloping carbonate surface before dropping off to great depths at the edge of the insular shelf.</p> <p>Watersheds are highly urbanized, with runoff channelized and/or part of a storm drain system.</p> <p>Recent bleaching events have resulted in massive die-offs of corals. No area-specific information on the long-term regional increase in ocean acidification is available.</p> |
| <p><b>Summary of Process:</b> Members of the Core Planning Team, together with the Technical Advisory Group and other experts, held a one-day workshop to conduct the two-step process for identifying geographic focus areas for the priority goal. The participants were divided into three groups. During Round 1, each group identified geographic areas on maps using different color pens to address the questions about functionality and benefits. The results of Round 1 were discussed in a plenary session, and focus areas were further refined. In Round 2, participants provided information to describe the management and biophysical contexts of each focus area based on their areas of expertise and knowledge.</p> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <p>Waves break on a reef in American Samoa.<br/>Credit: Katie Nalasere, American Samoa.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |



## 1C. Select Goal and Geographic Focus for Restoration Planning and Design

*Describe the restoration goal your team selected to continue with for planning and design, as well as the final geographic focus area(s). Describe the process and rationale used to make this determination.*

**Goal 1:** Within 15 years, restored reef structure reduces wave energy that contributes to coastal erosion, thereby strengthening the resilience of coastal communities to sea level rise and increasingly intense storms.

**Geographic Focus:** The windward coast, a 30 km stretch of fringing reef, was selected as the geographic focus area for restoration under this goal. Coastal erosion is prevalent along the entire coast and increasing due to large wave events exacerbated by sea level rise, shoreline armoring, and loss of corals from bleaching and severe storm events. Coastal erosion is greater along the southern portion of the windward coast due to tourism and other development close to the water's edge. Annual high waves are known to flood residential areas and damage sections of the coastal highway. Coastal erosion along the northern portion of the windward coast is significantly impacting the coastal highway, which is the only connection between the north and south portions of the island. This highway is regularly flooded by annual high wave events and King Tides.

Reef substrate and conditions vary along the length of this area. Along the northern portion of the windward coast, the reef flat is wide and dominated by a hard substrate with lobate and digitate corals. Subsistence and recreational fishing are important activities along this portion of the area. Along the southern portion of the windward coast, the reef flat is characterized by loose and cemented rubble-dominated substrate.

All along the windward coast, land-based runoff to nearshore water is fairly well managed, although invasive plant and animal species contribute to upland soil erosion, especially in the middle of the windward coast where a large watershed and estuarine area meet the coast. Specific sites for restoration will be identified, evaluated, and selected from the windward coast in Step 2.

**Summary:** The Core Planning Team and Technical Advisory Group worked together to identify priority goals and describe the management and biophysical context for each geographic focus area. The Core Planning Team then integrated information from stakeholder dialogues. Goal 1 and the windward coast focus area were prioritized for planning and design efforts based on these inputs and considering the potential for co-benefits. Restoration interventions designed to address Goal 1 have the potential to also contribute to *Goal 2, recover fisheries productivity and habitat connectivity* and *Goal 3, build technical and human resource capacity to respond to acute disturbances (e.g., storms, ship strikes)*, providing an opportunity to achieve multiple benefits.



### Step 1 Stakeholder Engagement

*List technical experts, stakeholders, and partners including scientists, engineers, community members, private sector, and federal and local governments engaged to review and prioritize restoration goals and geographic focus area(s) for this step.*

| Technical Expertise                                                                                                                                                                                                   | Key Stakeholders                                                                                                                                                                                                                                                                                            |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Coral reef biologist/coral ecologist<br>Coastal engineer<br>Coastal geologist/sedimentologist<br>Physical oceanographer<br>Modelers<br>Climate scientist<br>Watershed manager<br>Social scientist<br>Land use planner | <b>Non-Government</b><br>Residents impacted by chronic coastal erosion<br>Fishing community<br>Tourism industry representatives<br>Communities located along the windward coast<br>Representatives of environmental advocacy groups<br><b>Government</b><br>Regulatory Agencies (federal, state, and local) |

Provide a summary of stakeholder engagement activities taken for this step.

The Core Planning Team conducted extensive dialogues with community stakeholders to identify priority goals and geographic focus areas as part of Step 1. Additional outreach was conducted to communicate decisions and rationale for the selection of the priority goal and geographic focus area for restoration. In addition, in preparation for site selection (Step 2), focus group meetings, public meetings, and informal discussions were held with appropriate stakeholders to identify any sites within the geographic focus areas with possible natural and/or cultural resource considerations or recreational boating safety issues.

## STEP 2: IDENTIFY, PRIORTIZE, AND SELECT SITES

### 2A. Identify Potential Restoration Sites

List restoration sites within the selected geographic focus being considered for restoration. Document their location and provide a brief rationale for why the site was selected. Alternately, GIS software can be used to set a grid over the geographic focus area(s), and your team can determine the reef habitat cell/area size and make a map showing the gridded area and describing the number of grid cells.<sup>5</sup>

| Site Name/<br>Coordinates <sup>6</sup> | Site<br>Dimensions <sup>7</sup>                   | Rationale <sup>8</sup>                                                                                                                |                                                                                                                                                   |                                                                                                                                                                                                                               |
|----------------------------------------|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                        |                                                   | Management in Effect<br>Causes of reef degradation have been identified and are under effective management (now or in the future)     | Reef Value is High<br>Reef provides important ecosystem services that offer multiple benefits in addition to the goal, or has high cultural value | Data Are or Can Become Available <sup>9</sup><br>Long-term (at least 10 years) monitoring takes place, data and information on the site are available or accessible, or plans and resources are available to collect new data |
| 1 – North Point Reef                   | Width: 0.2 km<br>Length: 0.5 km<br>Depth: 2 – 5 m | Some human impacts on soil erosion from foot traffic to reach surf spots.                                                             | Reef area is important for kayaking and surfing during certain wave conditions, as well as coastal protection.                                    | Data availability limited, based on observations by stakeholders.                                                                                                                                                             |
| 2 – Fisher's Reef                      | Width: 0.5 km<br>Length: 1 km<br>Depth: 2 – 5 m   | Some overfishing occurs, especially of herbivores. New herbivore regulations are being established. Efforts to clean up marine debris | Reef area is important for recreational and subsistence fishing, as well as coastal protection.                                                   | Data available; creel surveys have been conducted.                                                                                                                                                                            |

<sup>5</sup> The Core Planning Team met to identify potential restoration sites in the geographic focus area.

<sup>6</sup> No coordinates are available as these are fictitious locations.

<sup>7</sup> For this hypothetical example, the workbook was modified to include approximate site dimensions instead of coordinates. In fact, it is recommended that site dimensions be included to support Step 4 of the planning process where SMART objectives and performance metrics are identified and scaled for the site.

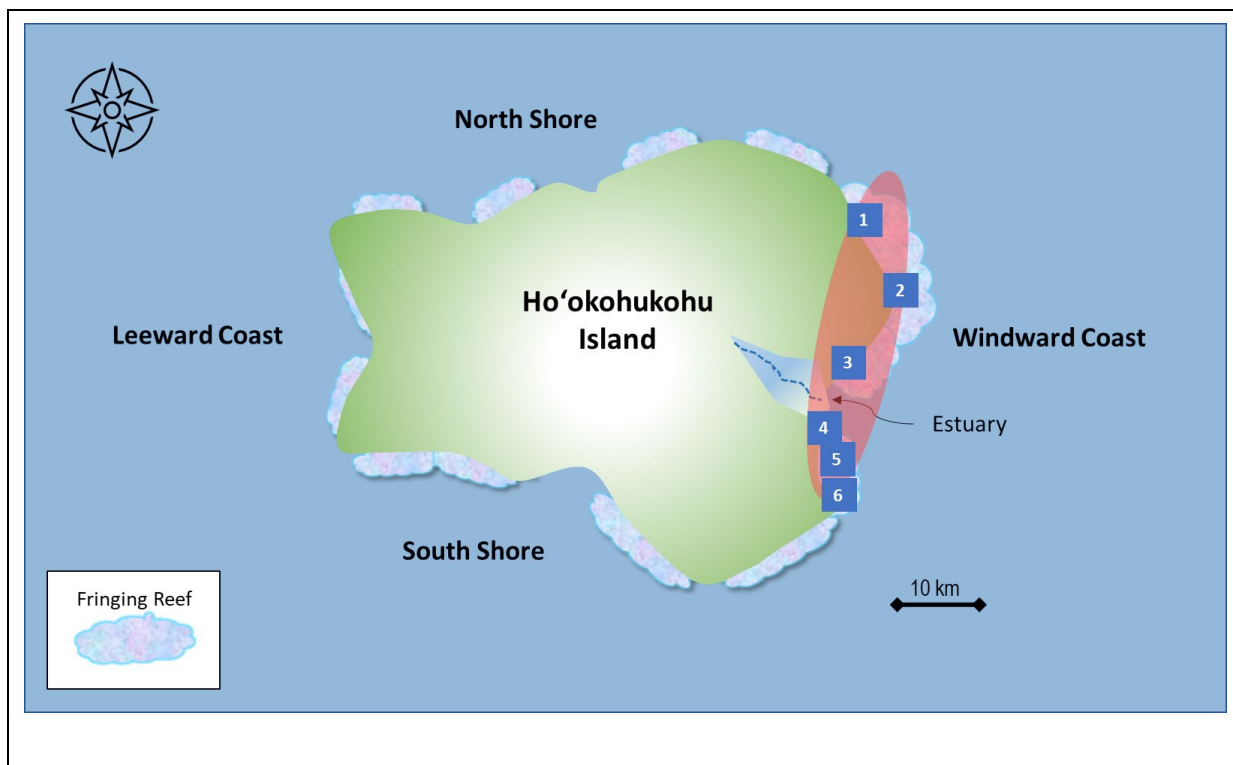
<sup>8</sup> In the Guide, these three components of rationale are recommended for consideration in selected sites in the geographic focus area. For this hypothetical example, the workbook was modified to add columns for each rationale to facilitate this review.

<sup>9</sup> Information in this column was derived from the analysis conducted in the subsequent Step 2B.

| Site Name/<br>Coordinates <sup>6</sup> | Site<br>Dimensions <sup>7</sup>                   | Rationale <sup>8</sup>                                                                                                                                              |                                                                                                                                                          |                                                                                                                                                                                                                                     |
|----------------------------------------|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                        |                                                   | <b>Management in Effect</b><br>Causes of reef degradation have been identified and are under effective management (now or in the future)                            | <b>Reef Value is High</b><br>Reef provides important ecosystem services that offer multiple benefits in addition to the goal, or has high cultural value | <b>Data Are or Can Become Available<sup>9</sup></b><br>Long-term (at least 10 years) monitoring takes place, data and information on the site are available or accessible, or plans and resources are available to collect new data |
|                                        |                                                   | and reduce physical impacts of destructive fishing practices is needed.                                                                                             |                                                                                                                                                          |                                                                                                                                                                                                                                     |
| 3 – North Bay Reef                     | Width: 0.5 km<br>Length: 0.5 km<br>Depth: 2 – 5 m | There is some soil runoff to nearshore waters, but it is mostly transported south and dissipated. Watershed management to reduce soil erosion is being implemented. | Reef area is important for being adjacent to embayment with estuarine habitat that serves as a nursery ground for fish, as well as coastal protection.   | Data available from monthly water quality monitoring data. A rainfall gauge is located in the upper watershed.                                                                                                                      |
| 4 – South Bay Reef                     | Width: 0.5 km<br>Length: 0.5 km<br>Depth: 2 – 5 m | Soil runoff to nearshore waters occurs. Watershed management to reduce soil erosion is being implemented.                                                           | Reef area is important for being adjacent to embayment with estuarine habitat that serves as a nursery ground for fish, as well as coastal protection.   | Data available from monthly water quality monitoring data. A rainfall gauge is located in the upper watershed.                                                                                                                      |
| 5 – Snorkeler's Cove                   | Width: 0.5 km<br>Length: 1 km<br>Depth: 2 – 5 m   | Efforts to clean up marine debris and reduce physical impacts from snorkelers are underway.                                                                         | Reef area serves as a snorkeling and recreational area for residents and tourists, as well as coastal protection.                                        | Data available; recreational use surveys have quantified level of use for snorkeling and observations of physical impacts.                                                                                                          |
| 6 – South Point Reef                   | Width: 0.2 km<br>Length: 0.5 km<br>Depth: 2 – 5 m | Some human impacts on soil erosion from foot traffic to reach surf spots.                                                                                           | Reef area is important for kayaking and surfing during certain wave conditions, as well as coastal protection.                                           | Data availability limited, based on observations by stakeholders.                                                                                                                                                                   |



Reefs serve as nursery grounds for fish.  
Credit: Susan White, U.S. Fish & Wildlife Service. Public domain.



## 2B. Use Framework to Prioritize Sites

List available datasets applicable to each part of the prioritization framework. Document any data or information that are missing or need to be collected.<sup>10</sup>

| Framework Part                                                                                                             | Available Datasets                            | Sites |   |   |   |   |   |
|----------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|-------|---|---|---|---|---|
|                                                                                                                            |                                               | 1     | 2 | 3 | 4 | 5 | 6 |
| <b>Relevance to Restoration Goal:</b><br><i>To what extent would restoration at the site help to achieve the set goal?</i> | Historical shoreline flooding and erosion     |       | • | • | • | • |   |
|                                                                                                                            | Reef bathymetry and rugosity                  |       | • | • | • | • |   |
|                                                                                                                            | Nearshore circulation patterns                |       | • | • | • | • |   |
|                                                                                                                            | Offshore wave climate/significant wave height | •     | • | • | • | • | • |
|                                                                                                                            | Sea level rise projections                    | •     | • | • | • | • | • |
|                                                                                                                            | Habitat mapping                               |       | • | • | • | • |   |

<sup>10</sup> Available datasets must be reviewed by the discipline experts for quality, data gaps and applicability to the project site. The range of possible disciplines needed was listed previously in the Step 1 Stakeholder Engagement Process.

| Framework Part                                                                                                                                                                                                                                                                                                                                                                                | Available Datasets                                                                | Sites |   |   |   |   |   |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------|---|---|---|---|---|
|                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                   | 1     | 2 | 3 | 4 | 5 | 6 |
| <u>Potential to Improve Condition:</u><br><i>To what extent will restoration improve site condition?</i>                                                                                                                                                                                                                                                                                      | Benthic surveys                                                                   |       | • | • |   | • |   |
|                                                                                                                                                                                                                                                                                                                                                                                               | Stormwater outfalls                                                               | •     | • | • | • | • | • |
|                                                                                                                                                                                                                                                                                                                                                                                               | Septic systems                                                                    | •     | • | • | • | • | • |
| <u>Future exposure:</u> <i>What is the likely frequency and severity of future disturbances?</i>                                                                                                                                                                                                                                                                                              | Bleaching conditions                                                              |       | • |   |   | • |   |
|                                                                                                                                                                                                                                                                                                                                                                                               | Disease                                                                           |       |   |   |   | • |   |
|                                                                                                                                                                                                                                                                                                                                                                                               | Projected (with sea level rise) shoreline erosion                                 | •     | • |   |   | • | • |
|                                                                                                                                                                                                                                                                                                                                                                                               | Rainfall monitoring                                                               |       |   | • | • |   |   |
|                                                                                                                                                                                                                                                                                                                                                                                               | Storm frequency, severity, impacts                                                | •     | • | • | • | • | • |
| <u>Resilience/ecological processes:</u><br><i>What is the capacity of the site to resist and recover from disturbances?</i>                                                                                                                                                                                                                                                                   | Incidence of post-bleaching recovery                                              |       | • | • |   | • |   |
|                                                                                                                                                                                                                                                                                                                                                                                               | Coral species growth rates and resistance to breakage                             |       | • | • |   | • |   |
| <u>Human impacts:</u> <i>What are the types and severity of human impacts affecting coral reef communities at the site, and which are or could be mitigated through management actions?</i>                                                                                                                                                                                                   | Repetitive loss estimates of coastal properties                                   | •     | • | • | • | • | • |
|                                                                                                                                                                                                                                                                                                                                                                                               | Recreational use surveys                                                          |       |   |   |   | • |   |
|                                                                                                                                                                                                                                                                                                                                                                                               | Fish biomass surveys                                                              |       | • |   |   | • |   |
|                                                                                                                                                                                                                                                                                                                                                                                               | Water quality/sediment contaminant monitoring                                     |       |   | • | • | • |   |
|                                                                                                                                                                                                                                                                                                                                                                                               | Coastal development policies, trends                                              | •     | • | • | • | • | • |
|                                                                                                                                                                                                                                                                                                                                                                                               | Potential for cultural/historical or indigenous native resources in the site area | •     | • | • | • | • | • |
|                                                                                                                                                                                                                                                                                                                                                                                               | Annual marine debris monitoring                                                   |       | • |   |   | • |   |
| <b>Remaining Critical Data Needs:</b> <ul style="list-style-type: none"> <li>• Baseline wave energy across reefs at each site</li> <li>• Benthic surveys of reef species and condition across all sites</li> <li>• Geology and geotechnical conditions at the site</li> <li>• Other marine resources in the site area</li> <li>• Potential for cultural resources in the site area</li> </ul> |                                                                                   |       |   |   |   |   |   |

*Describe the rationale for your decision to complete the framework quantitatively or semi-quantitatively, including the advantages and disadvantages in your case.*

A semi-quantitative framework was used to prioritize sites. This framework uses expert judgment along with available data to select and prioritize sites for restoration. A semi-quantitative framework was selected because a complete set of quantitative data was not readily available for the entire windward coast geographic focus area. This approach allowed the Core Planning Team and Technical Advisory Group to consider a wider range of sites and indicators.<sup>11</sup>

## **Completing the framework semi-quantitatively**

*Develop a statement for each framework part to be graded by local experts (first column; you may use the statements in the table below as an example). Record responses (on a scale from 1-5) and calculate the average. Complete this process for EACH site. You can use the table below or create a similar spreadsheet.*

The site prioritization team was composed of members of the Core Planning Team and Technical Advisory Group.<sup>12</sup> The site prioritization team met twice to review and discuss available datasets for each of the five framework parts. A benchmark statement for each framework part was developed to aid in the scoring process. Each member then identified one or more framework parts about which they had the greatest knowledge as a particular focus for their review, but all team members independently scored all framework parts on a scale of 1 to 5.<sup>13</sup> These scores were compiled, and the average and range were calculated for each framework part. Team members then met and discussed all scores. Framework parts with a high range of scores were discussed in greater depth. Where there was large uncertainty due to lack of data and/or variability of interpretations, the type and degree of uncertainty was noted in the rationale as documentation of the need for improved information. In discussions, team members with the greatest knowledge of the datasets and sites were asked to highlight the rationale for their scores, and team members revised scores as appropriate until agreement was reached. The priority level of each site was determined according to the following scale:

- High: average score  $\geq 4.0$
- Medium: average score  $\geq 3.0 - 3.9$
- Low: average score  $< 3.0$

<sup>11</sup> If comprehensive data are available, a quantitative approach should be used to move forward with the planning process. The Guide provides more information on the use of both approaches.


