Coral Reef Restoration for Risk Reduction (CR4): A Guide to Project Design and Proposal Development

Photo credit: Curt Storlazzi, USGS.

Working Group

Austen E. Stovall, University of California Santa Cruz
Michael W. Beck, University of California Santa Cruz
Curt Storlazzi, U.S. Geological Survey
Juliette Hayes, US Army Corps of Engineers
Janan Reilly, Federal Emergency Management Agency
Jen Koss, National Oceanic and Atmospheric Administration
Doug Bausch, NiyamIT/FEMA Hazus

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Introduction

The Federal Emergency Management Agency (FEMA), U.S. Geological Survey (USGS), U.S. Army Corps of Engineers (USACE), National Oceanic and Atmospheric Administration (NOAA), and University of California Santa Cruz (UCSC) are working through the U.S. Coral Reef Task Force to provide guidance on the development of coral reef restoration proposals for federal hazard mitigation funding.

What is coral reef restoration and what is coral reef restoration for risk reduction?
Typically, active coral restoration projects are designed to improve some ecological function of coral reef ecosystems through a variety of restoration methods (see Figure 1).

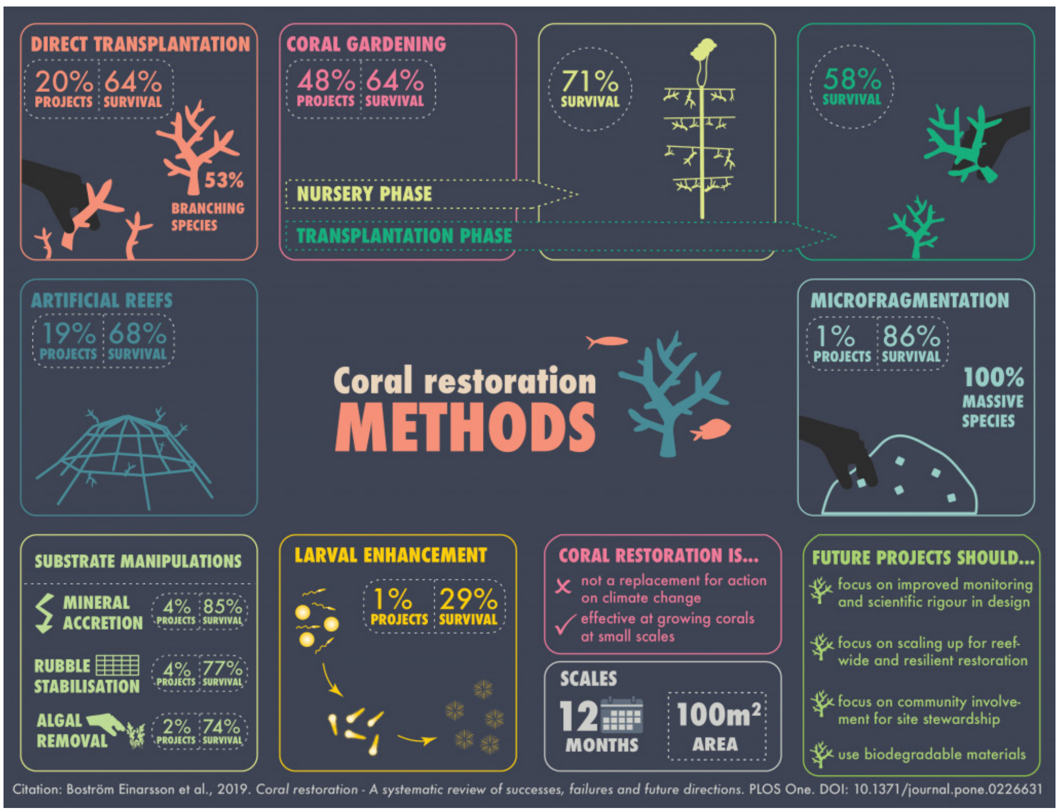


Figure 1. Coral restoration methods adapted from Bostrom-Einarsson et al. (2019).

Coral reef restoration for risk reduction (CR4) projects are designed to reduce flood or erosion risks by rehabilitating, recovering, and restoring reefs. This Guide focuses on projects for flood risk reduction. CR4 projects differ from solely ecological coral restoration projects, because CR4 projects aim to meet two different management objectives for environmental conservation and hazard mitigation. They often will require more specific placement and planning, detailed hydrodynamic analyses, and can require larger project scales to meet both objectives. CR4 is a relatively new approach and stakeholders including community leaders, natural resource managers, and government entities, may often not know when and where it can be used for flood risk reduction nor how to apply for hazard mitigation or recovery funding for CR4 projects.

How to Use this Guide

This Guide aims to provide potential project proponents from organizations to agencies an understanding of the key steps needed and critical information sources available to support CR4 proposals. This document guides potential applicants through the project conception, design, and implementation phases of a CR4 project. The Guide covers vital elements, including project scoping, identification of the project team, selection of site(s), benefit-cost analysis, identification of regulatory requirements, and potential funding opportunities.

Applications for federal assistance will usually need to be led and submitted by a local, state, territorial, or commonwealth agency. However, many stakeholders and project proponents can be involved in developing the project proposal and funding application. Further, the approaches outlined in this Guide can support many other nature-based projects and proposals beyond reef restoration for federal hazard mitigation funding.

PART I: BACKGROUND

Value of Coral Reefs

Coral reefs harbor significant biodiversity and provide a range of key ecosystem services (e.g., food provision, hazard mitigation, recreation) for people. Coral reefs are among the world's most diverse and biologically complex ecosystems. Despite covering less than 0.5% of the world's seafloor, coral reefs are home to more than 25% of known marine species. Coral reefs provide the primary subsistence source of protein for many island nations through fisheries and provide nursery habitat for many commercial species. They are also a major source of recreation and often a primary source of income through tourism. The total value of the world's coral reefs for tourism is estimated at $36 billion (Spalding et al. 2017). In the U.S., coral reef-related tourism (direct reef use) is valued at $550.8 million per year, with reef-adjacent tourism (reef existence driving visitors to certain locations) valued at $680.1 million per year (Spalding et al. 2017). In total, the tourism value of coral reefs in the U.S. is estimated to be about $1.2 billion per year (Spalding et al. 2017). When accounting for tourism, fisheries, and coastal protection, the total economic value of coral reefs in the U.S. is estimated at $3.4 billion (Brander and van Beukering 2013).

Figure 2. Healthy coral reef at Tumon Bay, Guam. Photo credit: Curt Storlazzi, USGS.

Figure 3. Healthy Elkhorn coral (Acropora palmata) near Buck Island, U.S. Virgin Islands. Photo credit: Curt Storlazzi, USGS.

Nature-based Solutions for Natural Hazard Mitigation

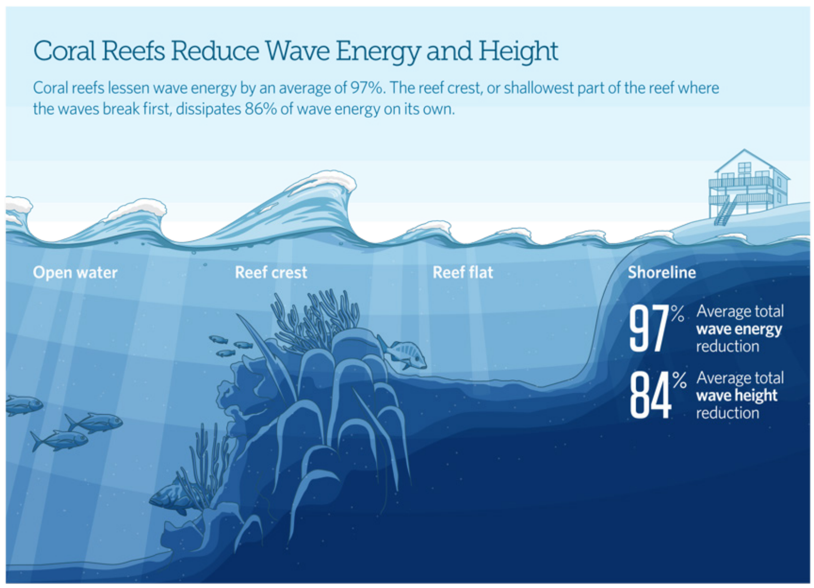
The Federal Emergency Management Agency (FEMA) identifies that "nature-based solutions (NBS) are sustainable planning, design, environmental management, and engineering practices that weave natural features or processes into the built environment to promote adaptation and resilience." The U.S. Army Corps of Engineers (USACE) has focused on a subset of NBS called Natural and Nature-Based Features (NNBF) which are landscape features that are used to provide engineering functions relevant to flood risk management while producing additional economic, environmental, and/or social benefits (Bridges et al. 2021).

Figure 4. Examples of nature-based solutions. Credit: World Bank.

NBS are increasingly recognized as viable solutions for hazard mitigation of flooding and erosion (IUCN 2020). Recent work quantifies these NBS benefits socially and economically to support their use in meeting goals for hazard mitigation, risk reduction, and adaptation projects (Storlazzi et al. 2021; Reguero et al. 2021). NBS have many characteristics that can make them preferred alternatives over solely gray infrastructure for both communities and managers, including cost, appearance, and adaptability (FEMA 2020). Overall, implementing NBS can reduce the costs of future hazards and increase community resilience in the face of increasing climate impacts.

Coral Reefs as Nature-based Solutions

Coral reefs offer coastal protection services by reducing flooding and erosion through wave breaking and friction. On average, coral reefs dissipate 97% of wave energy before it reaches coastlines (Ferrario et al. 2014). Individual coral colonies induce drag on waves, further reducing wave energy and flooding reaching the shoreline (Quataert et al. 2015). Coral colonies grow together and alongside each other to form a reef, resulting in an even more significant reduction in wave energy and thus, a greater reduction in onshore flooding. The value of U.S. coral reefs for flood protection has been quantitatively assessed at greater than $1.8 billion annually for the direct benefits of avoided flood damages to property (Storlazzi et al. 2019; Reguero et al. 2021). The value of the coastal protection services provided by reefs can be retained or enhanced through active coral restoration, or CR4 (an NBS which seeks to meet conservation and hazard mitigation management goals). Potential reef restoration across Florida and Puerto Rico has been valued at $232 million and $40 million, respectively, in terms of the annual value for flood risk reduction (Storlazzi et al. 2021). The present value (PV) of potential large-scale reef restoration across Florida and Puerto Rico exceeds $3.75 billion; when reef restoration is considered an infrastructure project with a 50-year project lifetime at a 7% discount rate, the guidelines suggested by FEMA for hazard mitigation projects.



Source: F. Ferrario, M.W. Beck, C.D. Storlazzi, F. Micheli, C.C. Shepard, and L. Airoldi, "The Effectiveness of Coral Reefs for Coastal Hazard Risk Reduction and Adaptation," *Nature Communications* (2014), doi: 10.1038/ncomms4794
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Figure 5. Coral reefs reduce wave energy by 97% on average. (Ferrario et al. 2014).

Current State of Coral Restoration

There are a rapidly growing number of coral reef restoration projects nationally and globally. Most of these efforts have focused on preserving reefs by reducing stressors (such as invasive algae); growing juvenile corals in nurseries and planting them on reefs; or providing fish habitat. A smaller set of projects have used structural restoration of reefs, for example, to mitigate damage from ship groundings on reef crests (e.g., NOAA's Damage Assessment, Remediation, and Restoration Program). A small but growing number of projects have focused directly on reef restoration for coastal hazard risk reduction, or CR4 (Ferrario et al. 2014; Reguero et al. 2018). Habitat restoration projects designed to meet hazard mitigation objectives often use hybrid techniques that combine structural restoration using a gray infrastructure component (e.g., concrete) with a green infrastructure component (e.g., nursery-grown corals). Hybrid projects aim to meet conservation and hazard mitigation goals through the combination of gray and green infrastructure.

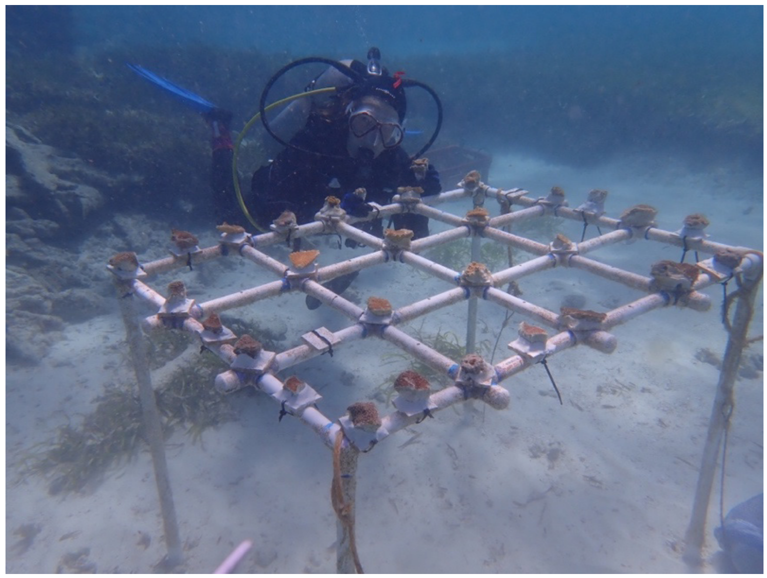

Figure 6. An in-situ table coral nursery structure with Elkhorn coral (A. palmata) fragments in the U.S. Virgin Islands. Photo credit: Austen Stovall.

Recent reviews of coral restoration project goals, objectives, and techniques highlight the somewhat limited focus of most restoration efforts (Bayraktarov et al. 2019; Bostrom-Einarsson et al. 2020). Most projects reviewed were of small scale (<100 m^2), with a short timeframe of implementation and monitoring (<18 months), focused mainly on fast-growing branching coral species, and utilized in-situ coral gardening methods (Bostrom-Einarsson et al. 2020). Techniques on the rise include ex-situ (land-based) nursery operations, microfragmentation, larval propagation, substrate stabilization, and the implementation of green-gray hybrid structures (Bostrom-Einarsson et al. 2020). The restoration techniques used in a specific project are usually based on a set of preselected, overarching goals or objectives for the restoration project but vary in scale and efficacy with the availability of resources and local capacity (Kaufman et al. 2021). Common goals or objectives include mitigating population decline and preserving biodiversity; recovering and sustaining fisheries production; re-establishing reef ecosystem structure and function; or responding to acute disturbances (Hein et al. 2021). There is a noticeable gap in restoration projects designed for the primary goal of reducing coastal hazard risks.

Coral restoration operations in the U.S. jurisdictions with coral reef resources are led by local or national non-profit conservation organizations, state or territorial coral programs, local universities or academic organizations, or citizen-led initiatives, often through partnerships among these organizations. The diversity of partnerships within coral restoration operations strengthens the likelihood of developing integrative CR4 projects. Each U.S. coral jurisdiction has a dedicated coral program within its relevant local government agency to lead decision-making, access funding, and ensure alignment with NOAA's Coral Reef Conservation Program

(CRCP). NOAA CRCP supports U.S. coral jurisdictions technically and financially and leads the development of federal guidance on coral conservation priorities. In recent years, restoration has been added as a pillar to the coral reef management priorities at the federal level in the U.S. Thus, the funding for and facilitation of coral restoration operations throughout the coral jurisdictions is growing. Many states and territories have expressed interest in using reef restoration as a strategy for enhancing coastal resilience.