<sup>12</sup> In this hypothetical example, the scores from only 4 members of the team are shown for brevity. Due to the complexity of the framework parts, a larger number of members would be needed (a minimum of one expert for each framework part) to provide the range of scientific and site knowledge to complete a semi-quantitative prioritization process. For Pacific jurisdictions that have worked through this process, the number of team members ranged from 5 to 10 people.

<sup>13</sup> In this hypothetical example, all framework parts were equally weighted, but different weights could be assigned to each part.

| Statements Crafted for Each Framework Part <sup>14</sup>                                                                                                                                                                                                                                                                                                             | Members         | Site Rating (Strongly Agree (5), Agree (4), Neutral (3), Disagree (2), Strongly Disagree (1))                                          |                                                                                    |                                                                                                                                       |                                                                                                                                       |                                                                                    |                                                                                                                                     |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|----------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                      |                 | 1 -North Point                                                                                                                         | 2 - Fisher's Reef                                                                  | 3 – North Bay Reef                                                                                                                    | 4 -South Bay Reef                                                                                                                     | 5 - Snorkeler's Reef                                                               | 6 - South Point Reef                                                                                                                |
| <i>Relevance to Restoration Goal: To what extent would restoration at the site help to achieve the selected goal?</i><br><b>Coral restoration at this site is directly relevant to achieving the restoration goal of reducing wave energy that causes flooding and coastal erosion. The extent of intact reef crest and width of reef flat will attenuate waves.</b> | <b>Member 1</b> | 2                                                                                                                                      | 5                                                                                  | 3                                                                                                                                     | 3                                                                                                                                     | 5                                                                                  | 2                                                                                                                                   |
|                                                                                                                                                                                                                                                                                                                                                                      | <b>Member 2</b> | 3                                                                                                                                      | 4                                                                                  | 4                                                                                                                                     | 4                                                                                                                                     | 4                                                                                  | 3                                                                                                                                   |
|                                                                                                                                                                                                                                                                                                                                                                      | <b>Member 3</b> | 2                                                                                                                                      | 4                                                                                  | 4                                                                                                                                     | 4                                                                                                                                     | 4                                                                                  | 2                                                                                                                                   |
|                                                                                                                                                                                                                                                                                                                                                                      | <b>Member 4</b> | 3                                                                                                                                      | 5                                                                                  | 3                                                                                                                                     | 3                                                                                                                                     | 5                                                                                  | 3                                                                                                                                   |
| <b>Average</b>                                                                                                                                                                                                                                                                                                                                                       |                 | <b>2.5</b>                                                                                                                             | <b>4.5</b>                                                                         | <b>3.5</b>                                                                                                                            | <b>3.5</b>                                                                                                                            | <b>4.5</b>                                                                         | <b>2.5</b>                                                                                                                          |
| <b>Rationale</b>                                                                                                                                                                                                                                                                                                                                                     |                 | Coastal bluff and adjacent reef together provide coastal protection. Reef crest is closer to shore and reef flat is relatively narrow. | Reef crest and wide reef flat is a key feature providing protection to the island. | Reef crest and reef flat narrow as they approach the bay, providing some coastal protection but with waves wrapping around the point. | Reef crest and reef flat narrow as they approach the bay, providing some coastal protection but with waves wrapping around the point. | Reef crest and wide reef flat is a key feature providing protection to the island. | Coastal protection provided by bluff together with adjacent reef. Reef crest is closer to shore and reef flat is relatively narrow. |


<sup>14</sup> One statement is presented per page, for ease of reading.



| Statements Crafted for Each Framework Part                                                                                                                                                                                                                                                                                                                                                             | Members   | Site Rating (Strongly Agree (5), Agree (4), Neutral (3), Disagree (2), Strongly Disagree (1))                       |                                                                                                                              |                                                                                                                                                                                   |                                                                                                                                                                                   |                                                                                                                             |                                                                                                                     |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|---------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                        |           | 1 -North Point Reef                                                                                                 | 2 - Fisher's Reef                                                                                                            | 3 – North Bay Reef                                                                                                                                                                | 4 -South Bay Reef                                                                                                                                                                 | 5 - Snorkeler's Reef                                                                                                        | 6 - South Point Reef                                                                                                |
| <p><i>Future exposure: What is the likely frequency and severity of future disturbances?</i></p> <p><b>Severity and extent of storm-driven coastal flooding with climate change are high at this site. Current and future projected erosion rates with sea level rise are high at this site. The incidence of bleaching at this site has been high and is expected to remain so in the future.</b></p> | Member 1  | 4                                                                                                                   | 4                                                                                                                            | 1                                                                                                                                                                                 | 1                                                                                                                                                                                 | 4                                                                                                                           | 4                                                                                                                   |
|                                                                                                                                                                                                                                                                                                                                                                                                        | Member 2  | 4                                                                                                                   | 4                                                                                                                            | 2                                                                                                                                                                                 | 2                                                                                                                                                                                 | 4                                                                                                                           | 4                                                                                                                   |
|                                                                                                                                                                                                                                                                                                                                                                                                        | Member 3  | 3                                                                                                                   | 5                                                                                                                            | 2                                                                                                                                                                                 | 2                                                                                                                                                                                 | 5                                                                                                                           | 3                                                                                                                   |
|                                                                                                                                                                                                                                                                                                                                                                                                        | Member 4  | 3                                                                                                                   | 5                                                                                                                            | 2                                                                                                                                                                                 | 2                                                                                                                                                                                 | 5                                                                                                                           | 3                                                                                                                   |
| Average                                                                                                                                                                                                                                                                                                                                                                                                |           | 3.5                                                                                                                 | 4.5                                                                                                                          | 1.8                                                                                                                                                                               | 1.8                                                                                                                                                                               | 4.5                                                                                                                         | 3.5                                                                                                                 |
|  <p>Coral bleaching.<br/>Credit: The Ocean Agency.</p>                                                                                                                                                                                                                                                                | Rationale | Increasing impacts from severe storm events and sea level rise. Potential for bleaching unknown (high uncertainty). | Experiences waves that are causing erosion of the highway. Many corals have experienced bleaching, and most did not recover. | Experiences some wave energy, but intact reef crest and wide reef flat dampen wave energy that wraps around the point. Few corals have experienced bleaching, and most recovered. | Experiences some wave energy, but intact reef crest and wide reef flat dampen wave energy that wraps around the point. Few corals have experienced bleaching, and most recovered. | Experiences waves causing erosion of coastal development. Many corals have experienced bleaching, and most did not recover. | Increasing impacts from severe storm events and sea level rise. Potential for bleaching unknown (high uncertainty). |

| Statements Crafted for Each Framework Part                                                                                                                                                                                                                                                                                         | Members         | Site Rating (Strongly Agree (5), Agree (4), Neutral (3), Disagree (2), Strongly Disagree (1))                                                                                                        |                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                              |                                                                                                                                                                                               |                                                                            |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                    |                 | 1 -North Point Reef                                                                                                                                                                                  | 2 - Fisher's Reef                                                                                                                                                                             | 3 – North Bay Reef                                                                                                                                                                                                                                                                                                                       | 4 -South Bay Reef                                                                                                                                                                                                                            | 5 - Snorkeler's Reef                                                                                                                                                                          | 6 - South Point Reef                                                       |
| <i>Resilience/ecological processes: What is the capacity of the site to resist and recover from disturbances?</i><br><b>This site is relatively resilient with higher relative capacity to resist and recover from disturbances such as temperature variability because of high coral cover, diversity, and herbivore biomass.</b> | <b>Member 1</b> | 3                                                                                                                                                                                                    | 5                                                                                                                                                                                             | 4                                                                                                                                                                                                                                                                                                                                        | 4                                                                                                                                                                                                                                            | 4                                                                                                                                                                                             | 2                                                                          |
|                                                                                                                                                                                                                                                                                                                                    | <b>Member 2</b> | 3                                                                                                                                                                                                    | 4                                                                                                                                                                                             | 5                                                                                                                                                                                                                                                                                                                                        | 5                                                                                                                                                                                                                                            | 3                                                                                                                                                                                             | 3                                                                          |
|                                                                                                                                                                                                                                                                                                                                    | <b>Member 3</b> | 3                                                                                                                                                                                                    | 4                                                                                                                                                                                             | 3                                                                                                                                                                                                                                                                                                                                        | 3                                                                                                                                                                                                                                            | 4                                                                                                                                                                                             | 3                                                                          |
|                                                                                                                                                                                                                                                                                                                                    | <b>Member 4</b> | 3                                                                                                                                                                                                    | 5                                                                                                                                                                                             | 4                                                                                                                                                                                                                                                                                                                                        | 4                                                                                                                                                                                                                                            | 4                                                                                                                                                                                             | 2                                                                          |
| <b>Average</b>                                                                                                                                                                                                                                                                                                                     |                 | <b>3.0</b>                                                                                                                                                                                           | <b>4.5</b>                                                                                                                                                                                    | <b>4.0</b>                                                                                                                                                                                                                                                                                                                               | <b>4.0</b>                                                                                                                                                                                                                                   | <b>3.8</b>                                                                                                                                                                                    | <b>2.5</b>                                                                 |
| <b>Rationale</b>                                                                                                                                                                                                                                                                                                                   |                 | Limited data to assess capacity to resist/recover from perturbations; however, other high-water flow environments have typically fared better in terms of bleaching response (moderate uncertainty). | Wide reef flat contributes to high residence time of the water and warmer temperatures. Documented bleaching and recovery of multiple coral species from temperature anomalies have occurred. | Corals experience high degree of temperature and sometimes salinity variations due to watershed and adjacent estuarine environment, which acclimatizes corals and makes them more resilient (able to resist and recover from perturbations). Documented bleaching and recovery of some species from temperature anomalies have occurred. | Corals experience high degree of temperature and sometimes salinity variations due to watershed and adjacent estuarine environment, which acclimatizes corals and makes them more resilient (able to resist and recover from perturbations). | Wide reef flat contributes to high residence time of the water and warmer temperatures. Documented bleaching and recovery of multiple coral species from temperature anomalies have occurred. | Capacity to resist/ recover from perturbations unknown (high uncertainty). |

| Statements Crafted for Each Framework Part                                                                                                                                                                                                                                                                                                                                                                                      | Members         | Site Rating (Strongly Agree (5), Agree (4), Neutral (3), Disagree (2), Strongly Disagree (1))  |                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                         |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|------------------------------------------------------------------------------------------------|-----------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                 |                 | 1 -North Point Reef                                                                            | 2 - Fisher's Reef                                         | 3 – North Bay Reef                                                                                                                                                                                                                               | 4 -South Bay Reef                                                                                                                                        | 5 - Snorkeler's Reef                                                                                                                                                                                                                                                                                                                                                                                                                              | 6 - South Point Reef                                                    |
| <p><i>Human impacts: What are the types and severity of human impacts affecting coral reef communities at the site, and which are or could be mitigated through management actions?</i></p> <p><b>Human impacts from reef fish fishing, marine-based pollution, watershed-based pollution, marine debris, coastal development, tourism, and shipping are relatively low or are being adequately addressed at this site.</b></p> | <b>Member 1</b> | 4                                                                                              | 3                                                         | 3                                                                                                                                                                                                                                                | 3                                                                                                                                                        | 3                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 4                                                                       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>Member 2</b> | 5                                                                                              | 2                                                         | 3                                                                                                                                                                                                                                                | 3                                                                                                                                                        | 3                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 5                                                                       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>Member 3</b> | 4                                                                                              | 3                                                         | 4                                                                                                                                                                                                                                                | 4                                                                                                                                                        | 2                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 4                                                                       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>Member 4</b> | 5                                                                                              | 3                                                         | 2                                                                                                                                                                                                                                                | 2                                                                                                                                                        | 2                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 5                                                                       |
| <b>Average</b>                                                                                                                                                                                                                                                                                                                                                                                                                  |                 | <b>4.5</b>                                                                                     | <b>2.8</b>                                                | <b>3.0</b>                                                                                                                                                                                                                                       | <b>3.0</b>                                                                                                                                               | <b>2.5</b>                                                                                                                                                                                                                                                                                                                                                                                                                                        | <b>4.5</b>                                                              |
| <b>Rationale</b>                                                                                                                                                                                                                                                                                                                                                                                                                |                 | Primary human activities are surfing off the point with some residential development on bluff. | Area is heavily fished using pole and line and spearguns. | Some recreational uses including picnicking and fishing at beach park adjacent to reef. Primary impact to reef is intermittent soil runoff and sedimentation from the adjacent watershed, which is exacerbated by invasive plants and ungulates. | Primary impact to reef is intermittent soil runoff and sedimentation from the adjacent watershed, which is exacerbated by invasive plants and ungulates. | Area is heavily used by residents and tourists for snorkeling, swimming, kayaking, and other recreational activities. Dense land use and large extent of impervious surfaces results in stormwater runoff to nearshore that carries pollutants. Some temporary erosion control measures to protect condominiums along the shoreline may be exacerbating coastal erosion. Overall, human impacts continue unabated and would need to be corrected. | Primary human activities are bodysurfing and kitesurfing off the point. |

| Statements Crafted for Each Framework Part                                                                                                                                                                                                                                                    | Members          | Site Rating (Strongly Agree (5), Agree (4), Neutral (3), Disagree (2), Strongly Disagree (1))                                 |                                                                                                                                                  |                                                                                                                                                                                                    |                                                                                                                        |                                                                                                                                                                                                                                                                                                                           |                                                                                                                                |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                               |                  | 1 -North Point Reef                                                                                                           | 2 - Fisher's Reef                                                                                                                                | 3 – North Bay Reef                                                                                                                                                                                 | 4 -South Bay Reef                                                                                                      | 5 - Snorkeler's Reef                                                                                                                                                                                                                                                                                                      | 6 - South Point Reef                                                                                                           |
| <i>Potential to improve condition: To what extent will restoration improve site condition?</i><br><b>Restoration at the site has potential to stabilize/improve coral structure and cover that has been lost from bleaching and physical disturbances such as snorkeling and wave events.</b> | <b>Member 1</b>  | 2                                                                                                                             | 5                                                                                                                                                | 3                                                                                                                                                                                                  | 3                                                                                                                      | 5                                                                                                                                                                                                                                                                                                                         | 2                                                                                                                              |
|                                                                                                                                                                                                                                                                                               | <b>Member 2</b>  | 3                                                                                                                             | 4                                                                                                                                                | 3                                                                                                                                                                                                  | 3                                                                                                                      | 5                                                                                                                                                                                                                                                                                                                         | 3                                                                                                                              |
|                                                                                                                                                                                                                                                                                               | <b>Member 3</b>  | 3                                                                                                                             | 5                                                                                                                                                | 3                                                                                                                                                                                                  | 3                                                                                                                      | 4                                                                                                                                                                                                                                                                                                                         | 3                                                                                                                              |
|                                                                                                                                                                                                                                                                                               | <b>Member 4</b>  | 2                                                                                                                             | 5                                                                                                                                                | 3                                                                                                                                                                                                  | 3                                                                                                                      | 5                                                                                                                                                                                                                                                                                                                         | 2                                                                                                                              |
| <b>Average</b>                                                                                                                                                                                                                                                                                |                  | <b>2.5</b>                                                                                                                    | <b>4.8</b>                                                                                                                                       | <b>3.0</b>                                                                                                                                                                                         | <b>3.0</b>                                                                                                             | <b>4.8</b>                                                                                                                                                                                                                                                                                                                | <b>2.5</b>                                                                                                                     |
|  <p>Healthy coral structure and cover at Palmyra Atoll.<br/>Credit: Jim Maragose, USFWS. Public domain.</p>                                                                                                  | <b>Rationale</b> | <i>Low potential for restoration to stabilize/improve coral cover and structure in this relatively high wave environment.</i> | <i>High potential for restoration to stabilize/ improve coral cover and structure that has been lost primarily from recent bleaching events.</i> | <i>Medium potential for restoration to stabilize/improve coral cover and structure; however, the variations in water quality and temperature provide an ideal location for an in situ nursery.</i> | <i>Medium potential for restoration to improve coral structure and cover that is regularly exposed to soil runoff.</i> | <i>High potential for restoration to improve coral cover and structure lost primarily from physical impacts from snorkelers and damage by marine debris scraping coral colonies as a result of a recent tropical cyclone; however, ongoing tourism overuse continues and threatens success of restoration activities.</i> | <i>Low potential for restoration to stabilize/ improve coral cover and structure in this relatively high wave environment.</i> |
| <b>OVERALL SITE SCORE AVERAGE (All framework parts)</b>                                                                                                                                                                                                                                       |                  | <b>3.2</b>                                                                                                                    | <b>4.2</b>                                                                                                                                       | <b>3.1</b>                                                                                                                                                                                         | <b>3.1</b>                                                                                                             | <b>4.0</b>                                                                                                                                                                                                                                                                                                                | <b>3.2</b>                                                                                                                     |

For each site, average the values for all framework parts, so each site has one numerical score. Use color coding to denote relative restoration priority. Develop your criteria for low, medium, and high priority or use the criteria in Step 2B of the Guide (Tables 2.3 and 2.4).