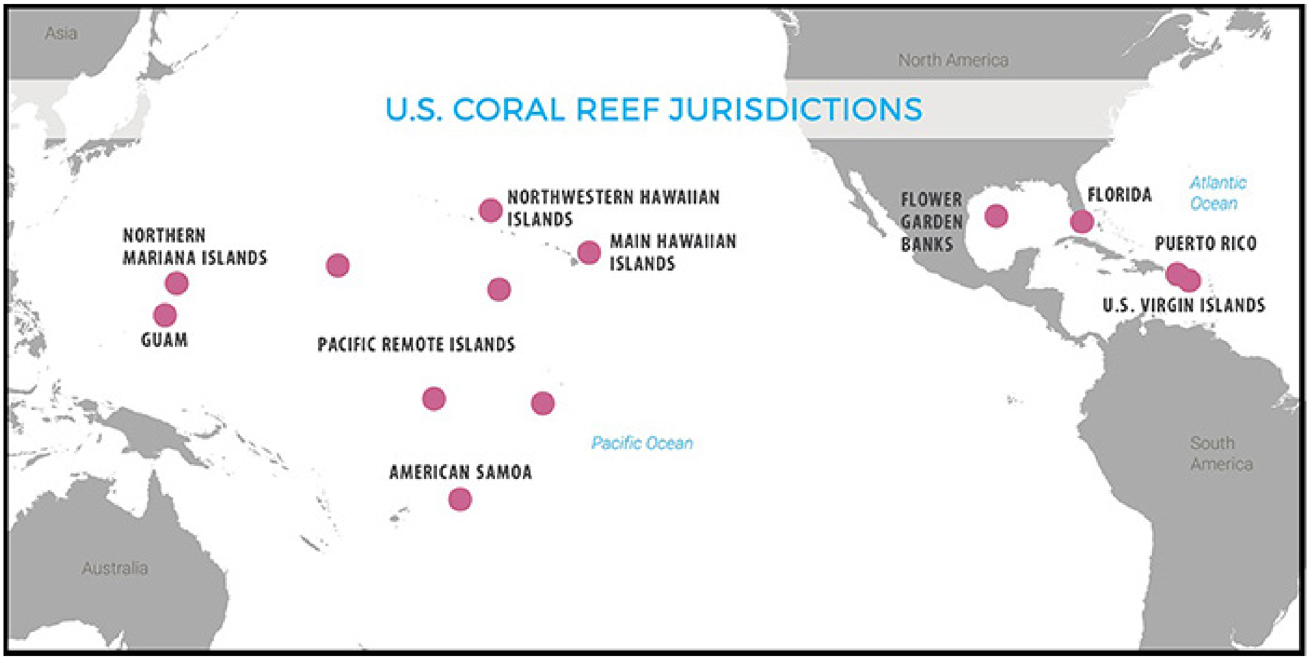

Figure 7. U.S. jurisdictions with coral reef resources. Credit: NOAA.

Coral Reefs and Climate Change

A great deal of concern has been raised about whether coral reefs, both natural and restored, can survive in the face of climate change. There are a few key points for consideration. While coral reefs have faced growing threats, there is evidence that areas of relatively high-functioning reef still exist around the world (Guest et al. 2018; Elahi et al. 2022). Despite the intense vulnerability of coral reefs to climate change, restoration is now one of the three accepted pillars necessary for the persistence of coral reef ecosystems: reduce global climate threats, improve local conditions, and invest in active restoration (Knowlton et al. 2021).

There is evidence that reefs can recover from large-scale stressors, such as bleaching from past El Niño events, and can be managed for recovery by reducing local stressors such as pollution, sedimentation, and destructive fishing (Pandolfi et al. 2011; Palumbi et al. 2014). A growing number of studies also show successful examples of coral reef restoration (Young et al. 2012; Bostrom-Einarsson et al. 2019). Further, select coral species have been observed to thrive in extreme conditions such as high elevated temperatures (Claar et al. 2020; Dandan et al. 2015) and low pH waters (Shamberger et al. 2014), suggesting that some coral populations still contain significant capacity to adapt to changing ocean conditions when adequately managed (Lowe et al., 2021). However, the rate of climate change is unprecedented, so increasingly innovative and significant interventions will be required for coral reef survival in the face of runaway climate change (NASEM 2019; Kleypas et al. 2021).

Figure 8. A coral reef in the Dominican Republic. Photo credit: Philip Hamilton, Ocean Image Bank.

A common concern expressed about restoration is that it should not be attempted until all the issues that caused coral mortality (e.g., global climate change, invasive species, sedimentation) are addressed. However, experience shows that flagship restoration sites can create the community drive and political will to address problems, especially at the local scale, which will provide other side benefits (e.g., cleaner beaches, better-managed watersheds) that would not be resolved otherwise. While it is preferable to reduce (or find sites with reduced) stressors ahead of time, in many cases, the restoration project can provide the impetus for communities to address these issues. For example, in Kāne’ohe Bay, HI, the removal of invasive algae preceded active coral restoration interventions at this site (Bahr et al. 2015). In general, adaptive management is critical to the success of coral restoration projects.

Figure 9. An aerial view of a reef in Kane’ohe Bay, Hawai’i. Photo credit: Toby Matthews, Ocean Image Bank.

Funding Mechanisms for Coral Reef Restoration for Risk Reduction

Current funding for active ecological coral restoration in the U.S. is divided among a handful of state, federal, and philanthropic sources, with an average amount of funding at $2.4 million (Hein & Staub 2021). Most funds are granted to government agencies and non-governmental organizations (NGOs) for local-scale ecological coral restoration involving direct outplant methodologies. Funding is typically tied to measurements of outplanting effort (e.g., number of outplants or hectares restored) rather than specific long-term goals of restoration success (e.g., flood risk reduction goals, socioeconomic goals) (Hein & Staub 2021). Additionally, the average, relatively short timeline of available funding (3.3 years) does not allow for adequate measures of long-term restoration success nor the implementation of adaptive management and long-term monitoring of projects (Hein & Staub 2021).

There are a small but growing number of CR4 projects, mainly internationally (e.g., Reguero et al. 2018; Zepeda-Centeno et al. 2018). To date, no CR4 projects have been funded through any U.S. federal funding opportunity, though some are currently under consideration. There is the potential to apply for large-scale CR4 projects through the relevant hazard mitigation funding opportunities described below.

Figure 10. Mars coral restoration project involving the use of rebar dome structures and out-planted corals. Photo credit: Mars Coral Reef Restoration, www.buildingcoral.com.

Federal Emergency Management Agency

Currently, the majority of grant funding in the U.S. for both pre-and post-disaster mitigation comes from FEMA. Mitigation actions differ from many disaster preparedness, response, and recovery activities, in that they are inherently preemptive and have a long-term goal of reducing hazard risk. As disaster spending increases year after year, FEMA is investing more resources in natural hazards mitigation to save taxpayer dollars and build more resilience to current and future disasters. In 2020, FEMA recognized the value of using NBS and considering ecosystem services in mitigation projects by eliminating the former benefit-cost ratio (BCR) requirement of 0.75, allowing for the consideration of ecosystem service benefits for eligible projects regardless of BCR value. This update allows for the easier inclusion of NBS into risk-based mitigation projects (see Ecosystem Service Benefits in Benefit-Cost Analysis for FEMA's Mitigation Programs Policy).

FEMA Hazard Mitigation Assistance (HMA)

FEMA administers several hazard mitigation grant programs, collectively referred to as Hazard Mitigation Assistance (HMA). HMA includes the Hazard Mitigation Grant Program (HMGP), the Flood Mitigation Assistance (FMA) Grant Program, and the Building Resilient Infrastructure and Communities (BRIC) Program (Figure 11). Eligible HMA applicants include states, federally recognized tribes, and territories, and the District of Columbia. Individuals cannot apply for HMA funding, but some NGOs may apply for HMGP funding. Applicants and sub-applicants to all programs must have a FEMA-approved hazard mitigation plan. Projects funded under HMA grants must align with the objectives and goals of the relevant hazard mitigation plan. Eligible mitigation activities differ for the various HMA programs. It is important to note that there is a cost-share responsibility for all HMA grants ranging from 75:25 to 90:10 federal:non-federal cost-share. In some cases, like under BRIC, Economically Disadvantaged Rural Communities (EDRCs) are eligible for reduced cost-share responsibility.

Hazard Mitigation Grant Program (HMGP)

HMGP funding is triggered by a major disaster declaration from the President under the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act), available on a sliding scale as a percentage of the estimated amount of total federal assistance for the disaster: up to 15% of the first $2 billion, up to 10% for amounts between $2 billion and $10 billion, and up to 7.5% for amounts between $10 billion and $35 billion. HMGP funding is available for all types of hazard mitigation across the state, tribe, or territory in which the disaster is declared. HMGP funds are administered by the affected state, tribe, or territory, so local communities interested in obtaining funding must work directly with the state or territory.

Building Resilient Infrastructure and Communities (BRIC) Program

BRIC funding is a nationally competitive program with funding available annually as a set aside of the estimated amount of total federal assistance for disasters (similar to HMGP). BRIC funding is available for all types of hazard mitigation, with specific program priorities outlined each year. FEMA will decide on the annual available funding each year; more information is available in the Notice of Funding Opportunity (NOFO).

Flood Mitigation Assistance (FMA) Grant Program

FMA funding is available annually via congressional appropriation through a national competition. Funding is limited to flood-related mitigation that reduces the risk of properties that repetitively flood and lessens future insurance claims for the National Flood Insurance Program (NFIP); more information is available in the NOFO.

FEMA Public Assistance (PA)
Additional hazard mitigation funding is also available as part of FEMA's largest grant program, Public Assistance (PA). PA provides funding to states, tribes, and territories when authorized as part of a presidential disaster declaration under the Stafford Act. PA provides funding for long-term recovery assistance to state, local, tribal, and territorial governments. As part of the long-term recovery assistance, PA authorizes permanent work, which includes efforts to repair, reconstruct or replace disaster-damaged public and eligible nonprofit facilities. These facilities include roads and bridges, water control facilities, buildings and equipment, utilities, parks, recreational facilities, and other public facilities.

During this recovery process, funding for mitigation is also available, known as PA 406 Mitigation (after Section 406 of the Stafford Act). Unlike the HMA grants, PA 406 mitigation funding is not competitive and does not have a funding cap. Funding is based on the eligible disaster damage to the facility and the cost-effectiveness of the proposed project. Like HMA grants, PA 406 mitigation typically has a 75% federal cost-share, but the President has the authority to increase the cost-share for any PA-declared disaster. Some common mitigation measures include floodproofing, replacing or upgrading existing materials with stronger or more resilient materials, elevating facilities or important equipment, adding protective materials like riprap or green infrastructure for erosion control, or replacing structures like culverts or pipes with multiple or larger structures. The proposed mitigation action for a PA project will depend on the public facility being protected.

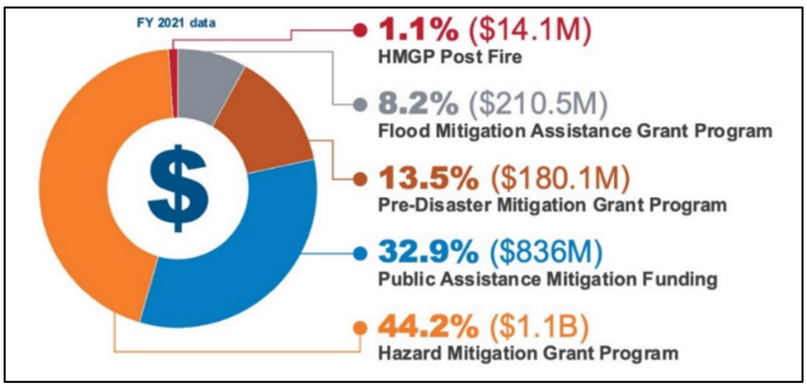

Figure 11. In FY2021 more than $2.34B in Hazard Mitigation Assistance Grants and Public Assistance Mitigation funds were delivered to states, local communities, tribes, and territories resulting in mitigation actions that will reduce risk. Note: Missing on this graph is the Building Resilience Infrastructure and Communities (BRIC) Program which was funded at $1B for FY2021.

United States Army Corps of Engineers
The United States Army Corps of Engineers (USACE) does not offer any federal grant programs for flood risk management projects. However, for larger flood risk reduction projects, the USACE can seek congressional authorization to evaluate flood risk and recommend specific flood mitigation project activities. For smaller projects, non-federal sponsors may request support from the USACE to evaluate potential flood risk reduction activities that might fit the Corps Continuing Authorities (CCA) program without congressional authorization. Since these potential funding avenues are not akin to a federal grant program, the process to include and propose a project is significantly different from most other grant application processes. However,

project components and considerations should align with the sections elucidated in this guide. Each of the 39 Corps Districts manages the CCA program to investigate and select relevant flood mitigation projects.

USACE Engineering with Nature

The USACE's Engineering with Nature (EWN) Program focuses on developing sustainable solutions for flood reduction using nature by considering social, environmental, and economic benefits. The EWN Program has technically and/or financially supported many NNBF and NBS projects over the past decade. Many NNBF projects have been highlighted in two Volumes of the EWN Atlases (Bridges et al. 2018, 2021), but at present, these have not included any CR4 projects. However, in 2022-2024 EWN will be supporting the assessment of CR4 projects developed as part of the Department of Defense DARPA Reefense program.

USACE Corps Continuing Authorities Program

Without specific authorization from congress, CCA allows the USACE to plan, design, and construct smaller flood risk management projects that align with Federal interests as described in Sections 14, 205, and 208 of the Flood Control Act of 1946, 1948, and 1954, respectively.

Other Hazard Mitigation Funds

National Fish and Wildlife Foundation & National Oceanic Atmospheric Administration National Coastal Resilience Fund

The National Coastal Resilience Fund (NCRF) supports the planning, implementation, and design of NNBF and NBS to help protect coastal communities from the impact of natural hazards and to increase resilience and ecosystem condition. The National Fish and Wildlife Foundation (NFWF) will invest in grants for projects in four priority areas: Community Capacity Building and Planning; Site Assessment and Preliminary Design; Final Design and Permitting; and Restoration and Monitoring.

National Fish and Wildlife Foundation America the Beautiful Challenge

The America the Beautiful Challenge (ATBC) is a grant program aimed at funding conservation and restoration projects across several focal areas, including improving ecosystem and community resilience to coastal flooding, drought, and other climate-related threats. ATBC funding is consolidated from several federal agencies and the private sector to support large-scale projects that meet shared conservation, resilience, and NBS priorities.

Department of the Interior Office of Insular Affairs Coral Reef and Natural Resources Initiative

The Coral Reef and Natural Resources (CRNR) Initiative provides grant funding for the management and protection of coral reefs and to combat invasive species in the U.S. insular areas. This includes the U.S. Territories of the U.S. Virgin Islands, Guam, American Samoa, Commonwealth of the Northern Mariana Islands, and Freely Associated States: Republic of Palau, Republic of the Marshall Islands, and the Federated States of Micronesia. The CRNR Initiative aims to improve the health of coral reef ecosystems and other natural resources in the U.S. insular areas for their long-term economic and social benefit. Priority is given to projects that help the insular areas address a variety of threats to coral reef ecosystems and for prevention, control, and eradication of aquatic and terrestrial plant, insect, and animal invasive species. Grants can be provided to insular area local governments and non-profit organizations whose projects benefit the insular areas. Annual grant funding from this program is approximately $2.5 million. Examples of coral-related projects include, but are not limited to: decreasing land-based pollution that impacts coral reefs; mapping of coral reefs; coral restoration from Stony Coral Tissue Loss Disease; funding of specialized strike teams to identify, treat and remove evidence of disease; watershed management plans, restoration/monitoring in watershed areas; revegetation of deforested and eroded inland areas to decrease threat of erosion and sedimentation buildup on coral reef and inshore ecosystems; cleanup projects to protect the marine environment from sedimentation and runoff; and other outreach and education projects to protect coral reefs.

Reef Insurance

Some recent work has focused on the use of insurance to protect and restore coral reef ecosystems damaged by storms. This new funding pathway requires detailed scoping, intensive partnerships, and specific pre-existing conditions to be implemented (Secaira et al. 2019).