Create a table with the average values for each framework part for all candidate restoration sites. Table 2.5 in the Guide provides an example of a completed table.

| Site Name            | Priority Level | Overall Site Score Average | Relevance to Goal | Potential to Improve Condition | Short and Long-term Survivorship |            |               |
|----------------------|----------------|----------------------------|-------------------|--------------------------------|----------------------------------|------------|---------------|
|                      |                |                            |                   |                                | [climate vulnerability]          |            |               |
|                      |                |                            |                   |                                | Future Exposure                  | Resilience | Human Impacts |
| 1 - North Point Reef | MEDIUM         | 3.2                        | 2.5               | 2.5                            | 3.5                              | 3.0        | 4.5           |
| 2 - Fisher's Reef    | HIGH           | 4.2                        | 4.5               | 4.8                            | 4.5                              | 4.5        | 2.8           |
| 3 - North Bay Reef   | MEDIUM         | 3.1                        | 3.5               | 3.0                            | 1.8                              | 4.0        | 3.0           |
| 4 - South Bay Reef   | MEDIUM         | 3.1                        | 3.5               | 3.0                            | 1.8                              | 4.0        | 3.0           |
| 5 - Snorkeler's Reef | HIGH           | 4.0                        | 4.5               | 4.8                            | 4.5                              | 3.8        | 2.5           |
| 6 - South Point Reef | MEDIUM         | 3.1                        | 2.5               | 2.5                            | 3.5                              | 2.5        | 4.5           |

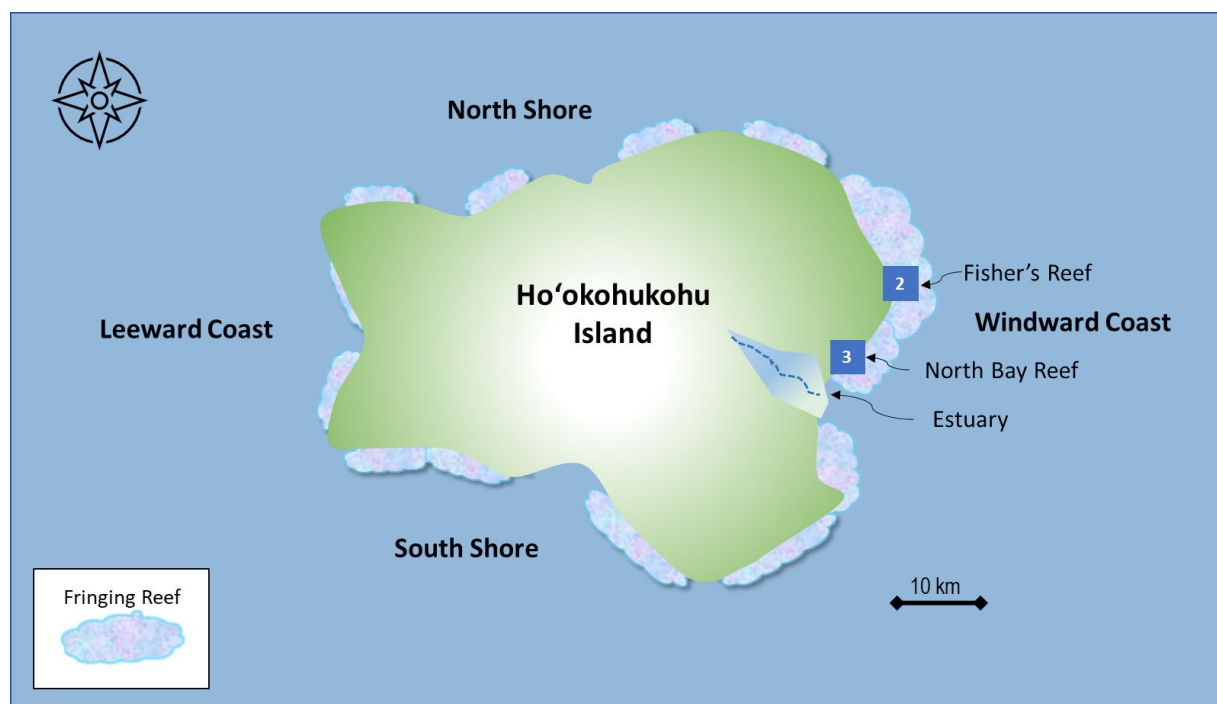
## 2C. Final Site Selection

Provide a brief description of the highest priority sites selected for restoration. Include the site name, general description of the site, and a summary (quantitative or qualitative) on how each site compared to other sites using the site prioritization framework. You may also use this table to indicate which site(s) might be suitable for the pilot phase.

| Site Name               | Site Description and Area                                                                                                                                                                                                                           | Comparison to Other Sites (based on framework parts)                                                                                                                                                                                                                                                                                                                       | Pilot Phase? |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|
| Site 2 – Fisher's Reef  | Reef important for recreational and subsistence fishing as well as coastal protection. Some overfishing, especially herbivores. New herbivore regulations are being established.                                                                    | Rated highest in all framework parts except human impacts due to overfishing.                                                                                                                                                                                                                                                                                              | Yes          |
| Site 3 – North Bay Reef | Reef is adjacent to embayment with estuarine habitat that serves as a nursery ground for fish. Some soil runoff to nearshore waters, but mostly transported south and dissipated. Watershed management to reduce soil erosion is being implemented. | Rated high in resilience and low in exposure, with medium rankings in remaining framework parts. For this reason, this site is being considered as a field nursery for propagating corals to outplant at Site 2. Coral colonies experience a range of temperature, water quality, and wave conditions that appear to acclimatize them to potential climate change impacts. | Yes          |



Develop a map of the geographic area of focus for the restoration goal with the final selected sites clearly marked.



Provide a summary of the process used to finalize your list of restoration sites, including stakeholders or decision-makers involved.

In Step 2A and 2B, the Core Planning Team and Technical Advisory Group identified 6 sites, summarized the rationale for site selection, and identified available datasets within the geographic focus area. A semi-quantitative approach for site selection was used due to the inconsistent coverage of available data across all 6 sites. Non-government and government stakeholders participated in a workshop to provide input on the site selection process and site selection. The Core Planning Team then selected two priority sites for a restoration project under Goal 1.<sup>15</sup>



## Step 2 Stakeholder Engagement

List technical experts, stakeholders, and partners including scientists, engineers, community members, private sector, and federal and local government engaged for this step.

| Technical Expertise                                      | Key Stakeholders                                                       |
|----------------------------------------------------------|------------------------------------------------------------------------|
| Coral reef biologist/coral ecologist<br>Coastal engineer | <b>Non-Government</b><br>Residents impacted by chronic coastal erosion |

<sup>15</sup> Scoring is a useful tool for prioritization; however, it should be noted that it relies on expert judgement, interpretation, and discussion.

| Technical Expertise                                                                                                                           | Key Stakeholders                                                                                                                                                                                                                  |
|-----------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Coastal geologist<br>Physical/chemical oceanographer<br>Social scientist<br>Watershed manager<br>Water quality specialist<br>Land use planner | Fishing community<br>Tourism industry representatives<br>Communities located along the windward coast<br>Representatives of environmental advocacy groups<br><b>Government</b><br>Regulatory agencies (federal, state, and local) |

*Provide a summary of stakeholder engagement activities taken for this step.*

At this stage in the process, several informational meetings were conducted along the windward coast to gather additional information on the six sites identified. For communities near sites under consideration, meetings with community stakeholder groups presented initial results of the site selection analysis. Communication about the site selection process and goal of restoration work was provided through pamphlets, presentations, and question-and-answer sessions. Discussions and solicitation of stakeholder feedback focused on the need for restoration and the types of community supports that would be essential for restoration success. Community members were invited to voice concerns and provide input on specific places on the reef that would be good candidates for restoration. Communities were asked to indicate their support for work at their locations. The communities at Fisher's Reef and North Bay Reef were both in favor of the proposed activities.

## STEP 3: IDENTIFY, DESIGN, AND SELECT INTERVENTIONS

### 3A: Brainstorm an Array of Intervention Options

*List the full array of intervention options that could be applied toward your restoration goal, indicating how they connect to the goal where appropriate. Then, summarize the process used to make these decisions.*

**Restoration Goal:** Within 15 years, restored reef structure reduces wave energy that contributes to coastal erosion, thereby strengthening the resilience of coastal communities to sea level rise and increasingly intense storms.

**Intervention Options:**<sup>16</sup>

- **OPTION 1 – Propagation and Outplanting:** Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure (Site 2, outplanting and Site 3, field nursery)
- **OPTION 2 – Substrate Stabilization:** Stabilize rubble to protect existing corals and enhance natural recruitment (Site 2)
- **OPTION 3 – WAUs:** Deploy reef-friendly WAUs designed to reduce wave energy, support natural recruitment, and enhance fish habitat (Site 2)
- **OPTION 4 – Herbivore Enhancement:** Enhance and diversify herbivore biomass to reduce algal overgrowth and enhance natural coral recruitment and survival (Sites 2, 3)



Herbivorous fish help reduce algal overgrowth. Credit: Curt Storlazzi, USGS. Public domain.

**Process:** The Core Planning Team convened to brainstorm ideas for restoration to achieve the goal.

<sup>16</sup>The number of restoration options shown for this example is limited to four for brevity; however, the Guide recommends that a full array of all possible options to support achieving the goal be identified and retained until Step 3C.

### 3B: Apply Climate-Smart Design Considerations

For each intervention option, use the Step 3B table provided to record your answers to the basic design questions that apply. After reviewing the climate-smart design considerations in Table 3.3 of the Guide, develop a checklist of questions appropriate to your situation (see following checklist) and use the checklist to build climate-smart improvements into all relevant design elements in your Step 3B table. These improvements can be highlighted in blue text. Add additional Option columns until all brainstormed intervention options from 3A above have been designed.

| Design Questions                 | Restoration Interventions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                         |                                                                                                                                                     |                                                                                                                                   |
|----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
|                                  | OPTION 1<br>Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure                                                                                                                                                                                                                                                                                                                                                                                                                                 | OPTION 2<br>Stabilize rubble to protect existing corals and enhance natural recruitment | OPTION 3<br>Deploy reef-friendly wave attenuation units designed to reduce wave energy, support natural coral recruitment, and enhance fish habitat | OPTION 4<br>Enhance and diversify herbivore biomass to reduce algal overgrowth and enhance natural coral recruitment and survival |
| What coral species will be used? | Branching coral, <i>Pocillopora meandrina</i> and boulder coral, <i>Porites lobata</i> will be used for propagation because they will create the most hydrodynamic roughness on the reef flat while also being more resistant to bleaching and robust against high wave energy.                                                                                                                                                                                                                                                                      | N/A                                                                                     | N/A                                                                                                                                                 | N/A                                                                                                                               |
| Where will corals be obtained?   | Coral fragments will be obtained from sites outside the restoration site that have sufficient numbers for collection. Corals will be collected from sites that have experienced past bleaching events such that corals are more likely to be acclimatized or have genes for increased stress tolerance. Fragments will only be collected from corals that appear to be healthy and show no signs of disease. A nursery site suitability study identified Site 3 – North Bay Reef as not only a source of corals but also a suitable site for a field | N/A                                                                                     | N/A                                                                                                                                                 | N/A                                                                                                                               |

| Design Questions                                                       | Restoration Interventions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                         |                                                                                                                                                     |                                                                                                                                   |
|------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
|                                                                        | OPTION 1<br>Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | OPTION 2<br>Stabilize rubble to protect existing corals and enhance natural recruitment | OPTION 3<br>Deploy reef-friendly wave attenuation units designed to reduce wave energy, support natural coral recruitment, and enhance fish habitat | OPTION 4<br>Enhance and diversify herbivore biomass to reduce algal overgrowth and enhance natural coral recruitment and survival |
|                                                                        | nursery. Coral fragments will be collected from “corals of opportunity” that are already broken, or by taking small fragments from intact donor colonies. <i>Fragments will be collected every 5 m to attempt to collect as many distinct genotypes as possible.</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                         |                                                                                                                                                     |                                                                                                                                   |
| <i>What coral propagation and/or outplanting methods will be used?</i> | <b>Propagation:</b> Asexual fragmentation will be followed by grow-out in two field nurseries along the windward coast. <i>In addition to Site 3, another field nursery will be established to spread the risk of loss due to unanticipated events.</i> Coral trees will be used for propagation [30]. Coral trees are light-weight structures tethered to the ocean floor and buoyed with a subsurface float. Coral trees suspended in the water column can move with storm-generated waves or be moved up and down to avoid storms and episodes of high sea surface temperature or heavy freshwater runoff, preventing damage to the tree structure and the corals themselves. Branching coral fragments will be attached directly to coral trees using CoralClips (Suggett et al., 2020). Fragments of boulder corals will be | N/A                                                                                     | N/A                                                                                                                                                 | N/A                                                                                                                               |

| Design Questions | Restoration Interventions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                         |                                                                                                                                                     |                                                                                                                                   |
|------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
|                  | OPTION 1<br>Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | OPTION 2<br>Stabilize rubble to protect existing corals and enhance natural recruitment | OPTION 3<br>Deploy reef-friendly wave attenuation units designed to reduce wave energy, support natural coral recruitment, and enhance fish habitat | OPTION 4<br>Enhance and diversify herbivore biomass to reduce algal overgrowth and enhance natural coral recruitment and survival |
|                  | <p>epoxied to plates and attached to the coral tree. The coral tree propagation method will enable corals to be vertically adjusted or shaded as needed for acclimatization and lowered in case of storms. The field nursery will be exposed to a range of temperatures, water quality conditions, and wave energy, which is expected to create more resilient corals for outplanting.</p> <p><b>Outplanting:</b> Branching and boulder coral fragments will be transplanted to the substrate using CoralClips [27] and epoxy techniques. Attachment techniques including epoxy and CoralClips will be tested during the pilot phase and adjustments made in the event of high failure rates to ensure that they can withstand existing and future wave conditions and sea level rise. The specific adhesive will be marine epoxy, which has been shown to have the lowest detachment rate and thus should hold up the best against wave action [31]. Corals will be outplanted based on the results of baseline studies of coral demography and reef structure. Corals will be outplanted on the reef flat and upper fore reef in areas of</p> |                                                                                         |                                                                                                                                                     |                                                                                                                                   |