PART II: CR4 PROJECT ELEMENTS

Investigating, developing, and applying for funding for a CR4 project involves several distinct elements, steps, and methodologies. Below, we highlight the key considerations and provide step-by-step guidance for CR4 project realization.

Step 1. Pre-project Planning, Building Your Team, and Capacity Evaluation

Pre-project Planning

Before designing and measuring the costs and benefits of a CR4 project, it is essential to consider several baseline activities that will inform the application process. The following sections provide guidance on pre-project planning steps that will define a project's eligibility and streamline project development.

Meet with a Reef Resource Manager (if not already on your team)

The state or territorial agency responsible for managing coral reef ecosystems will differ for each jurisdiction but often reside within a coastal management and/or natural resource management agency. Consulting the relevant resource management entity should be one of the first steps in developing a CR4 project. Local resource managers will be able to provide critical information regarding permitting, extenuating reef ecosystem stressors, current and planned projects, relevant partners, and priority areas appropriate for a potential CR4 project. Further, contacting federal natural resource managers, such as NOAA, Environmental Protection Agency (EPA), or Department of the Interior (DOI), can help inform the application requirements and project timeline.

Application Timeline and Automatic Determinations of Ineligibility

State and federal application deadlines

State and federal application deadlines will vary based on the specific funding organization and program. For example, for the FEMA BRIC program, the application deadline for applicants (states, tribes, and territories) is set in the NOFOs each year. However, typically the application period opens in September and closes at the end of January. However, the application deadline for project submissions for sub-applicants (local/regional communities) will vary in each state, tribe, and territory. Those interested in submitting projects for BRIC funding should reach out to the State Hazard Mitigation Officer (SHMO) to identify localized deadlines and priorities.

FEMA HMA Project Ineligibilities

FEMA HMA mitigation grants have some specific ineligibility issues to consider when developing a potential coral reef restoration project. These ineligible project activities include:

- Projects that do not reduce the risk to people, structures, or infrastructure;
- Activities on federal lands or associated with facilities owned by another federal entity;
- Projects related to beach nourishment or re-nourishment;
- Projects that address, without an increase in the level of protection, the operation, deferred or future maintenance, rehabilitation, restoration, or replacement of existing structures, facilities, or infrastructure (e.g., dredging, debris removal, replacement of obsolete utility systems, or

bridges, maintenance/rehabilitation of facilities, including dams and other flood control structures).

For more information on project eligibility/ineligibility, please refer to the current FEMA Hazard Mitigation Assistance Guidance.

Permitting

Acquiring the necessary permits for a CR4 project could be the most challenging aspect of project development. Getting a project 'shovel-ready' for implementation requires at least 18-24 months and potentially longer depending on permitting processes in the particular jurisdiction. Additionally, the monitoring requirements outlined in certain permits should be carefully considered in terms of the additional cost or time needed to implement a project successfully. It may be appropriate to consider a phased project approach if consultation work will be necessary to evaluate the impact on critical habitats or species, for example. A phased project application typically assumes that the sub-applicant knows the project and proposed solution(s) but needs extra time and guidance for permit consultations. A project application with the necessary permits obtained or in process will be more highly considered by FEMA (FEMA 2015).

Building Your Team

Multiagency collaboration will be essential throughout the CR4 project planning process. Establishing relationships with actors across permitting, natural resource, and hazard management agencies and securing buy-in from the local community affected by the proposed CR4 project will streamline the project development and application process. Below, we elaborate on the non-exhaustive list of key players to consider and contact early in the project planning process.

Determine Resource Stakeholders and Champions

Adjacent communities and businesses are often the first to observe coral reef declines and threats. Thus, the ideation of a CR4 project may often originate from a community champion who has felt or seen significant loss from natural hazard impacts. Seeing the local reef ecosystem actively decline and feeling heavier impacts from coastal hazards can serve as the nexus of CR4 project development.

As an emerging strategy for coastal risk reduction, the current limitations and future benefits of CR4 projects are not yet widely understood. Although CR4 projects have the potential to provide substantial risk reduction benefits to an array of beneficiaries, project proponents and champions should have a clear understanding of the overarching goals and objectives of a proposed project, as well as where and when a CR4 project is appropriate.

Identify Lead Applicant

Figure 12. Shallow reef system in Turner Hole, St. Croix, USVI. Photo credit: Austen Stovall.

The lead applicant, or the organization responsible for submitting the project proposal, will differ depending on the source of funding. For FEMA HMA grants, the eligible applicant is the state, federally recognized tribe, or territory (typically the emergency management agency). For FEMA BRIC funding, the eligible applicant will submit one grant application consisting of an unlimited number of sub-applications from throughout the state, territory, or tribe. Eligible sub-applicants for BRIC are local governments (including cities, towns, counties, special district governments, or other state agencies) who must have a FEMA-approved hazard mitigation plan by the application deadline and at the time of grant funding obligation. While individuals and nonprofit organizations cannot be sub-applicants under BRIC, local governments can apply for funding on their behalf. Under FEMA's HMGP, nonprofits can apply as sub-applicants for mitigation funding. Regardless, alignment with local hazard mitigation priorities and resource management plans is beneficial. Thus, in most cases, partnerships are essential. While project proponents or champions can include NGOs, homeowners, and business operators, the lead applicant or sub-applicant requirements may differ for each funding application. Before the project proposal is developed, establishing relationships with all relevant key partners is essential to enhance the likelihood of application submission success.

Contact Key Local Partners

Local Coral Resource Manager: Partnership with a local resource manager will allow project proponents to utilize existing grant development and management resources, access expert knowledge of coral reef resources and understand the permits required to implement a restoration project. The local agency within which the resource manager resides will differ for each jurisdiction, but guidance for the seven U.S. states and territories with coral reef resources is below.

U.S. Coral Jurisdiction	Coral Resource Management Department
American Samoa	Department of Marine and Wildlife Resources
Commonwealth of the Northern Mariana Islands	Bureau of Environmental and Coastal Quality
Florida	Department of Environmental Protection
Guam	Bureau of Statistics and Plans
Hawai'i	Department of Aquatic Resources
Puerto Rico	Department of Land and Natural Resources

U.S. Virgin Islands	Department of Planning and Natural Resources

Local Emergency and Hazard Managers: For federal hazard mitigation funding opportunities, contact with the SHMO and/or local emergency management agency has the potential to strengthen a CR4 application. This partnership will allow the applicant to understand if and how CR4 projects fit into jurisdictional hazard mitigation priorities.

U.S. Coral Jurisdiction	Local Emergency Management Agency
American Samoa	American Samoa Territorial Emergency Management Coordination
Commonwealth of the Northern Mariana Islands	CNMI Homeland Security and Emergency Management
Florida	Division of Emergency Management
Guam	Guam Homeland Security Office of Civil Defense
Hawai'i	Hawai'i Emergency Management Agency
Puerto Rico	Puerto Rico Emergency Management Agency
U.S. Virgin Islands	Virgin Islands Territorial Emergency Management Agency

Local Coral Restoration Operator(s): Project proponents should also have established relationships with local coral restoration operators. Coral restoration operations can be led by NGOs, academic institutions, businesses and resource management agencies. Understanding the local coral restoration priorities and production capacity will influence the engineering design and lifespan of a CR4 project.

Federal, State and Local Permitting Entities: Permitting can often be a critical barrier to the development and implementation of CR4 projects. Obtaining the proper permits early in the project planning timeline helps improve project standardization and minimize impacts to sensitive resources. Establishing communication with the relevant permitting agencies is essential prior to project development and throughout the process. Local permit requirements will differ for each jurisdiction, but federal permit requirements may be triggered by legislation such as the Endangered Species Act, National Environmental Protection Act, or Coastal Zone Management Act and managed by agencies such as EPA or USACE.

Impacted Local Businesses: Local businesses impacted by flooding can potentially be critical stakeholders in the development of a CR4 project. The co-benefits of a CR4 project could be significant for these businesses, so their involvement, support, and even active contribution can increase the likelihood of project success.

Stakeholders & Community Buy-in
The inclusion of and support from local stakeholders, community members, indigenous peoples, and traditional owners is critical to successfully implementing any reef restoration project, but even more so for CR4 projects. Stakeholders provide local hazard knowledge, key site selection considerations, and input on potential barriers to success or areas of opportunity. Public participation and input during project design may be required to comply with certain environmental and historic preservation laws. The involvement of communities with environmental justice concerns during project development can help identify where those communities may be experiencing disproportionate impacts from natural hazards or a proposed project and support the development of equitable solutions. In many cases, community involvement can bolster a potential project's success through direct participation in project implementation (e.g., job creation) or instilling community pride and protection of a CR4 project. Overall, the beneficial outcomes of a CR4 project will be felt by impacted stakeholders, so their involvement from the beginning is key to gaining support for a successful project proposal.

Figure 13. Reef Restoration and Tourism: Explaining Reef Restoration Activities with Public Divers near Bali, Indonesia. Photo credit: MW Beck.

Capacity Evaluation
The development of a CR4 project, from design to application to implementation to monitoring, could necessitate the involvement of a third-party contractor to complete all or part of the project requirements. A thorough evaluation of local capacity for reef restoration, elements of CR4 project design, large-scale project implementation and monitoring, and application development, management, and dissemination is necessary to determine if guidance is needed for any or all parts of a CR4 project. For example, environmental engineers could give input on structural design and installation for a hybrid approach, or environmental economic consultants could help ease the heavy lifting required for the completion of a rigorous benefit-cost analysis (BCA).

Coral Restoration Operations
It is important to assess local coral restoration capacity to determine the ability of local restoration practitioners to fulfill the requirements of a proposed CR4 project. Limitations of coral growth rates, coral species available that will thrive in the selected location, and restoration methodologies will impact the design and scale of a CR4 project. Additionally, project proponents should evaluate the coral stock needed to implement a CR4 project, which could potentially extend the realistic timeframe for implementing a CR4 project depending on the current production capacity of restoration operations. While regions with well-established coral restoration operations could likely design, apply for, and implement a CR4 project sooner, regions with rapidly developing coral restoration operations can prioritize CR4 project goals as

they design and develop local operations. For example, jurisdictions with less-established coral restoration operations could keep CR4 projects in mind when developing scalable restoration methodologies that are able to produce robust coral stock for restoration projects.

Grant Development and Management Capacity

Project proposal development is a challenge, especially for FEMA and USACE applications, as these processes are very demanding in terms of time, detail, and effort. Project proponents must determine whether internal capacity is sufficient to design and lead a project, compile and submit an application, and communicate with essential partners. Project proponents should consider bringing on an external independent contractor for projects that exceed internal grant application management capacity. Existing partnerships may be able to financially or technically support the development and completion of key application components. For example, FEMA Region IX has established a cooperative technical partnership with The Nature Conservancy and Earth Economics/Radbridge Inc. to support the BCA components of Region IX HMA applications.

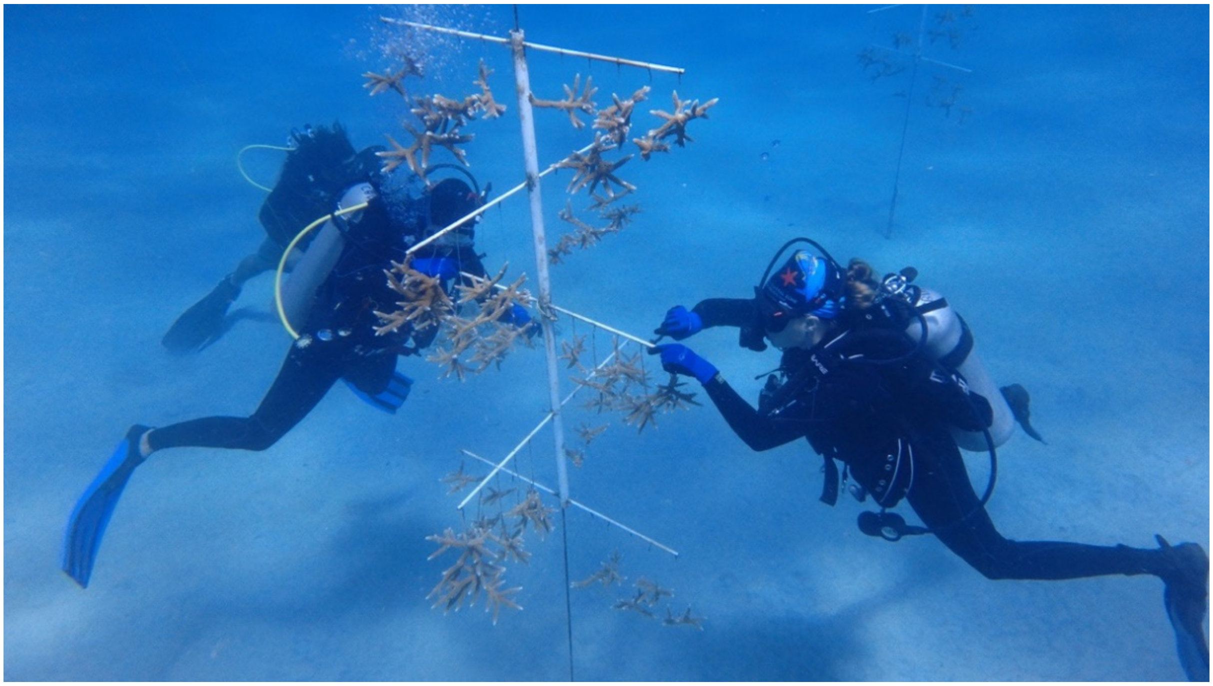

Figure 14. In-situ coral restoration nursery operation in the US Virgin Islands. Photo credit: Austen Stovall.

Step 2. Picking Your Site

For most projects, a critical step is initial site selection, which includes identifying where reef restoration is likely to yield significant risk reduction benefits relative to project costs and where stakeholders will have sufficient will and expertise to complete proposals and project development. It is essential to recognize that reef restoration designed for risk reduction will not be appropriate for every site where reef restoration may be desired. For projects designed to reduce flood risk, flooding and flood impacts must be focal components in measuring benefits and costs. Even though restored reefs can also have a significant impact on erosion reduction, these cannot be the primary benefit assessed for a flood risk reduction project.

Figure 15. An aerial view of Great Pond Bay on St. Croix in the USVI. Photo credit: Austen Stovall.

To be eligible for federal hazard mitigation or recovery funding, project proponents must assess *where reef restoration will likely have sufficient benefits for flood risk reduction to justify costs*. Hazard managers and agencies will ultimately assess the capacity of a project to reduce risk to property and people first, with any ecosystem services (such as recreation, tourism, and aesthetic values) as potential co-benefits.

There are some key resources that can help project proponents identify sites where reefs are likely to provide significant benefits for flood risk reduction (e.g., Beck et al. 2018, 2022; Storlazzi et al. 2019; Reguero et al. 2021). The maps and databases from these sources, particularly those from USGS & UCSC, provide a strong basis for initial screening on where sites might offer sufficient risk reduction (e.g., Figure 16).

Additional site-specific factors for consideration include identification of the stressors that might impede restoration success; the level of documented degradation or reef loss; knowledge of the pre-degradation coral community and the level of reef development (i.e., data on carbonate build-up and reef thickness); the level of interest in reef restoration from environmental managers, hazard managers, and the local community; the likelihood of permitting success for a restoration site (i.e., is the site in a marine protected area, around endangered species, or in a navigable waterway); and the level of local capacity for coral restoration (e.g., coral nurseries). Reaching out to environmental and historic preservation authorities early in project design and throughout the process can help determine the potential benefits and limitations of a priority project site or design and identify proposed solutions.