| Design Questions                                        | Restoration Interventions                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|---------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                         | OPTION 1<br>Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure                                                                                                                                                                                                                                        | OPTION 2<br>Stabilize rubble to protect existing corals and enhance natural recruitment                                                                                                                                                            | OPTION 3<br>Deploy reef-friendly wave attenuation units designed to reduce wave energy, support natural coral recruitment, and enhance fish habitat                                                                                                | OPTION 4<br>Enhance and diversify herbivore biomass to reduce algal overgrowth and enhance natural coral recruitment and survival                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                                         | the site where additional structural complexity could prove beneficial to wave energy reduction and in multiple locations and at different depths within the site to account for sea level rise and spread the risk of impacts from potential bleaching events. A rapid response plan will be created for repair or replacement of structures after storms. |                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <i>What biological control techniques will be used?</i> | Macroalgae removal by hand or mechanical means may be required at the nursery site to protect propagated corals and at restoration sites to protect coral outplants. Algae removal frequency may have to be increased if rising ocean temperatures and/or increased nutrient inputs increase algal growth in the future.                                    | Macroalgae removal by hand or mechanical means may be required to support natural recruitment. Algae removal frequency may have to be increased if rising ocean temperatures and/or increased nutrient inputs increase algal growth in the future. | Macroalgae removal by hand or mechanical means may be required to support natural recruitment. Algae removal frequency may have to be increased if rising ocean temperatures and/or increased nutrient inputs increase algal growth in the future. | Sea urchins, currently being raised in a land-based laboratory, will be outplanted at appropriate densities to the restoration site. It is not known how the adults or larvae are affected by increased sea-surface temperature and ocean acidification. Regular monitoring of urchin density and condition will be conducted. A rapid response plan will be put into place for replenishment of urchins lost due to disease or temperature or acidification effects. Herbivore biomass on the reef should be diversified to address uncertainty in impacts of climate change on urchins and other herbivores and macroalgae they consume. Other herbivore management efforts, such as place-based protection (e.g., herbivore replenishment areas), fishing gear restrictions, and size limits will be needed; however, to diversify |

| Design Questions                                             | Restoration Interventions                                                                                            |                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                      |
|--------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                              | OPTION 1<br>Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure | OPTION 2<br>Stabilize rubble to protect existing corals and enhance natural recruitment                                                                                                                                                                   | OPTION 3<br>Deploy reef-friendly wave attenuation units designed to reduce wave energy, support natural coral recruitment, and enhance fish habitat                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | OPTION 4<br>Enhance and diversify herbivore biomass to reduce algal overgrowth and enhance natural coral recruitment and survival                                                                                                                                                                                                                    |
|                                                              |                                                                                                                      |                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | herbivore biomass at the restoration site, different functional groups of herbivorous fishes (e.g., scarids, acanthurids, kyphosids) are needed to support reef growth and recruitment. In addition, scarids are important contributors to sand production on the reef. New regulations will be needed to support herbivore biomass diversification. |
| <i>What physical or engineering techniques will be used?</i> | N/A                                                                                                                  | Metal stakes and natural fiber, wire mesh, or other methods will be piloted to stabilize rubble areas [32]. Mesh will be checked and maintained regularly to ensure that it can withstand storms and wave action, which may increase with climate change. | Wave attenuation units (WAUs) will be deployed to the restoration site to reduce wave energy. WAUs will incorporate reef friendly materials, such as pH-neutral concrete or lightweight concrete with an organic matter matrix to accelerate biological colonization. WAU stabilization will be enhanced with the installation of a scour blanket to reduce potential scouring effects. Zepeda-Centeno C. [21], the World Bank [28], and other sources will be consulted to identify WAU prototypes for pilot testing to evaluate their ability to support natural recruitment, withstand severe wave events, and improve fish habitat as a co-benefit of the restoration intervention. WAUs will be located based on the results of wave modeling to determine optimal siting and alignment of | The land-based laboratory where urchins are currently being raised is resistant to hurricane force winds and has a back-up power generator.                                                                                                                                                                                                          |

| Design Questions | Restoration Interventions                                                                                            |                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                   |
|------------------|----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
|                  | OPTION 1<br>Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure | OPTION 2<br>Stabilize rubble to protect existing corals and enhance natural recruitment | OPTION 3<br>Deploy reef-friendly wave attenuation units designed to reduce wave energy, support natural coral recruitment, and enhance fish habitat                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | OPTION 4<br>Enhance and diversify herbivore biomass to reduce algal overgrowth and enhance natural coral recruitment and survival |
|                  |                                                                                                                      |                                                                                         | <p>WAUs along the width and length of the site in areas with the greatest potential to minimize erosion along the shoreline under existing and future conditions, including sea level rise and increasingly severe storm events, while still allowing for circulation to maintain water quality. The configuration and placement density of WAUs may have an influence on local circulation that may need modeling to evaluate potential effects. Wave modeling programs used in reef environments include XBeach, SWAN, and Delft3D [5, 11, 29]. Baseline mapping of reef geometry at the restoration site (e.g., height, structural complexity) using the best available technology (e.g., airborne high-resolution topo/bathymetric LiDAR or UAV imagery) that can be repeated over time will need to be conducted to support modeling [33-36].</p> |                                                                                                                                   |



Wave attenuation units. Credit: Steve Schill, The Nature Conservancy.

**Checklist:** Use the checklist of climate-smart design considerations to indicate which questions apply to each intervention option to support discussion of climate-smart improvements. Begin with the checklist presented in Table 3.3 of the Guide and add questions as necessary to address Category 1 and 2 climate-smart considerations.<sup>17</sup>

| Design Questions                 | Category 1: How will climate change and its interaction with local stressors of concern impact the biological resilience of the restoration intervention?                              |          |          |          |          | Category 2: How will climate change affect the physical functionality of the restoration intervention through direct impacts on structural components?                                 |          |          |          |          |
|----------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------|----------|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------|----------|----------|
|                                  | Indicate (X) which questions apply to the option to support discussion and development of climate-smart improvements. Add questions as necessary to address Category 1 considerations. | Option 1 | Option 2 | Option 3 | Option 4 | Indicate (X) which questions apply to the option to support discussion and development of climate-smart improvements. Add questions as necessary to address Category 2 considerations. | Option 1 | Option 2 | Option 3 | Option 4 |
| What coral species will be used? | What is the vulnerability of the site to bleaching conditions? Are certain coral species more resistant to bleaching?                                                                  | X        |          |          |          | How much is wave energy expected to increase with increasingly intense storms? Are certain coral species less brittle or more robust against storm damage?                             | X        |          |          |          |
|                                  | Are certain coral species more resistant to disease?                                                                                                                                   | X        |          |          |          |                                                                                                                                                                                        |          |          |          |          |
|                                  | How is climate change affecting sediment, nutrient, and contaminant transport to the site? Are certain coral species more tolerant?                                                    | X        |          |          |          |                                                                                                                                                                                        |          |          |          |          |
|                                  | Are enough coral species being used to account for genetic and functional diversity and redundancy?                                                                                    | X        |          |          |          |                                                                                                                                                                                        |          |          |          |          |

<sup>17</sup> This checklist was developed from Table 3.3 of the Guide. It is intended to help consider climate-smart improvements in the design of each restoration option. These considerations are indicated in blue text in the preceding Step 3B design table. Option 1=Propagation and outplanting; Option 2=Substrate stabilization; Option 3=Wave attenuation units; Option 4=Herbivore enhancement.

| Design Questions                                  | Category 1: How will climate change and its interaction with local stressors of concern impact the biological resilience of the restoration intervention?                                                                                                                    |          |          |          |          | Category 2: How will climate change affect the physical functionality of the restoration intervention through direct impacts on structural components?                                                                                                  |          |          |          |          |
|---------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------|----------|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------|----------|----------|
|                                                   | Indicate (X) which questions apply to the option to support discussion and development of climate-smart improvements. Add questions as necessary to address Category 1 considerations.                                                                                       | Option 1 | Option 2 | Option 3 | Option 4 | Indicate (X) which questions apply to the option to support discussion and development of climate-smart improvements. Add questions as necessary to address Category 2 considerations.                                                                  | Option 1 | Option 2 | Option 3 | Option 4 |
| Where will corals be obtained?                    | Will coral growth rates be able to keep up with sea level rise?                                                                                                                                                                                                              | X        |          |          |          |                                                                                                                                                                                                                                                         |          |          |          |          |
|                                                   | Are there <i>in situ</i> sites where corals have naturally been acclimatized to bleaching or poor water quality?                                                                                                                                                             | X        |          |          |          | Are there sites that have experienced intense storm events from which corals that have withstood damage could be collected?                                                                                                                             | X        |          |          |          |
|                                                   | Are there lab-designed species or genotypes with special characteristics with respect to climate change-related stressors specific to the restoration site?                                                                                                                  |          |          |          |          |                                                                                                                                                                                                                                                         |          |          |          |          |
| What coral propagation and/or outplanting methods | Is there enough brood stock genetic diversity to maximize chances of long-term survival and potential to scale-up efforts in the long-term?                                                                                                                                  |          |          |          |          |                                                                                                                                                                                                                                                         |          |          |          |          |
|                                                   | Are there nursery sites in the field where corals could be acclimatized during propagation?                                                                                                                                                                                  | X        |          |          |          | How much is wave energy expected to increase with increasingly intense storms? Does this affect the decision whether to use natural substrate or build an artificial substrate? (Also see engineering question below.)                                  | X        |          | X        |          |
|                                                   | Is there a lab with options for pre-treating corals to acclimate them to variations in temperature or other stressors?                                                                                                                                                       |          |          |          |          | How often will it be necessary to outplant more corals to replace losses from storms?                                                                                                                                                                   | X        |          |          |          |
|                                                   | How often will it be necessary to outplant more corals to replace losses from bleaching?                                                                                                                                                                                     | X        |          |          |          | At what depths should outplants be placed given projected rates of sea level rise?                                                                                                                                                                      | X        |          |          |          |
| What biological control techniques will be used?  |                                                                                                                                                                                                                                                                              |          |          |          |          | Will materials or methods used to outplant corals be able to withstand wave energy from storms?                                                                                                                                                         | X        |          |          |          |
|                                                   | How will climate change affect predator populations or algal outbreaks? And will this in turn, affect the frequency or intensity with which removal techniques will need to be used? Will removal techniques be able to keep up with algal growth under changing conditions? | X        | X        | X        | X        | Will certain predator or algae removal techniques be difficult to do in areas of increasingly high wind and wave energy? Will this limit the time of year or efficiency (amount that can be done in a given time) with which the technique can be used? | X        | X        | X        |          |
|                                                   | How will climate change affect environmental conditions for valued herbivore populations? Will regular replenishment of herbivores be needed?                                                                                                                                |          |          |          | X        | Will the chosen materials be able to stand up to increasingly intense wave energy and storms?                                                                                                                                                           | X        | X        | X        |          |
|                                                   | How will climate change affect the frequency and severity of disease outbreaks? Will this affect the type, method, or frequency of treatments needed? Is it expected to affect the coral species chosen?                                                                     | X        |          |          | X        | At what depth should structures be placed to account for sea level rise given coral growth rates?                                                                                                                                                       | X        |          | X        |          |



| Design Questions             | Category 1: How will climate change and its interaction with local stressors of concern impact the biological resilience of the restoration intervention?                              |          |          |          |          | Category 2: How will climate change affect the physical functionality of the restoration intervention through direct impacts on structural components?                                 |          |          |          |          |
|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------|----------|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------|----------|----------|
|                              | Indicate (X) which questions apply to the option to support discussion and development of climate-smart improvements. Add questions as necessary to address Category 1 considerations. | Option 1 | Option 2 | Option 3 | Option 4 | Indicate (X) which questions apply to the option to support discussion and development of climate-smart improvements. Add questions as necessary to address Category 2 considerations. | Option 1 | Option 2 | Option 3 | Option 4 |
| What physical or engineering | Is there anything about the coral attachment methods or materials that could render corals more or less susceptible to climate change-related stress?                                  | X        |          |          |          | How will the laboratory where urchins will be propagated be safeguarded to withstand intense storms? Are structures and water intake fortified? Is there back-up power generation?     |          |          |          | X        |

Prepare a summary description of each intervention option, synthesized from the design consideration questions. Each intervention option should be specifically tailored to the goal, address all relevant design elements, and include climate-smart design details as appropriate. Add additional rows to include all of your brainstormed intervention options.<sup>18</sup>

**OPTION 1: Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure (Sites 2, outplanting and 3, propagation).**

Branching coral *Pocillopora meandrina* and boulder coral, *Porites lobata* will be used for propagation because they will create the most hydrodynamic roughness on the reef flat and upper fore reef while also being more resistant to bleaching and robust against high wave energy. Coral fragments will be obtained from sites outside the restoration site that have sufficient numbers for collection. Fragments will only be collected from corals that appear to be healthy and show no signs of disease. Corals will be collected from sites that have experienced past bleaching events such that corals are more likely acclimatized or have genes for increased stress tolerance. A nursery site suitability study identified Site 3 – North Bay Reef as not only a source of corals but also a suitable site for a field nursery. Coral fragments will be collected from “corals of opportunity” that are already broken, or by taking small fragments from intact donor colonies. Fragments will be collected every 5 meters to attempt to collect as many distinct genotypes as possible.

Asexual fragmentation will be followed by grow-out in two field nurseries along the windward coast. In addition to Site 3, another field nursery will be established to spread the risk of loss due to unanticipated events. Branching coral fragments will be attached directly to coral trees for propagation using CoralClips [27] or other methods if deemed more viable. Coral trees are lightweight structures tethered to the ocean floor and buoyed with a subsurface float. Coral trees suspended in the water column can move with storm-generated waves or be moved up and down to avoid storms and episodes of high sea surface temperature or heavy freshwater runoff, preventing damage to the tree structure and the corals themselves. Fragments of boulder corals will be epoxied to plates and attached to the coral tree. The coral tree propagation method will enable corals to be vertically adjusted or shaded as needed for acclimatization and lowered in case of storms. The field nursery is exposed to a range of temperatures, water quality conditions, and wave energy, which is expected to create more resilient corals for outplanting.



A scientist measures a coral fragment growing in a coral tree nursery. Credit: Pheona David, Division of Coastal Resources Management, CNMI.

Branching and boulder coral fragments will be transplanted to the substrate using CoralClips and epoxy techniques. These attachment techniques will be tested during the pilot phase and adjustments made in the event of high failure rates to ensure that they can withstand existing and future wave conditions and sea level rise. Marine epoxy has been shown to have the lowest detachment rate and thus should hold up the best against wave action [31]. Other adhesives will be explored based on the best available information. Corals will be outplanted based on the results of baseline studies of coral demography and reef structure. For a given site, corals will be outplanted on the reef flat in areas characterized by additional structure complexity which could prove beneficial to wave energy reduction, as well as at different depths to account for sea level rise and decrease the risk of impacts from potential bleaching events. A rapid response plan will be created for repair or replacement of structures after storms.

Removal of macroalgae by hand or mechanical means may be required at the nursery site to protect propagated corals and at restoration sites to protect coral outplants and recruits. Algae removal frequency may have to be increased if rising ocean temperatures and/or increased nutrient inputs increase algal growth in the future.

**OPTION 2: Stabilize rubble to protect existing corals and enhance natural recruitment (Site 2).** Metal stakes and natural fiber or metal mesh will be used to stabilize rubble areas [32]. Mesh will be checked and maintained regularly to ensure that it can withstand storms and wave action, which may increase with climate change. Mechanical removal of macroalgae by hand or mechanical means from stabilization sites may be required to support natural recruitment. Algae removal frequency may have to be increased if rising ocean temperatures and/or increased nutrient inputs increase algal growth in the future.

<sup>18</sup> The summary of each option should be an easy-to-read paragraph that fully describes the option and incorporates all information from the Step 3B design table. The team found that in writing the summary, some additional information came to light that was included in this paragraph. Such new information should be entered back into the Step 3B design table for rigorous record-keeping.

**OPTION 3: Deploy reef-friendly wave attenuation units designed to reduce wave energy, support natural coral recruitment, and enhance fish habitat (Site 2).** Wave attenuation units (WAUs) will be deployed to the restoration site to reduce wave energy. WAUs will incorporate biologically friendly materials, such as pH-neutral concrete or lightweight concrete with an organic matter matrix to accelerate biological colonization. WAU stabilization will be enhanced with the installation of a scour blanket to reduce potential scouring effects. Sources such as Zepeda-Centeno C. [21] and the World Bank [28] will be consulted to identify WAU prototypes for pilot testing to evaluate their propensity to support natural recruitment, withstand severe wave events, and improve fish habitat as a co-benefit of the restoration intervention. The location and alignment of WAUs will be determined using wave modeling, which will identify configurations with the greatest potential to minimize erosion along the shoreline under existing and future conditions including sea level rise and increasingly severe storm events. In addition, the configuration and density of WAUs may influence local circulation, thus models may also be needed to evaluate these potential effects and to determine the WAU placements that will allow for sufficient circulation to maintain water quality. Wave modeling programs used in reef environments include XBeach, SWAN, and Delft3D [5, 11, 29].

Baseline mapping of reef geometry at the restoration site (e.g., height, structural complexity) using the best available technology (e.g., airborne high-resolution topo/bathymetric LiDAR or UAV imagery) that can be repeated over time [33-36] will need to be conducted to support wave modeling. In addition, macroalgae removal by hand or mechanical means from WAUs may be required to support natural recruitment. Algae removal frequency may have to be increased if rising ocean temperatures and/or increased nutrient inputs increase algal growth in the future.

**OPTION 4: Enhance and diversify herbivore biomass to reduce algal overgrowth and enhance natural coral recruitment (Sites 2, 3).** Sea urchins will be outplanted at appropriate densities to the restoration site from an existing land-based laboratory that is resistant to hurricane force winds and has a back-up power generator. Natural urchin species and densities will first be assessed on other reefs to determine how many urchins are needed to support algae removal at the restoration site. A rapid response plan will be put into place for replenishment of urchins lost at high rates due to disease or temperature extremes. Other herbivore management efforts such as place-based protection, fishing gear restrictions, and catch size limits will also be pursued to diversify herbivore biomass at the restoration site as different functional groups of herbivorous fish (e.g., scarids, acanthurids, kyphosids) are needed to support reef growth and recruitment. For example, scarids are important contributors to sand production on the reef.

### 3C: Evaluate & Select Restoration Interventions

*Describe the evaluation criteria used to select restoration interventions and provide a summary for how these details were determined.*

The Core Planning Team reviewed the multi-evaluation criteria framework in the Guide and made adjustments based on key aspects of the goal. The Core Planning Team and Technical Advisory Group convened to finalize the evaluation framework. One-on-one meetings were held with federal, territorial, and local officials that may be involved in the review and approval of permits for implementation. Input from these agencies helped define aspects of the feasibility of the interventions in terms of additional legal requirements (e.g., environmental assessments) and timelines for receiving permits. The Technical Advisory Group conducted the evaluation individually and submitted their results to the Core Planning Team, which compiled the scores and rationale. A workshop with the Technical Advisory Group and a broader range of stakeholders including local government department staff, nongovernmental organizations, and community members was held to gain feedback on the restoration options. During the workshop, the process and information used to arrive at this step were described to participants, emphasizing the careful, data-driven approach used to set the goal, prioritize sites, and develop restoration options. Feedback was solicited on preferences for various restoration options. Four stations were established, one for each restoration option. Participants visited each station and were given additional information about the options and the opportunity to discuss and provide feedback. Participants were given a shortened version of the evaluation criteria to evaluate each option and submit their scores at the end of the workshop. This feedback was reviewed by the Core Planning Team along with the evaluation conducted with the Technical Advisory Group to select the restoration interventions. The ratings and rationale in the following table represent an average of the individual ratings of the Core Planning Team, Technical Advisory Group, and stakeholder workshop.

Record ratings for each evaluation criteria (scale from 1-5) for each intervention option, using criteria from Table 3.4 and/or criteria developed by your planning team. Add additional columns until all brainstormed intervention options have been evaluated.<sup>19</sup>

| Evaluation Criteria                                                                                                  | Restoration Intervention Rating                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                             |
|----------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                      | Strongly Agree (5), Agree (4), Neutral (3), Disagree (2), Strongly Disagree (1)                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                             |
|                                                                                                                      | OPTION 1<br>Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure                                                                                                                                                                                                                                                                              | OPTION 2<br>Stabilize rubble to protect existing corals and enhance natural recruitment                                                                                                                                                                                                                                                                                                                                                     | OPTION 3<br>Deploy reef-friendly wave attenuation units (WAUs) designed to reduce wave energy and support natural coral recruitment                                                                                                                                        | OPTION 4<br>Enhance and diversify herbivore biomass to reduce algal overgrowth and enhance natural coral recruitment                                                                                                                                                                                                                        |
| <b>Effectiveness</b>                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                             |
| Intervention will be technically effective at achieving restoration goal                                             | 4                                                                                                                                                                                                                                                                                                                                                                                                 | 4                                                                                                                                                                                                                                                                                                                                                                                                                                           | 5                                                                                                                                                                                                                                                                          | 3                                                                                                                                                                                                                                                                                                                                           |
| Intervention will be climate-smart in addressing changing conditions and uncertainties in climate change projections | 4                                                                                                                                                                                                                                                                                                                                                                                                 | 4                                                                                                                                                                                                                                                                                                                                                                                                                                           | 3                                                                                                                                                                                                                                                                          | 2                                                                                                                                                                                                                                                                                                                                           |
| <b>Average rating</b>                                                                                                | <b>4.0</b>                                                                                                                                                                                                                                                                                                                                                                                        | <b>4.0</b>                                                                                                                                                                                                                                                                                                                                                                                                                                  | <b>4.0</b>                                                                                                                                                                                                                                                                 | <b>2.5</b>                                                                                                                                                                                                                                                                                                                                  |
| <b>Rationale</b>                                                                                                     | Intervention will gradually become effective within 15 years as new coral structure will be created with acclimatized structure-building corals designed to survive future sea surface temperature (SST) and high wave events. Monitoring will determine if and how intervention would need to be further adjusted to account for increasing wave action due to more severe storms in the future. | Intervention will be effective early in minimizing physical damage to surrounding corals and supporting natural coral recruitment. New coral structure will be created with acclimatized structure-building corals designed to survive future SSTs and high wave events. Monitoring will determine if and how intervention would need to be further adjusted to account for increasing wave action due to more severe storms in the future. | Intervention will begin working immediately via installation of engineered structures designed to attenuate waves. Natural recruitment from surrounding corals could be hampered by future SSTs. Macroalgal overgrowth could inhibit recruitment on engineered structures. | Intervention effective in the short-term by enhancing natural recruitment but does not directly address wave attenuation that contributes to coastal erosion. Non-acclimatized natural recruits, as well as surrounding adults, may not survive future SSTs thereby reducing the likelihood of enhancing reef structure as sea level rises. |

<sup>19</sup> The ratings and rationale in this table represent an average of the individual ratings of the Core Planning Team, Technical Advisory Group, and stakeholder workshop.

| Evaluation Criteria                                                                                        | Restoration Intervention Rating                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                       |
|------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                            | Strongly Agree (5), Agree (4), Neutral (3), Disagree (2), Strongly Disagree (1)                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                       |
|                                                                                                            | OPTION 1<br>Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure                                                                                                                                                                                                                                                                                            | OPTION 2<br>Stabilize rubble to protect existing corals and enhance natural recruitment                                                                                                                                                                                                                                                                                                                                          | OPTION 3<br>Deploy reef-friendly wave attenuation units (WAUs) designed to reduce wave energy and support natural coral recruitment                                                                                                                                                                                                                                                                                   | OPTION 4<br>Enhance and diversify herbivore biomass to reduce algal overgrowth and enhance natural coral recruitment                                                                                                  |
| <b>Feasibility</b>                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                       |
| Costs of implementation and maintenance are feasible                                                       | 4                                                                                                                                                                                                                                                                                                                                                                                                               | 4                                                                                                                                                                                                                                                                                                                                                                                                                                | 2                                                                                                                                                                                                                                                                                                                                                                                                                     | 5                                                                                                                                                                                                                     |
| Technical capacity will be in place to implement intervention (data, technical knowledge, number of staff) | 4                                                                                                                                                                                                                                                                                                                                                                                                               | 4                                                                                                                                                                                                                                                                                                                                                                                                                                | 3                                                                                                                                                                                                                                                                                                                                                                                                                     | 5                                                                                                                                                                                                                     |
| Physical infrastructure is achievable to implement intervention (e.g., land-based laboratory)              | 5                                                                                                                                                                                                                                                                                                                                                                                                               | 5                                                                                                                                                                                                                                                                                                                                                                                                                                | 4                                                                                                                                                                                                                                                                                                                                                                                                                     | 5                                                                                                                                                                                                                     |
| Required government regulations and permits are obtainable within the implementation timeline              | 4                                                                                                                                                                                                                                                                                                                                                                                                               | 4                                                                                                                                                                                                                                                                                                                                                                                                                                | 2                                                                                                                                                                                                                                                                                                                                                                                                                     | 5                                                                                                                                                                                                                     |
| Strong community, political, and private sector acceptance/support for intervention is available           | 5                                                                                                                                                                                                                                                                                                                                                                                                               | 5                                                                                                                                                                                                                                                                                                                                                                                                                                | 5                                                                                                                                                                                                                                                                                                                                                                                                                     | 3                                                                                                                                                                                                                     |
| <b>Average Rating</b>                                                                                      | <b>4.4</b>                                                                                                                                                                                                                                                                                                                                                                                                      | <b>4.4</b>                                                                                                                                                                                                                                                                                                                                                                                                                       | <b>3.2</b>                                                                                                                                                                                                                                                                                                                                                                                                            | <b>4.6</b>                                                                                                                                                                                                            |
| <b>Rationale</b>                                                                                           | <i>Cost is not prohibitive, consisting of labor and transportation to and from sites (no land-based operations) and supplies such as attachment plates, CoralClips, etc. Field staff have piloted propagation and outplanting techniques proposed in this option. Field nursery is in pilot phase at Site 3, and some proposed outplanting methods have been tested. Permitting process for propagation and</i> | <i>Costs are similar to Option 1, primarily labor, transportation to and from the sites (no land-based operations) and supplies such as attachment plates and coral clips. In addition, natural fiber or wire mesh will be needed for substrate stabilization. A small pilot of this intervention conducted after the tropical cyclone hit the area revealed rubble stabilization and the permitting process to be feasible.</i> | <i>Key challenges for this option are high cost of materials and deployment of WAUs and permitting of the installation of artificial structures on the reef flat. A pilot test is needed to develop and refine protocols for deployment. Community and tourism sector likely to support this intervention as it would provide snorkelers with something to look at and fishers with habitat to support fish stock</i> | <i>Enhancing urchin populations is feasible as a land-based laboratory is already producing a regular supply of urchins. Any efforts to develop new fishing regulations are met with strong community opposition.</i> |

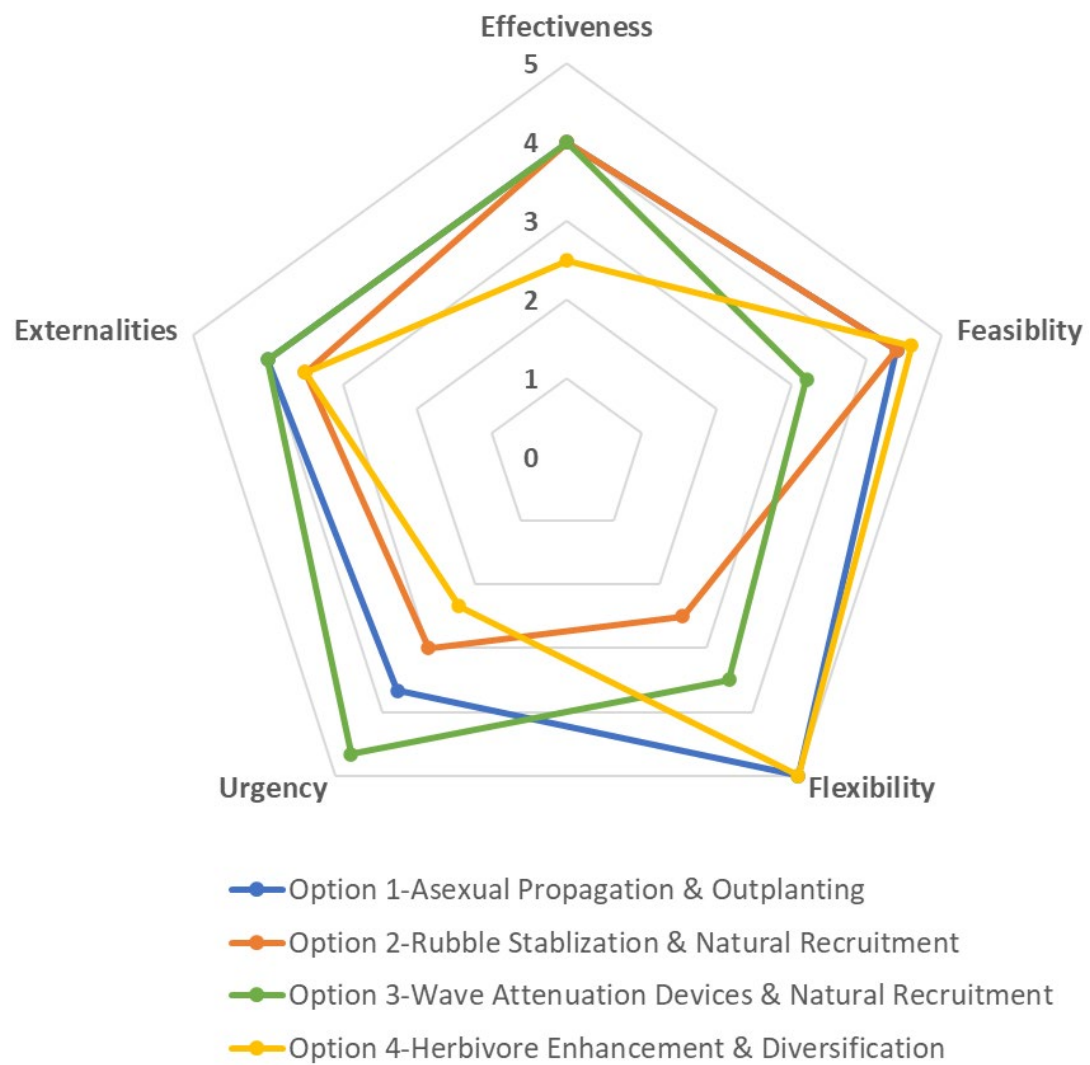


| Evaluation Criteria                                                                                   | Restoration Intervention Rating                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                            |                                                                                                                                                                                                                            |
|-------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                       | Strongly Agree (5), Agree (4), Neutral (3), Disagree (2), Strongly Disagree (1)                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                            |                                                                                                                                                                                                                            |
|                                                                                                       | OPTION 1<br>Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure                                                                                                                                                                                                                                                                                                                                                     | OPTION 2<br>Stabilize rubble to protect existing corals and enhance natural recruitment                                                                                                                                                                                                                   | OPTION 3<br>Deploy reef-friendly wave attenuation units (WAUs) designed to reduce wave energy and support natural coral recruitment                                        | OPTION 4<br>Enhance and diversify herbivore biomass to reduce algal overgrowth and enhance natural coral recruitment                                                                                                       |
|                                                                                                       | <i>outplanting is known and was used for pilot studies. Community support for this option is high as everyone wants coral structure maintained for coastal protection and co-benefits to fishing (Site 2).</i>                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                           | <i>recovery. Public-private partnerships between government and tourism sector could generate funds to support restoration in conjunction with education and outreach.</i> |                                                                                                                                                                                                                            |
| <b>Flexibility</b>                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                            |                                                                                                                                                                                                                            |
| Intervention is designed to be adjustable to accommodate changing conditions and incorporate learning | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 3                                                                                                                                                                                                                                                                                                         | 4                                                                                                                                                                          | 5                                                                                                                                                                                                                          |
| Intervention is reversible if needed                                                                  | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 2                                                                                                                                                                                                                                                                                                         | 3                                                                                                                                                                          | 5                                                                                                                                                                                                                          |
| <b>Average Rating</b>                                                                                 | <b>5.0</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                               | <b>2.5</b>                                                                                                                                                                                                                                                                                                | <b>3.5</b>                                                                                                                                                                 | <b>5.0</b>                                                                                                                                                                                                                 |
| <b>Rationale</b>                                                                                      | <i>Coral trees are designed to be adjustable to changing nursery conditions as they can be moved horizontally and vertically. Corals can be outplanted at different depths to accommodate rates of coral growth and sea level rise. Ongoing protocols are reversible or changeable. For example, different corals can be used in subsequent years to adjust to new conditions. With minimal structures involved, removing coral trees for the nursery would be easy.</i> | <i>Substrate stabilization approach can be adjusted to changing conditions such as wave energy. Unlikely to undo/revise intervention if conditions change. Wire mesh could be removed depending on amount of calcification; however, outplanted corals could be damaged while removing the wire mesh.</i> | <i>WAUs can be designed and installed to accommodate sea level rise and increasing intensity of wave events. Depending on the type of WAU used, it could be removable.</i> | <i>The number and timing of transplantation of urchins and other herbivores is flexible and can be adjusted based on biological conditions on the reef. Urchins can be culled from the reef if densities are too high.</i> |