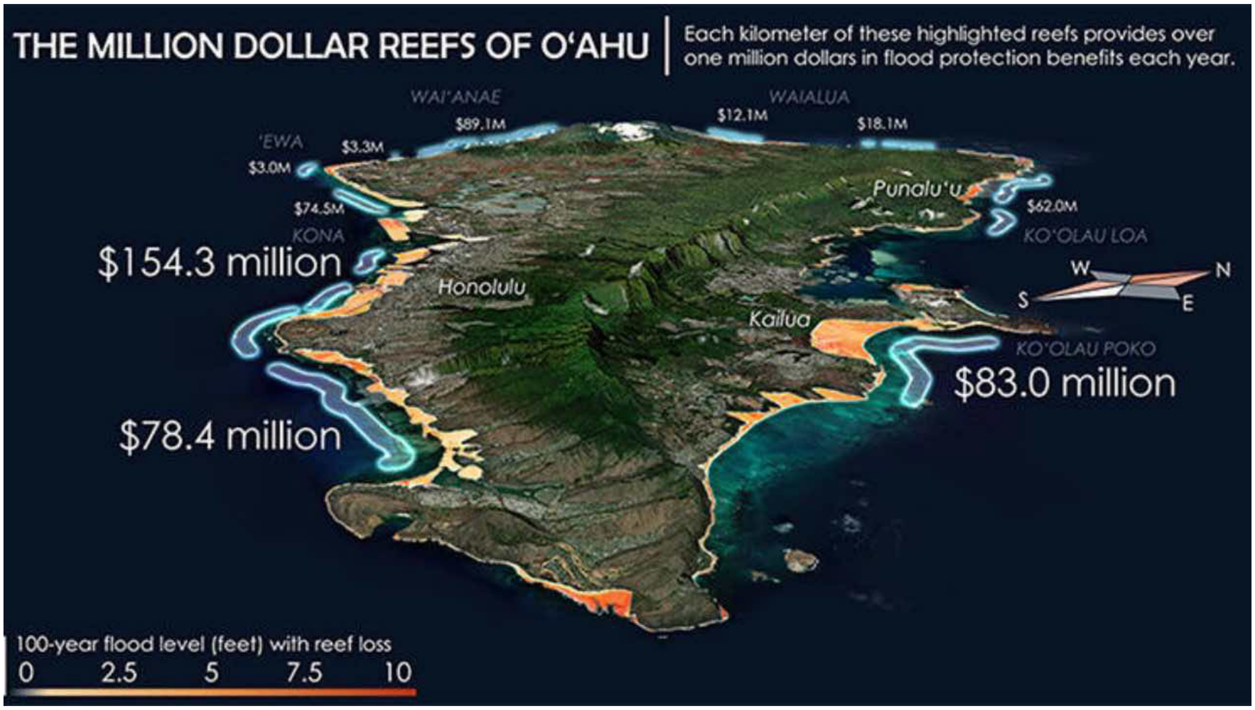

Figure 16. The highlighted reefs around O'ahu all provide greater than USD$1 million in expected flood reduction benefits per kilometer per year. The values in the figure are the sum of the annual expected benefits for reef sections that are several kilometers long (modified from Storlazzi et al., 2019; Reguero, 2021).

Step 3. Benefit-Cost Analysis

<u>What is the benefit-cost analysis and why is it important?</u>

A BCA is a method to determine the future risk reduction benefits of a hazard mitigation project compared to its costs. Mitigation projects funded by FEMA HMA and PA Mitigation grants are required by law to be cost-effective.

<u>Estimating Project Benefits</u>

The approaches and data under 'Picking Your Site' above provide examples of how to broadly estimate the benefits of existing reefs. Below we go into more depth on the approaches widely used in the scientific community for estimating the benefits of specific projects, which are valid for all types of risk reduction projects (e.g., dikes, seawalls, low crested breakwaters, and reefs). It is important to reiterate that the following steps will require significant technical expertise (e.g., hydrodynamic modeling, economic analysis, reef design) which may require additional capacity in the form of consultants or outside experts. Ultimately for a reef restoration project, proponents will have to identify the specific characteristics of the proposed restoration (e.g., restoration height, width and offshore location, depth) and model those site-based benefits. Restoration benefits for several idealized restoration scenarios were developed for the coral reef-lined coasts of Florida and Puerto Rico (e.g., Figure 17; Storlazzi et al. 2021); project proponents would need to modify these scenarios for their site-specific considerations.

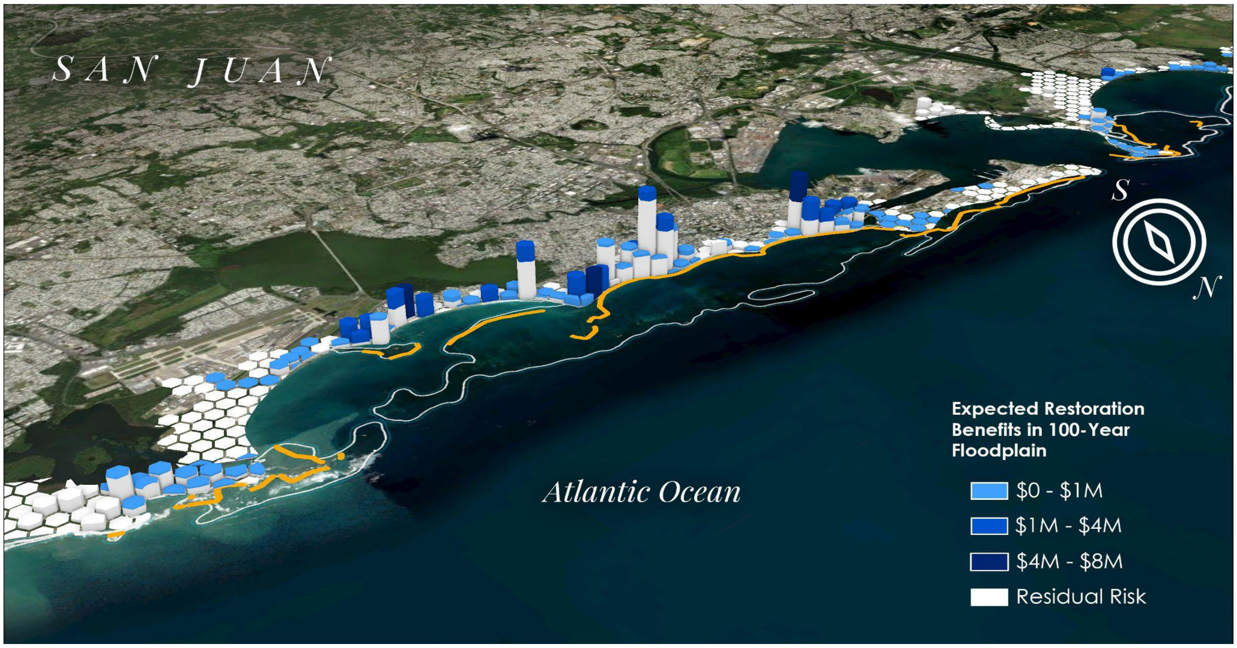

Figure 17. Risk reduction benefits of reef restoration around San Juan, Puerto Rico. The full height of the bars indicates current expected flood risk in the 100-year floodplain. The blue bar tops indicate the risk that could be reduced with reef restoration; their height and color represent the expected benefit from restoration per 50,000 m² (hexagon max width = 277 m). Residual risk remains even after reef restoration. The orange line offshore indicates the location of potential reef restoration. The offshore polygon outlined in white represents the extent of current reef habitats. Modified from Storlazzi et al. (2021).

Below we highlight some of the critical steps and data required for assessing the benefits of reef conservation and restoration. Versions of this approach are widely used in risk science and by the risk industry and are being adapted for use with NBS (Barbier 2015; World Bank 2016; Storlazzi et al. 2019, 2021; Bridges et al. 2021; FEMA 2022; Reguero et al. 2021; Beck et al. 2022). These methods combine oceanographic, coastal engineering, ecologic, geospatial, social, and economic data and tools to provide a quantitative valuation of coastal protection benefits provided by potential coral reef restoration. The goal at this stage is to identify how, where, and when coral reef restoration could increase the coastal flood reduction benefits socially and economically. The method follows a sequence of steps that integrate physics-based hydrodynamic modeling, quantitative geospatial modeling, and social and economic analyses to quantify the hazard, the role of coral reef restoration in decreasing coastal flooding, and the resulting economic and social consequences.