| Evaluation Criteria                                                                                                                                                  | Restoration Intervention Rating                                                                                                                                                                                                                             |                                                                                                                        |                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                              |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                      | Strongly Agree (5), Agree (4), Neutral (3), Disagree (2), Strongly Disagree (1)                                                                                                                                                                             |                                                                                                                        |                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                              |
|                                                                                                                                                                      | OPTION 1<br>Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure                                                                                                                                        | OPTION 2<br>Stabilize rubble to protect existing corals and enhance natural recruitment                                | OPTION 3<br>Deploy reef-friendly wave attenuation units (WAUs) designed to reduce wave energy and support natural coral recruitment                                                                                                                                | OPTION 4<br>Enhance and diversify herbivore biomass to reduce algal overgrowth and enhance natural coral recruitment                                                                                                                         |
| <b>Urgency</b>                                                                                                                                                       |                                                                                                                                                                                                                                                             |                                                                                                                        |                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                              |
| Degree of threat and cost of inaction are high if intervention is not implemented                                                                                    | 4                                                                                                                                                                                                                                                           | 4                                                                                                                      | 5                                                                                                                                                                                                                                                                  | 2                                                                                                                                                                                                                                            |
| There is an immediate opportunity associated with implementing the intervention based on availability of partnerships, funding, or leveraging other existing efforts | 3                                                                                                                                                                                                                                                           | 3                                                                                                                      | 4                                                                                                                                                                                                                                                                  | 3                                                                                                                                                                                                                                            |
| Results from the intervention can be achieved in a timeframe aligned with urgency of threat                                                                          | 4                                                                                                                                                                                                                                                           | 2                                                                                                                      | 5                                                                                                                                                                                                                                                                  | 2                                                                                                                                                                                                                                            |
| <b>Average Rating</b>                                                                                                                                                | <b>3.7</b>                                                                                                                                                                                                                                                  | <b>3.0</b>                                                                                                             | <b>4.7</b>                                                                                                                                                                                                                                                         | <b>2.3</b>                                                                                                                                                                                                                                   |
| <b>Rationale</b>                                                                                                                                                     | <i>Intervention directly addresses urgent threat of erosion due to both chronic and event-based flooding with sea-level rise. There is great interest in coral gardening and funding this intervention. Wave attenuation will take time to be realized.</i> | <i>Intervention addresses urgent threat of reducing future physical damage to corals by stabilizing the substrate.</i> | <i>Intervention directly addresses urgent threat of erosion due to chronic and event-based flooding with sea-level rise. There is interest from private sector partners in supporting this intervention. Wave attenuation will be immediate upon installation.</i> | <i>Intervention primarily addresses a chronic threat of algal overgrowth which has impeded natural recruitment. Wave attenuation from increased reef structure is unlikely to be achieved in the timeframe needed to address the threat.</i> |
| <b>External Benefits</b>                                                                                                                                             |                                                                                                                                                                                                                                                             |                                                                                                                        |                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                              |
| Intervention achieves benefits outside of the target system, to other ecosystems, and/or human communities (including environmental justice and equity)              | 5                                                                                                                                                                                                                                                           | 4                                                                                                                      | 5                                                                                                                                                                                                                                                                  | 4                                                                                                                                                                                                                                            |

| Evaluation Criteria                                                                           | Restoration Intervention Rating                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|-----------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                               | Strongly Agree (5), Agree (4), Neutral (3), Disagree (2), Strongly Disagree (1)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|                                                                                               | OPTION 1<br>Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | OPTION 2<br>Stabilize rubble to protect existing corals and enhance natural recruitment                                                                                                                                                                                                                                                                                                                                                            | OPTION 3<br>Deploy reef-friendly wave attenuation units (WAUs) designed to reduce wave energy and support natural coral recruitment                                                                                                                                                                                                                 | OPTION 4<br>Enhance and diversify herbivore biomass to reduce algal overgrowth and enhance natural coral recruitment                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Intervention minimizes unintended negative consequences, including carbon footprint           | 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 3                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 3                                                                                                                                                                                                                                                                                                                                                   | 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Average Rating</b>                                                                         | <b>4.0</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | <b>3.5</b>                                                                                                                                                                                                                                                                                                                                                                                                                                         | <b>4.0</b>                                                                                                                                                                                                                                                                                                                                          | <b>3.5</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Rationale</b>                                                                              | Benefits realized over time for fish habitat and resilient coastal communities. Acclimatized coral larvae may be dispersed beyond the target system. Intervention designed to reduce erosion of the coastal highway that provides the only access to residents and visitors. Moderate carbon footprint from extensive boat use for collection and transport trips to nurseries and outplanting site. Propagation and outplanting protocols will minimize damage to adjacent live colonies and prevent transfer of any corals with disease. Coral tree nursery structures can be lowered to be more secure under severe storm events. | This intervention will minimize the potential for rubble and other loose material to be transported beyond the target system during storm events preventing potential damage to other habitats such as sea grass beds. Corals that settle and grow through natural recruitment will eventually support larval dispersal beyond the target system. One-time minimal carbon footprint from development of structures and boat use for installations. | Corals that settle and grow through natural recruitment will eventually support larval dispersal beyond the target system. Intervention designed to reduce erosion to the coastal highway that provides the only access to residents and visitors. One-time minimal carbon footprint from development of structures and boat use for installations. | Corals that settle and grow through natural recruitment will eventually support larval dispersal beyond the target system. Potential for unintended consequences if outplanted urchins overpopulate the reef and cause bioerosion. As other proposed herbivore management efforts, such as place-based protection, fishing gear restrictions, and catch size limits are pursued, the increase in herbivore biomass will have positive community impacts by supporting subsistence and recreational fishers. Moderate carbon footprint from boat use for transport trips from the nursery to outplanting site. |
| <b>Interactions</b>                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>Are there interdependencies, sequencing requirements, or conflicts with other options?</b> | Intervention will take time to realize structural change needed to support goal. Use of man-made structures (Option 3) would help expedite results. Herbivore management is an issue at Site 2 where fishing is heavy. This option should be paired with Option 4 to support preparation                                                                                                                                                                                                                                                                                                                                             | This option would be used at Site 2 to correct problems from loose rubble due to human impacts. This option should be paired with Option 4 to support natural recruitment on stabilized reef structure.                                                                                                                                                                                                                                            | Natural coral recruitment may be inhibited by algal growth. Propagating and outplanting acclimatized corals (Option 1) directly on WAUs and in the surrounding areas may support more resilient natural coral recruitment.                                                                                                                          | This intervention may be appropriate for maintenance of Options 1, 2, and 3 if macroalgal growth becomes problematic on existing reef, stabilized rubble, and/or WAUs.                                                                                                                                                                                                                                                                                                                                                                                                                                        |

| Evaluation Criteria    | Restoration Intervention Rating                                                                                             |                                                                                                |                                                                                                                                            |                                                                                                                             |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|
|                        | Strongly Agree (5), Agree (4), Neutral (3), Disagree (2), Strongly Disagree (1)                                             |                                                                                                |                                                                                                                                            |                                                                                                                             |
|                        | <b>OPTION 1</b><br>Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure | <b>OPTION 2</b><br>Stabilize rubble to protect existing corals and enhance natural recruitment | <b>OPTION 3</b><br>Deploy reef-friendly wave attenuation units (WAUs) designed to reduce wave energy and support natural coral recruitment | <b>OPTION 4</b><br>Enhance and diversify herbivore biomass to reduce algal overgrowth and enhance natural coral recruitment |
|                        | <i>and maintenance of restoration site conditions.</i>                                                                      |                                                                                                |                                                                                                                                            |                                                                                                                             |
| <b>OVERALL AVERAGE</b> | <b>4.2</b>                                                                                                                  | <b>3.5</b>                                                                                     | <b>3.9</b>                                                                                                                                 | <b>3.6</b>                                                                                                                  |



<sup>20</sup> A radar diagram was used to assist in visualizing the differences in scoring among options.



Document the intervention(s) that best support the priority goal as well as the process and rationale used during your evaluation process.

**Selected Interventions(s): Propagation at Site 3: North Bay Reef and Outplanting on Existing Reef and Wave Attenuation Units (WAU) at Site 2, Fisher's Reef**

After evaluating all options, the team determined that a hybrid green-gray restoration intervention would be needed to achieve the goal within 15 years. Option 1, asexually propagate structure-building corals in a field nursery and outplant on existing reef structure and Option 3, install wave attenuation units (WAUs), will be used in combination, including outplanting of corals onto WAUs to further accelerate reef build-up. Attachment methods for WAUs will be the same as those for natural substrate. In addition, Option 4 will be used to prepare and maintain the site by outplanting sea urchins raised in a land-based nursery and by advocating for other herbivore management interventions. This combination of options will focus on Site 2 as the restoration sites and Site 3 as the nursery site. Substrate stabilization, Option 2, will not be carried forward until the impacts of marine debris and destructive fishing practices have been addressed.

**Propagation.** Structure-building corals will be propagated in a field nursery. Branching coral *Pocillopora meandrina* and boulder coral *Porites lobata* will be used because they will create the most friction on the reef flat while also being more resistant to bleaching and robust against high wave energy. Coral fragments will be obtained from sites outside the restoration site that have sufficient numbers for collection, as well as from sites that have experienced past thermal bleaching events so that the corals are more likely to have greater thermal stress tolerance. A nursery site suitability study identified Site 3 – North Bay Reef as not only a source of corals but also a suitable site for a field nursery. Coral fragments will be collected from “corals of opportunity” that are already broken, or from taking small fragments from intact donor colonies. Fragments will be collected every 5 m to attempt to collect as many distinct genotypes as possible. Corals with indications of disease or stress will be avoided. Asexual fragmentation will be followed by grow-out in two field nurseries along the windward coast. In addition to Site 3, another field nursery will be established to mitigate the risk of loss due to unanticipated events. Branching coral fragments will be attached directly to coral trees for propagation using CoralClips (Suggett, 2020). Fragments of boulder corals will be epoxied to plates and attached to the coral tree. The coral tree propagation method will enable corals to be vertically adjusted or shaded as needed for acclimatization and lowered in case of storms. The nursery is exposed to a range of temperatures, water quality conditions, and wave energy, so is expected to engender more resilient corals for outplanting.

**Outplanting Techniques.** Propagated corals will be outplanted on existing reef structure and WAUs at Site 2. Branching and boulder coral fragments will be transplanted to existing reef structure and WAUs using techniques (e.g., CoralClips and epoxy) that will be tested during the pilot phase and in the event of high failure rates, adjustments will be made to ensure that the outplanted corals will withstand existing and future wave conditions and sea level rise (Dizon et al., 2008).



An artificial reef structure with coral recruits.  
Credit: Boze Hancock.

WAUs will incorporate biologically friendly materials, such as pH-neutral concrete or lightweight concrete with an organic matter matrix to accelerate biological colonization. WAU stabilization will be enhanced with the installation of scour blankets to reduce potential scouring effects. Sources such as Zepeda-Centeno C. [21] and the World Bank [28] will be consulted to identify WAU prototypes for pilot testing to evaluate their propensity to support natural recruitment, withstand severe wave events, and improve fish habitat as a co-benefit of the restoration intervention.

**Outplanting Configuration.** The number and configuration of WAUs will be based on the results of wave modeling, using programs such as XBeach, SWAN, and Delft3D [5, 11, 29]. These programs can generally model reef areas at the scale needed to determine the WAU

configurations that have the greatest potential to minimize shoreline erosion under existing and future conditions, including sea level rise and increasing severe storm events. The locations of corals outplanted to existing reef areas will be based on both the configuration of WAUs determined through wave modeling as well as baseline studies of coral demography and reef structure. For a given site, corals will be outplanted on the reef flat in areas characterized by additional structural complexity, which could prove beneficial to wave energy reduction, as well as at different depths to account for sea level rise and decrease the risk of impacts from potential bleaching events. A rapid response plan will be created for the repair or replacement of structures after storms.

**Site Preparation and Maintenance.** Removal of macroalgae by hand or mechanical means may be required at the nursery site to protect propagated corals and at the restoration site to protect coral outplants and recruits. Algae removal frequency may have to be increased if rising ocean temperatures and/or increased nutrient inputs increase algal growth in the future. Sea urchins will be outplanted at appropriate densities to the restoration site from an existing land-based laboratory that is resistant to hurricane force winds and has a back-up power generator. Natural urchin species and densities will first be assessed on other reefs to determine how many urchins are needed to support algae removal at the restoration site. A rapid response plan will be put into place for replenishment of urchins lost at high rates due to disease or temperature extremes. Other herbivore management efforts, such as place-based protection, fishing gear restrictions, and catch size limits will also be pursued in order to diversify herbivore biomass at the restoration site as different functional groups of herbivorous fish (e.g., scarids, acanthurids, kyphosids) are needed to support reef growth and recruitment. This will also counterbalance uncertainty in impacts of climate change on urchins and other herbivores and the macroalgae they consume.

**Process and Rationale.** The Core Planning team, with input from the Technical Advisory Group, decided that a combination of restoration Options 1 and 3 was needed to achieve the goal. In addition, it was decided that these restoration efforts should be focused on Site 2 for the outplanting and Site 3 for the field-based nursery. The Technical Advisory Group provided vital feedback throughout this step. Meetings with federal, state, and local officials were held to identify any constraints in terms of approach or timing (e.g., permitting) that could adversely impact the implementation of a restoration option.

While propagation and outplanting of structure-building corals on existing reef will support wave attenuation in the long term, the deployment of reef-friendly WAUs is likely needed for more immediate results. Wave modeling will be needed to determine effectiveness of this combined intervention and to inform decisions on the number and configuration of outplants and WAUs. Herbivore management (Option 4) was also deemed necessary for site preparation and maintenance but is of secondary importance in promoting settlement of coral recruits. Herbivore management on its own may not be sufficient to support reef resilience to wave events over the long term [37].

Reef restoration using this intervention will be focused on Site 2, Fisher's Reef, whilst the setup of a nursery for coral propagation should be focused on Site 3, North Bay Reef. An additional nursery site will be needed to reduce the risk that coral propagation is jeopardized by unfavorable environmental conditions and/or events at a single site.



## Step 3 Stakeholder Engagement

*List technical experts, stakeholders, and partners including scientists, engineers, community members, private sector, and federal and local government engaged for this step.*

| Technical Expertise                                                                                                                                                                                        | Key Stakeholders                                                                                                                                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| Coral reef biologist/coral ecologist<br>Coastal engineer<br>Coastal geologist<br>Physical/chemical oceanographer<br>Climate scientist<br>Watershed manager<br>Water quality specialist<br>Land use planner | <b>Non-Government</b><br>Representatives of environmental advocacy groups<br><b>Government</b><br>Regulatory Agencies (federal, state, and local) |

*Provide a summary of stakeholder engagement activities to be taken for this step.*

For this step, stakeholder engagement was confined to the Technical Advisory Group and government and nongovernmental entities. With the restoration interventions and sites finalized, education and outreach activities will be conducted for communities where restoration sites are located. Factsheets on the selected restoration interventions will be developed and disseminated during community meetings and presentations. These factsheets will describe the restoration interventions and highlight the need to minimize any human disturbances to the restoration sites.

## STEP 4: DEVELOP RESTORATION ACTION PLAN

### 4A: Define SMART Objectives

*Identify potential performance metrics and intermediate results for the priority goal and restoration intervention(s) selected in Step 3C.*

**Goal:** Within 15 years, restored reef structure reduces wave energy that contributes to coastal erosion, thereby strengthening the resilience of coastal communities to sea level rise and increasingly intense storms.

**Intervention:** Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure and reef-friendly wave attenuation units (WAUs). Use herbivore management for restoration site preparation and maintenance.

A worker distributes juvenile urchins on a reef.  
Credit: Kyle Rothenborg, Hawaii.



| Objectives                                      | Time (Years)                                                                                                                                                                                                                          |                                                                                                                                                                                        |                                                                                                                                                                    |                                                                                                                                                                        |
|-------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                 | 1 – 3                                                                                                                                                                                                                                 | 4 – 6                                                                                                                                                                                  | 7 – 10                                                                                                                                                             | 11 – <15                                                                                                                                                               |
| Potential Performance Metrics                   | <ul style="list-style-type: none"> <li>• Coral survival in field nursery</li> <li>• Number of sea urchins outplanted</li> <li>• Sea urchin density (baseline)</li> </ul>                                                              | <ul style="list-style-type: none"> <li>• Coral survival of outplants on existing reef structure</li> <li>• Sea urchin density</li> </ul>                                               | <ul style="list-style-type: none"> <li>• Restored coral height</li> <li>• % reduction in wave energy from restored reef structure</li> </ul>                       | <ul style="list-style-type: none"> <li>• % reduction in wave energy from restored reef structure</li> </ul>                                                            |
| Intermediate Results (Goal)                     |                                                                                                                                                                                                                                       |                                                                                                                                                                                        | <ul style="list-style-type: none"> <li>• Increased colony height, coral cover, and rugosity</li> <li>• Wave energy reduced from restored reef structure</li> </ul> | <ul style="list-style-type: none"> <li>• Increased coral colony size, coral cover, and rugosity</li> <li>• Wave energy reduced from restored reef structure</li> </ul> |
| Intermediate Results (Restoration Intervention) | <ul style="list-style-type: none"> <li>• Nursery is established and producing corals for propagation</li> <li>• Urchins seeded at restoration sites</li> <li>• Outplanting to reef structure tested</li> <li>• WAUs tested</li> </ul> | <ul style="list-style-type: none"> <li>• High survival of outplanted corals</li> <li>• Increased urchin population maintained at restoration sites</li> <li>• WAUs deployed</li> </ul> |                                                                                                                                                                    |                                                                                                                                                                        |

Craft SMART objectives and metrics that will be used to monitor performance of the restoration intervention(s) toward the goal.

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Questions to identify metrics for medium to long-term objectives related to the goal</b></p> <ul style="list-style-type: none"> <li>• What is the percent reduction in wave energy desired/possible from reef restoration at the site?</li> <li>• What type of storm event must the restored reef structure/WAUs withstand?</li> <li>• How should the restored reef structure be designed to keep up with sea level rise?</li> <li>• By what timeframes should we expect to see reduced wave energy from restoration?</li> </ul>                                                                                                                                                                                                | <p><b>Activity to Address Information/Data Gaps:</b></p> <ul style="list-style-type: none"> <li>• Measure wave energy by installing wave buoys and/or bottom mounted pressure sensors to establish the baseline wave energy across the restoration site under different wave conditions</li> <li>• Conduct wave modeling and simulations to determine the number and configuration WAUs under various wave energy scenarios</li> <li>• Determine the appropriate density of urchins needed for site preparation and maintenance</li> <li>• Identify other herbivores for diversification planning</li> </ul>                                                                                                                                                                                                                                                                                               |
| <p><b>Intervention(s):</b> Asexually propagate structure-building corals in a field nursery and outplant on existing reef structure and reef-friendly WAUs. Enhance and diversify herbivore biomass through outplanting urchins from land-based nursery and other measures for restoration site preparation and maintenance.</p>                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <p><b>Questions to identify metrics for short-term and medium-term objectives related to the intervention:</b></p> <ul style="list-style-type: none"> <li>• How many colonies of <i>Pocillopora</i> and <i>Porites</i> can be propagated per year?</li> <li>• How many nurseries will be required? Where should the nurseries be established to achieve desired pre-conditioning?</li> <li>• How many colonies of <i>Pocillopora</i> and <i>Porites</i> should be propagated in nurseries to account for future losses of corals?</li> <li>• How many colonies of <i>Pocillopora</i> and <i>Porites</i> must be outplanted to natural reef structure and WAUs to achieve sufficient reef build-up for reduced wave energy?</li> </ul> | <p><b>Activity to Address Information/Data Gaps:</b></p> <ul style="list-style-type: none"> <li>• Conduct baseline monitoring of natural reefs to determine density and number of coral colonies required</li> <li>• Conduct pilot study on coral propagation and outplanting</li> <li>• Conduct monitoring of potential nursery sites for desired pre-conditioning environment</li> <li>• Conduct pilot study on viability of reef-friendly WAU prototypes</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <p><b>List SMART Objectives:</b></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | <p><b>Corresponding Performance Metrics</b></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <p><b>Objective 1:</b> Within 5 years, 250 fragments each of branching coral <i>Pocillopora meandrina</i> and boulder coral <i>Porites lobata</i> have been preconditioned in a field nursery and outplanted with 50% survival on existing reef structure and WAU prototypes to demonstrate proof of concept.</p>                                                                                                                                                                                                                                                                                                                                                                                                                     | <ul style="list-style-type: none"> <li>• Number of WAU prototypes created and deployed at Fisher's Reef (Site 2)</li> <li>• Number and % survival of corals propagated in nurseries (Site 3) and outplanted on existing reef and WAU prototypes (Site 2)</li> <li>• Number and density of urchins outplanted at Fisher's Reef</li> <li>• Number of corals naturally recruited on WAU prototypes</li> <li>• Universal Metrics [12]:             <ul style="list-style-type: none"> <li>○ Monthly minimum, maximum, and mean temperature (nursery and outplanting sites)</li> <li>○ Restored reef areal dimension: outplant plot and ecological footprint (baseline)</li> <li>○ Population metrics: mean coral size, abundance, size-frequency distribution (baseline)</li> </ul> </li> <li>• Monthly minimum, maximum, and mean total suspended solids, salinity, and temperature (nursery site)</li> </ul> |

|                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
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| <p><b>Objective 2:</b> Within 3 years, the wave energy reduction goal and outplanting configuration needed to achieve that goal are determined via models, and the results peer-reviewed.</p> | <ul style="list-style-type: none"> <li>• Baseline physical characteristics of the restoration site established including wave energy, bathymetry, geology, geotechnical conditions, and wave climate</li> <li>• Modeling of the existing and proposed reef configuration for different wave energy reduction goals completed</li> <li>• Wave energy reduction goal and WAU configuration established for the restoration site</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <p><b>Objective 3:</b> Within 10 years, wave energy is reduced by 50%, and restored reef areal dimension expands naturally by an additional 30% after reef restoration.</p>                   | <p>Long-term monitoring and evaluation plan will include universal metrics and goal-specific metrics [12]:</p> <ul style="list-style-type: none"> <li>• Restored reef areal dimension: outplant plot and ecological footprint</li> <li>• Population metrics: mean coral size, height, abundance, size-frequency distribution</li> <li>• Reduced wave energy</li> </ul> <p><i>The percent reduction in wave energy, measured as a function of wave height, will be determined as the ratio of the wave energy landward of the restored reef to the wave energy on the seaward side. Bottom mounted pressure sensors or wave buoys will be used for short periods of time to measure the wave height and period. Estimated wave energy reduction goals for the restored reef will be reviewed and validated based on modeling.</i></p> <ul style="list-style-type: none"> <li>• 25% reduction in wave energy 5 years after reef restoration</li> <li>• 50% reduction in wave energy 10 years after reef restoration</li> </ul> |
| <p><b>Objective 4:</b> Within 15 years, wave energy is reduced by 90%, the restored reef areal dimension is maintained, and natural reef build-up continues after reef restoration.</p>       | <p>Long-term monitoring and evaluation plan will include universal metrics and goal-specific metrics [12]:</p> <ul style="list-style-type: none"> <li>• Restored reef areal dimension: outplant plot and ecological footprint</li> <li>• Population metrics: mean coral size, height, abundance, size-frequency distribution</li> <li>• Reduced wave energy</li> </ul> <p><i>The percent reduction in wave energy, measured as a function of wave height, will be determined as the ratio of the wave energy landward of the restored reef to the wave energy on the seaward side. Bottom mounted pressure sensors or wave buoys will be used for short periods of time to measure the wave height and period. Estimated wave energy reduction goals will be reviewed and validated based on modeling.</i></p> <ul style="list-style-type: none"> <li>• 90% reduction in wave energy within 15 years of reef restoration</li> </ul>                                                                                          |



## 4B: Develop Activities and Implementation Timeline

Prepare a table describing restoration activities (intervention activities as well as supporting management and community engagement activities), with the timeframe and responsible party for completing each activity.<sup>21</sup>

**Goal:** Within 15 years, restored reef structure reduces wave energy that contributes to coastal erosion, thereby strengthening the resilience of coastal communities to sea level rise and increasingly intense storms.

**Objective 1:** Within 5 years, 250 fragments each of branching coral *Pocillopora meandrina* and boulder coral *Porites lobata* have been preconditioned in a field nursery and outplanted with 50% survival on existing reef structure and WAU prototypes to demonstrate proof of concept.

**Performance Metrics:**

- Number of WAU prototypes created and deployed on at Fisher's Reef (Site 2)
- Number and % survival of corals propagated in nurseries (Site 3) and outplanted on WAU prototypes and existing reef structure (Site 2)
- Number and density of urchins outplanted at Fisher's Reef
- Number of corals recruited on WAU prototypes
- Universal Metrics [12]:
  - Monthly minimum, maximum, and mean temperature (nursery and outplanting sites)
  - Restored reef areal dimension: outplant plot and ecological footprint (baseline)
  - Population metrics: mean coral size, abundance, size-frequency distribution (baseline)
- Monthly minimum, maximum, and mean total suspended solids, salinity, and temperature (nursery site)

| Activities |                                                                                                                                                                                                                                                                             | Timeframe  |
|------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| 1.1        | Establish a Coral Propagation and Outplanting Pilot Study Working Group with a lead and experts in coral ecology, biology, and artificial reef structures, such as coastal engineers, to develop a detailed design and work plan for the pilot phase and its implementation | Year 1 – 5 |
| 1.2        | For restoration sites, conduct baseline survey of population metrics (mean coral size, abundance, size-frequency distribution)                                                                                                                                              | Year 1     |
| 1.3        | Establish location, number, configuration, and size of outplant plots for pilot studies                                                                                                                                                                                     | Year 1     |
| 1.4        | Monitor temperature and water quality at both restoration sites as well as the field nursery to document the pre-conditioning environment                                                                                                                                   | Year 1 – 5 |
| 1.5        | Develop propagation and outplanting protocols                                                                                                                                                                                                                               | Year 1     |
| 1.6        | Obtain permits for field activities                                                                                                                                                                                                                                         | Year 1     |
| 1.7        | Outplant sea urchins from land-based nursery and monitor survival                                                                                                                                                                                                           | Year 2     |
| 1.8        | Establish <i>in situ</i> nursery and develop and test propagation protocol                                                                                                                                                                                                  | Year 1 – 2 |
| 1.9        | Develop and test WAU prototypes with and without outplanted corals                                                                                                                                                                                                          | Year 2 – 3 |
| 1.10       | Outplant corals and monitor coral outplant survival                                                                                                                                                                                                                         | Year 3 – 5 |
| 1.11       | Conduct peer review of the pilot study and make any adjustments in coral species, propagation and outplanting techniques, and WAU designs based on Activity 2.7                                                                                                             | Year 5     |

<sup>21</sup> Note that a responsible party for each objective and activity should be identified in the Action Plan. In this hypothetical example, it was decided not to invent fictitious names.

| <b>Goal:</b> Within 15 years, restored reef structure reduces wave energy that contributes to coastal erosion, thereby strengthening the resilience of coastal communities to sea level rise and increasingly intense storms.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                    |                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|
| <b>Objective 2:</b> Within 3 years, the wave energy reduction goal and outplanting configuration needed to achieve that goal are determined via models, and the results peer-reviewed.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                    |                  |
| <b>Performance Metrics:</b> <ul style="list-style-type: none"> <li>Baseline physical characteristics of the restoration site documented including wave energy, bathymetry, geology, geotechnical conditions, and wave climate</li> <li>Modeling of the existing and proposed reef configuration for different wave energy reduction goals completed</li> <li>Wave energy reduction goal and WAU configuration established for the restoration site</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                    |                  |
| Activities                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                    | Timeframe        |
| 2.1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Establish a Coastal Processes Pilot Study Working Group with relevant experts to create a detailed work plan                                                                                                       | Year 1 – 3       |
| 2.2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Prepare detailed work plan to develop model wave energy reduction scenarios for outplanting corals on existing structures and WAUs.                                                                                | Year 2           |
| 2.3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Conduct baseline mapping of reef geometry at the restoration site (e.g., height, structural complexity) using the best available technology such as high-resolution airborne topo/bathymetric LiDAR or UAV imagery | Year 1 – 2       |
| 2.4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Conduct baseline monitoring of wave energy across the restoration site using instrumentation (e.g., bottom-mounted pressure sensors or wave buoys) and methods that can be repeated over time                      | Year 1 – 2       |
| 2.5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Conduct hydrodynamic modeling to simulate different configurations and combinations of coral outplants and WAUs to establish feasible wave energy reduction goals for restoration                                  | Year 2           |
| 2.6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Develop and test WAU prototypes with and without outplanted corals                                                                                                                                                 | Year 2 – 3       |
| 2.7                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Conduct peer review of the results of the modeling and make any adjustments to outplanting configurations and WAU designs                                                                                          | Year 4           |
| <b>Objective 3:</b> Within 10 years, wave energy is reduced by 50%, and restored reef areal dimension expands naturally by an additional 30% after reef restoration.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                    |                  |
| <b>Performance Metrics:</b> Long-term monitoring and evaluation plan will include universal metrics and goal-specific metrics [12]: <ul style="list-style-type: none"> <li>Restored reef areal dimension: outplant plot and ecological footprint</li> <li>Population metrics: mean coral size, height, abundance, size-frequency distribution</li> <li>Reef structure and complexity: mean height of corals and reef structure at a restoration site</li> <li>Reduced wave energy: <i>The percent reduction in wave energy, measured as a function of wave height, will be determined as the ratio of the wave energy landward of the restored reef to the wave energy on the seaward side. Bottom mounted pressure sensors or wave buoys will be used for short periods of time to measure the wave heights. Wave energy is measured by wave height and period. Estimated wave energy reduction goals will be reviewed and validated based on baseline assessment and modeling conducted under Objective 2:</i> <ul style="list-style-type: none"> <li>25% reduction in wave energy 5 years after reef restoration</li> <li>50% reduction in wave energy 10 years after reef restoration</li> </ul> </li> </ul> |                                                                                                                                                                                                                    |                  |
| Activities                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                    | Timeframe        |
| 3.1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Review and refine Restoration Action Plan, adjusting SMART objectives and metrics and activities as needed based on results of pilot phases                                                                        | Year 5           |
| 3.2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Refine propagation and outplanting protocol and schedule                                                                                                                                                           | Year 5           |
| 3.3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Develop long-term restoration monitoring and evaluation plan                                                                                                                                                       | Year 5           |
| 3.4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Update existing or obtain new permits for field activities                                                                                                                                                         | Year 5           |
| 3.5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Scale-up nursery operations                                                                                                                                                                                        | Year 6 – ongoing |

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                              |                   |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|
| <b>Goal:</b> Within 15 years, restored reef structure reduces wave energy that contributes to coastal erosion, thereby strengthening the resilience of coastal communities to sea level rise and increasingly intense storms.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                              |                   |
| 3.6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Scale-up outplanting operations                                                                                                                                              | Year 6 – ongoing  |
| 3.7                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Monitor reef geometry at the restoration site (e.g., height, structural complexity) using methodology used in Activity 2.3 to compare to baseline images collected in Year 1 | Year 6, 8, and 10 |
| 3.8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Implement long-term restoration monitoring and evaluation plan                                                                                                               | Year 6 – ongoing  |
| 3.9                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Conduct peer review of restoration operations and results                                                                                                                    | Bi-Annual         |
| <b>Objective 4:</b> Within 15 years, wave energy is reduced by 90%, the restored reef areal dimension is maintained, and natural reef build-up continues after reef restoration.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                              |                   |
| <b>Performance Metrics:</b> Long-term monitoring and evaluation plan will include universal metrics and goal-specific metrics [12]: <ul style="list-style-type: none"> <li>• Restored reef areal dimension: outplant plot and ecological footprint</li> <li>• Population metrics: mean coral size, height, abundance, size-frequency distribution</li> <li>• Reef structure and complexity: mean height of corals and reef structure at a restoration site</li> <li>• Reduced wave energy: <i>The percent reduction in wave energy, measured as a function of wave height, will be determined as the ratio of the wave energy landward of the restored reef to the wave energy on the seaward side. Bottom mounted pressure sensors or wave buoys will be used for short periods of time to measure the wave height and period. Estimated wave energy reduction goals will be reviewed and validated based on baseline assessment and modeling conducted under Objective 2:</i> <ul style="list-style-type: none"> <li>○ 90% reduction in wave energy within 15 years of reef restoration</li> </ul> </li> </ul> |                                                                                                                                                                              |                   |
| <b>Activities</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                              | <b>Timeframe</b>  |
| 4.1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Implement long-term restoration monitoring and evaluation plan                                                                                                               | Years 10 – 15     |
| 4.2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Maintain and replace damaged WAUs as needed after severe storm events                                                                                                        | Years 10 – 15     |
| 4.3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Maintain outplanting activities to replace corals lost from severe storm events and bleaching                                                                                | Years 10 – 15     |
| 4.4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Maintain algae removal and urchin outplanting as needed                                                                                                                      | Years 10 – 15     |



Wave attenuation units reduce wave energy.  
Credit: Boze Hancock.

Prepare a table with this information for any supporting management and community engagement activities.<sup>22</sup>

|                                                                                                                                                                                                                                                                         |                                                                                                                                                                            |                  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|
| <b>Objective 5:</b> Provide scientific information to local governments to inform decision-making on methods to reduce coastal erosion by improving floodplain management, limiting shoreline armoring, and incentivizing living shorelines in the face of rising seas. |                                                                                                                                                                            |                  |
| <b>Activities</b>                                                                                                                                                                                                                                                       |                                                                                                                                                                            | <b>Timeframe</b> |
| 5.1                                                                                                                                                                                                                                                                     | Review existing land use and development plans and projects that contribute to coastal erosion now and in the future with climate change                                   | Year 1 – 2       |
| 5.2                                                                                                                                                                                                                                                                     | Identify opportunities to improve plans and projects to reduce coastal erosion                                                                                             | Year 1 – 2       |
| 5.3                                                                                                                                                                                                                                                                     | Conduct education and outreach with communities on how to improve shoreline management                                                                                     | Year 2 – 5       |
| <b>Objective 6:</b> Work with the local government and communities to improve herbivore diversity and biomass at the restoration site.                                                                                                                                  |                                                                                                                                                                            |                  |
| 6.1                                                                                                                                                                                                                                                                     | Conduct education and outreach with a wide range of stakeholders on the importance of increasing the diversity and abundance of herbivorous fish biomass                   | Year 1 – 2       |
| 6.2                                                                                                                                                                                                                                                                     | Identify options for enhancing herbivore diversity and biomass                                                                                                             | Year 1 – 2       |
| 6.3                                                                                                                                                                                                                                                                     | Provide scientific information to inform decisions on place-based management of herbivores                                                                                 | Year 2 – 5       |
| <b>Objective 7:</b> Develop options for sustainable financing mechanisms to support restoration costs through long-term public-private partnerships.                                                                                                                    |                                                                                                                                                                            |                  |
| <b>Activities</b>                                                                                                                                                                                                                                                       |                                                                                                                                                                            | <b>Timeframe</b> |
| 7.1                                                                                                                                                                                                                                                                     | Develop a restoration advisory group including government, nongovernment, and private partners                                                                             | Year 1           |
| 7.2                                                                                                                                                                                                                                                                     | Provide regular updates of restoration activities to the advisory group                                                                                                    | Ongoing          |
| 7.3                                                                                                                                                                                                                                                                     | Work with the advisory group to identify sustainable financing options for restoration including site-specific restoration funds, reef insurance [38], and other resources | Ongoing          |

## 4C: Build Action Plan

Develop your Restoration Action Plan (you can use Appendix 2 as a template). Provide an overview of the process used to develop your plan.

The Core Planning team leader used the Workbook to populate the Restoration Action Plan template. The completed Action Plan is found at the beginning of this report. The Action Plan was sent to the rest of the core planning team for review. The plan was then shared with technical advisors for their final review. This Action Plan served as the basis for a grant proposal.

<sup>22</sup> The Guide and Workbook do not direct the reader to develop SMART objectives for other supporting management activities. These illustrative objectives were considered useful in this example to help organize key activities that support restoration.



## Step 4 Stakeholder Engagement

*List technical experts, stakeholders, and partners including scientists, engineers, community members, private sector, and federal and local government engaged for this step.*

| Technical Expertise                                                                               | Key Stakeholders                                                                                                                                                                                                                                                                                            |
|---------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Coral reef biologist/coral ecologist<br>Coastal engineer<br>Watershed manager<br>Land use planner | <b>Non-Government</b><br>Residents impacted by chronic coastal erosion<br>Fishing community<br>Tourism industry representatives<br>Communities located along the Windward coast<br>Representatives of environmental advocacy groups<br><b>Government</b><br>Regulatory Agencies (federal, state, and local) |

*Provide a summary of stakeholder engagement activities to be taken for this step.*

Now finalized, the Ho'okohukohu 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 a combination of in-person and virtual. 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. In addition, two Pilot Study Working Groups will be established to conduct literature review and develop a detailed design of the pilot studies and modeling for Objectives 1 and 2. These groups will regularly meet together and share information, progress, and insights on restoration design and implementation that will be used to update the Action Plan. The results of the pilot phase and modeling studies will be presented to communities and key stakeholder groups. Education and outreach activities will be conducted to foster and maintain support for coral restoration and herbivore management. Educational presentations and materials on the restoration project will be prepared and communicated to students, particularly in target communities.



Hawksbill turtle encounter.  
Credit: Valentine Vaeoso, American Samoa.

## REFERENCES

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1. Shaver, E. C., Courtney, C.A., West, J.M., Maynard, J., Hein, M., Wagner, C., Philibotte, J., MacGowan, P., McLeod, L., Böstrom-Einarsson, L., Bucchianeri, K., Johnston, L., and Koss, J. 2020. A Manager's Guide to Coral Reef Restoration Planning and Design. NOAA Technical Memorandum CRCP 36, 128 pp. [https://www.coris.noaa.gov/activities/restoration\\_guide/welcome.html](https://www.coris.noaa.gov/activities/restoration_guide/welcome.html)
2. Reguero, B. G., Secaira, F., Toimil, A., Escudero, M., Díaz-Simal, P., Beck, M. W., Rodolfo, S., Storlazzi, C., and Losada, I. J. 2019. The Risk Reduction Benefits of the Mesoamerican Reef in Mexico. *Frontiers in Earth Science*, 7, 125. Doi:10.3389/feart.2019.00125.
3. Storlazzi, C. D., Reguero, Borja G., Cole, Aaron D., Lowe, Erik, Shope, James B., Gibbs, Ann E., Nickel, Barry A., McCall, Robert T., van Dongeren, Ap R., and Beck, M. W. 2019. Rigorously Valuing the Role of U.S. Coral Reefs in Coastal Hazard Risk Reduction. (Open-File Report 2019–1027) Doi:10.3133/ofr20191027.
4. Harris, D., Rovere, A., Parravicini, V., and Casella, E. 2016. The role of coral reef rugosity in dissipating wave energy and coastal protection. EPSC2016-17446. <https://ui.adsabs.harvard.edu/abs/2016EGUGA..1817446H>
5. Quataert, E., Storlazzi, C., van Rooijen, A., Cheriton, O., and van Dongeren, A. 2015. The influence of coral reefs and climate change on wave-driven flooding of tropical coastlines. *Geophysical Research Letters*, 42, 6407–6415. Doi:10.1002/2015GL064861.
6. Ferrario, F., Beck, M. W., Storlazzi, C. D., Micheli, F., Shepard, C. C., and Airolidi, L. 2014. The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. *Nature Communications*, 5(1), 3794. Doi:10.1038/ncomms4794.
7. Alvarez-Filip, L., Dulvy, N. K., Côte, I. M., Watkinson, A. R., and Gill, J. A. 2011. Coral identity underpins architectural complexity on Caribbean reefs. *Ecol Appl*, 21(6), 2223–2231. Doi:10.1890/10-1563.1.
8. Precht, W., Aronson, R., and Swanson, D. 2001. Improving scientific decision-making in the restoration of ship-grounding sites on coral reefs. *Bulletin of Marine Science*, 69, 1001–1012.
9. Perry, C. T., Kench, P. S., Smithers, S. G., Riegl, B., Yamano, H., and O'Leary, M. J. 2011. Implications of reef ecosystem change for the stability and maintenance of coral reef islands. *Global Change Biology*, 17(12), 3679–3696. Doi:10.1111/j.1365-2486.2011.02523.x.
10. Storlazzi, C. D., Elias, E., Field, M. E., and Presto, M. K. 2011. Numerical modeling of the impact of sea-level rise on fringing coral reef hydrodynamics and sediment transport. *Coral Reefs*, 30, 83–96. Doi:10.1007/s00338-011-0723-9.
11. Grady, A. E., Moore L.J., Storlazzi, C.D., Elias, E., and Reidenbach, M.A. 2013. The influence of sea-level rise and changes in fringing reef morphology on gradients in alongshore sediment transport. *Geophysical Research Letters*, 40, 3096–3101. Doi:10.1002/grl.50577.
12. Goergen, E. A., Schopmeyer, S., Moulding, A.L., Moura, A., Kramer, P., and Viehman, T.S. 2020. Coral Reef Restoration Monitoring Guide: Methods to evaluate restoration success from local to ecosystem scales. NOAA Technical Memorandum NOS NCCOS 279, 145. Doi:10.25923/xndz-h538.
13. Viehman, T. S., Reguero, B. G., Rosman, J. H., Lenihan, H. S., Storlazzi, C. D., Goergen, E. A., Canals Silander, M.F., Groves, S.H., Holstein, D.M., Bruckner, A.W., Carrick, J.V., Haus, B.K., Royster, J.B., Duvall, M.S., Torres, W.I., and Hensch, J. L. In review. Coral restoration for coastal resilience: a framework for multi-scale integration of ecology, hydrodynamics, and engineering. *Restoration Ecology*.
14. Lowe, R. J., McLeod, E., Reguero, B. G., Altman, S., Harris, J., Hancock, B., Hofstede, R. ter, Rendle, E., Shaver, E., and Smith, J. M. 2021. International Guidelines on Natural and Nature-Based Features for



- Flood Risk Management. Chapter 12: Reefs. Vicksburg, MS: U.S. Army Engineer Research and Development Center. Doi:10.21079/11681/41946.
15. Vaughn, D. 2021. Active Coral Restoration: Techniques for a Changing Planet. 540 pp. J. Ross Publishing, Inc. Plantation, FL. ISBN: 978-1604271430.
  16. Masselink, G., McCall, R., Beetham, E., Kench, P., and Storlazzi, C. 2021. Role of Future Reef Growth on Morphological Response of Coral Reef Islands to Sea-Level Rise. *Journal of Geophysical Research: Earth Surface*, 126(2), e2020JF005749. Doi:10.1029/2020JF005749.
  17. Reguero, B. G., Storlazzi, C. D., Gibbs, A. E., Shope, J. B., Cole, A. D., Cumming, K. A., and Beck, M. W. 2021. The value of US coral reefs for flood risk reduction. *Nature Sustainability*, 4(8), 688-698. Doi:10.1038/s41893-021-00706-6.
  18. Roelvink, F. E., Storlazzi, C. D., van Dongeren, A. R., and Pearson, S.G. 2021. Coral reef restorations can be optimized to reduce coastal flooding hazards. *Frontiers in Marine Science*, 8(440). Doi:10.3389/fmars.2021.653945.
  19. Osorio-Cano, J. D., Alcérreca-Huerta, J. C., Mariño-Tapia, I., Osorio, A. F., Acevedo-Ramírez, C., Enriquez, C., Costa, M., Pereira, P., Mendoza, E., Escudero, M., Astorga-Moar, A., López-González, J., Appendini, C.M., Silva, R., and Oumeraci, H. 2019. Effects of roughness loss on reef hydrodynamics and coastal protection: Approaches in Latin America. *Estuaries and Coasts*, 42(7), 1742-1760. Doi:10.1007/s12237-019-00584-4.
  20. Reguero, B. G., Beck, M. W., Agostini, V.N., Kramer, P., and Hancock B. 2018. Coral reefs for coastal protection: A new methodological approach and engineering case study in Grenada. *Journal of Environmental Management*, 210, 146. Doi:10.1016/j.jenvman.2018.01.024.
  21. Zepeda-Centeno C., M.-T. I., McLeod, E., Rodríguez-Martínez, R., Alvarez-Filip, L., Banaszak, A. T., Escudero-Castillo, M., Silva-Casarín, R., Mendoza-Baldwin, E., Beck, M., and Shaver, E. 2018. Guidance Document for Reef Management and Restoration to Improve Coastal Protection: Recommendations for Global Applications based on lessons learned in Mexico. [https://www.researchgate.net/publication/335676053\\_GUIDANCE\\_DOCUMENT\\_FOR\\_REEF\\_MANAGEMENT\\_AND\\_RESTORATION\\_TO\\_IMPROVE\\_COASTAL\\_PROTECTION Recommendations for Global Applications based on lessons learned in Mexico](https://www.researchgate.net/publication/335676053_GUIDANCE_DOCUMENT_FOR_REEF_MANAGEMENT_AND_RESTORATION_TO_IMPROVE_COASTAL_PROTECTION_Recommendations_for_Global_Applications_based_on_lessons_learned_in_Mexico).
  22. Haapkylä, J., Unsworth, R. K. F., Flavell, M., Bourne, D. G., Schaffelke, B., and Willis, B. L. 2011. Seasonal rainfall and runoff promote coral disease on an inshore reef. *PLoS ONE*, 6(2), e16893. Doi:10.1371/journal.pone.0016893.
  23. Sheridan, C., Baele, J.M., Kushmaro, A., Frejaville, Y., and Eeckhaut, I. 2014. Terrestrial runoff influences white syndrome prevalence in SW Madagascar. *Marine Environmental Research*, 101, 44-51. Doi:10.1016/j.marenvres.2014.08.003.
  24. Zweifler, A., O'Leary, M., Morgan, K., and Browne, N. K. 2021. Turbid coral reefs: Past, present and future—A review. *Diversity*, 13(6), 251. Doi:10.3390/d13060251.
  25. Sully, S., and van Woesik, R. 2020. Turbid reefs moderate coral bleaching under climate-related temperature stress. *Global Change Biology*, 26(3), 1367-1373. Doi:10.1111/gcb.14948.
  26. Precht, W. F., and Robbart, M. 2005. Coral reef restoration: the rehabilitation of an ecosystem under siege: Coral Reef Restoration Handbook. <https://nmsfloridakeys.blob.core.windows.net/floridakeys-prod/media/archive/review/documents/erreefsundersiege.pdf>.
  27. Suggett, D. J., Edmondson, J., Howlett, L. and Camp, E.F. 2020. Camp1Coralclip®: a low-cost solution for rapid and targeted out-planting of coral at scale. *Restoration Ecology*, 28, 289-296. Doi:10.1111/rec.13070.
  28. World Bank. 2016. Managing Coasts with Natural Solutions: Guidelines for Measuring and Valuing the Coastal Protection Services of Mangroves and Coral Reefs. M. W. Beck and G-M. Lange, editors.

- Wealth Accounting and the Valuation of Ecosystem Services Partnership (WAVES), World Bank, Washington, DC. <http://hdl.handle.net/10986/23775>.
29. Deltares. 2021. XBeach. <https://www.deltares.nl/en/software/xbeach/>.
  30. Nedimyer, K., Gaines, K., and Roach, S. 2011. Coral tree nursery ©: An innovative approach to growing corals in an ocean-based field nursery. *AACL Bioflux*, 4, 442-446.
  31. Dizon, R. M., Edwards, A. J., and Gomez, E. D. 2008. Comparison of three types of adhesives in attaching coral transplants to clam shell substrates. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 18(7), 1140-1148. Doi:10.1002/aqc.944.
  32. Ceccarelli, D. M., McLeod, I. M., Boström-Einarsson, L., Bryan, S. E., Chartrand, K. M., Emslie, M. J., Gibbs, M.T., Gonzalez Rivero, M., Hein, M.Y., Heyward, A., Kenyon, T.M. Lewis, B.M., Mattocks, N., Newlands, M., Schläppy, M.L., Suggett, D.J., and Bay, L. K. 2020. Substrate stabilisation and small structures in coral restoration: State of knowledge, and considerations for management and implementation. *PLoS ONE*, 15(10), e0240846. Doi:10.1371/journal.pone.0240846.
  33. Collin, A., Ramambason, C., Pastol, Y., Casella, E., Rovere, A., Thiault, L., Espiau, B., Siu, G., Lerouvreur, F., Nakamura, N., Hench, J.L., Schmitt, R.J., Holbrook, S.J., Troyer, M., and Davies, N. 2018. Very high resolution mapping of coral reef state using airborne bathymetric LiDAR surface-intensity and drone imagery. *International Journal of Remote Sensing*, 39(17), 5676-5688. Doi:10.1080/01431161.2018.1500072.
  34. Asner, G. P., Vaughn, N.R., Balzotti, C., Brodrick, P.G., and Heckler, J. 2020. High-resolution reef bathymetry and coral habitat complexity from airborne imaging spectroscopy. *Remote Sensing*, 12, 310. Doi: 10.3390/rs12020310.
  35. Storlazzi, C. D., Logan, J. B., and Field, M. E. 2003. Quantitative morphology of a fringing reef tract from high-resolution laser bathymetry; southern Molokai, Hawaii. *Geological Society of America Bulletin*, 115(11), 1344-1355. Doi:10.1130/B25200.1.
  36. Leon, J. X., Roelfsema, C. M., Saunders, M. I., and Phinn, S. R. 2015. Measuring coral reef terrain roughness using 'Structure-from-Motion' close-range photogrammetry. *Geomorphology (Amsterdam, Netherlands)*, 242, 21-28. Doi:10.1016/j.geomorph.2015.01.030.
  37. Edwards, H. J., Elliott, I. A., Eakin, C. M., Irikawa, A., Madom, J. S., McField, M., Morgan, J.A., van Woesik, R., and Mumby, P. J. 2010. How much time can herbivore protection buy for coral reefs under realistic regimes of hurricanes and coral bleaching? *Global Change Biology*. Doi:10.1111/j.1365-2486.2010.02366.x.
  38. Berg, C., Bertolotti, L., Bieri, T., Bowman, J., Braun, R., Cardillo, J., Chaudhury, M., Falinski, K., Geselbracht, L., Hum, K., Lustic, C., Roberts, E., Young, S., and Way, M. 2020. Insurance for natural infrastructure: Assessing the feasibility of insuring coral reefs in Florida and Hawaii. [https://www.nature.org/content/dam/tnc/nature/en/documents/TNC\\_BOA\\_ReefInsuranceFeasibility\\_FLHI\\_113020.pdf](https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_BOA_ReefInsuranceFeasibility_FLHI_113020.pdf).



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