Projecting the Coastal Hazards. To define the flooding hazards, a long (multiple decades) record, either from wave buoys or numerical wave model hindcasts of wave heights and periods for the site, is helpful. If the buoy or hindcast model output location is close to the proposed restoration site, such information can be used to drive the coastal flood models to derive nearshore wave time series for the site. If they are not close to the proposed site, the waves need to be translated to the site via dynamical or statistical methods.

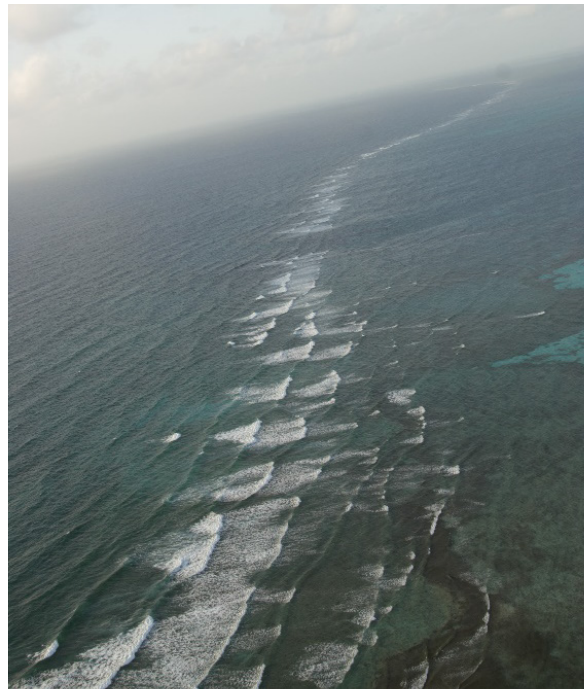

Figure 18. Waves breaking on the Mesoamerican Reef near Cancun, Mexico. Photo credit: MW Beck.

Evaluating the Role of Coral Reefs in Coastal Protection. The nearshore wave time series at the site can be fit to a General Extreme Value (GEV) distribution to obtain the wave heights and wave periods associated with the different return-period storm events, such as the 1-year, 10-year, 20-year, 50-year, and 100-year storm return periods. The corresponding storm-return period extreme water levels for a given location can be computed from water level data at the nearest tidal station, which should include the effects of tropical cyclones.

The return value wave heights, wave periods, and extreme water levels are then propagated over the coral reefs using a physics-based, numerical coastal hydrodynamics and flood model. These models should either be two-dimensional depth-integrated (‘2DH’) or fully three-dimensional to accurately model the reef benefits. Reef height (bathymetry) and roughness (friction) are the critical factors that influence the effects of reefs on flooding. Friction is usually parameterized based on its relationship with coral cover (Sheppard et al. 2005; Quataert et al. 2015).

Reef Restoration Scenarios. Project proponents should identify potential reef restoration project designs (i.e., scenarios) that consider: (i) the likelihood of delivering flood reduction benefits, (ii) existing coral restoration practices, and (iii) permitting factors such as depth for potential navigational hazards. The restoration scenario(s) will be represented in the model based on width (cross-shore), length (alongshore), and height, as well as friction or hydrodynamic roughness, to quantify the waves and water levels over the restoration and the resulting coastal flooding.

Evaluating the Role of Potential Coral Reef Restoration in Increasing Coastal Protection. The return period (e.g., 10-year, 50-year) wave heights and wave periods can then be propagated over the coral reefs and modified to account for scenarios with and without coral reef restoration using the same physics-based, numerical coastal hydrodynamics, and flood models.

Quantifying the Social and Economic Benefits of Potential Coral Reef Restoration. The differences with and without restoration in flood extent and depth are then used to quantify the avoided damages to people and property. The avoided damages to people are usually assessed based on census data, and the avoided damages to structures are based on data from granular, site-specific, local building data sources. Damages to the flooded structures are assessed by structure type (e.g., mobile homes) with flood-depth damage curves. The protection provided by reef restoration is ultimately assessed across three or more storm return intervals (e.g., 10-year, 50-year, 100-year, and 500-year storm return periods) to determine the annual expected protection provided by the coral reef restoration.

FEMA requires a 7% discount rate to be applied to future benefits, but the discount rate requirement for other agencies may vary. It is generally assumed that discount rates at this relatively high level will require that project benefits (i.e., flood reduction) be delivered early in a project (e.g., within the first year or two). Early delivery of flood reduction benefits likely means that reef restoration projects could not rely on planted coral fragments and growth alone and would need to pair structural (gray) and biological (green) restoration components for a hybrid approach. Still, there are scenarios where reef restoration could deliver significant returns on investment (i.e., B:C > 1) even if some of these benefits develop over time and with high discount rates (Beck et al. 2022).

FEMA BCA Toolkit

Most projects demonstrate cost-effectiveness using FEMA's BCA Toolkit software unless explicitly authorized by FEMA to use an alternate methodology. Cost-effective mitigation projects must have a BCR greater than or equal to 1.0 to demonstrate that the benefits outweigh the costs. FEMA's BCA toolkit requires specific data to be entered to evaluate the BCR, and documentation must be provided for any values entered unless they are a default within the tool. Projects are evaluated by property structure type, hazard type, mitigation action type, and the damage-frequency relationship (modeled damages, historic damages, professional expected damages). All projects require a project cost estimate, project useful life, and annual maintenance costs. Depending on the type of hazard, project, and damage-frequency relationship, different information about the damage history or avoided future damages is required. Additional benefits like ecosystem services can only be incorporated for some projects and hazard types. In 2022, FEMA released additional ecosystem service values, including for coral reefs and shellfish reefs. While the value for coral reefs includes some flood risk reduction benefits, the intent is that it can also be combined with other types of analysis to more fully quantify the risk reduction benefits that coral reefs provide. More information is available on FEMA's BCA website, which includes the BCA Toolkit, policy and guidance updates, and training materials.

Economic Analyses

When deemed appropriate or for planning purposes, economic impacts and benefits can be assessed quickly using the FEMA Flood Assessment Structure Tool (FAST). FEMA's FAST is freely available under the Hazus Open-Source Tools download. On its own, Hazus is currently not acceptable to demonstrate cost-effectiveness. However, FAST can provide the economic losses with and without coral reef restoration by using flood risk reduction values from USGS/UCSC datasets showing flooding by storm return period in combination with other economic data of potential local benefits as described here.

FAST rapidly analyzes building-level flood risk using the Hazus flood model methodology. It was designed to make building-specific flood risk assessments quicker, simpler, and more resource-effective. Site-specific building data in a spreadsheet format are a required input that includes several attributes related to building vulnerability (e.g., building area, first-floor height, and foundation type). FAST includes a Help file that outlines the building data requirements, which is part of the FAST download. FEMA and USACE have developed national baseline inventories of structures that support this effort, including the National Structure Inventory (NSI). Several coral reef and mangrove test cases have been completed in Florida and Hawai'i using these data (Bergh et al. 2020; Stovall et al. 2022; Menendez et al. in press). Within FAST, Hazus provides a large library of damage functions that can be selected and assigned by the user. If not assigned by the user, defaults are provided as recommended by the expert panels and committees that developed these for Hazus. For user inputs, FAST requires hazard data in the form of depth grids with depth of water in feet. To estimate potential losses avoided as a result of the project, depth grids that represent the with and without project are required. FAST provides Average Annualized Losses (AAL) using two methods since AAL can better guide investment decisions over the life of the project. The first is a standard AAL method that requires a minimum of three return periods ranging anywhere between 10 and 1,000 years. The second is an exceedance probability function (PELV) AAL method (based on the actuarial curves developed by USACE and the FEMA NFIP) and requires only the 100-year return period. USGS has developed FAST-ready depth data for almost 2,000 miles of coral reef habitat based on the potential loss of the upper 1 meter of the reef system (Storlazzi et al. 2019). This compilation of information provides the framework to estimate the overall benefits of the coral reef system in reducing losses.

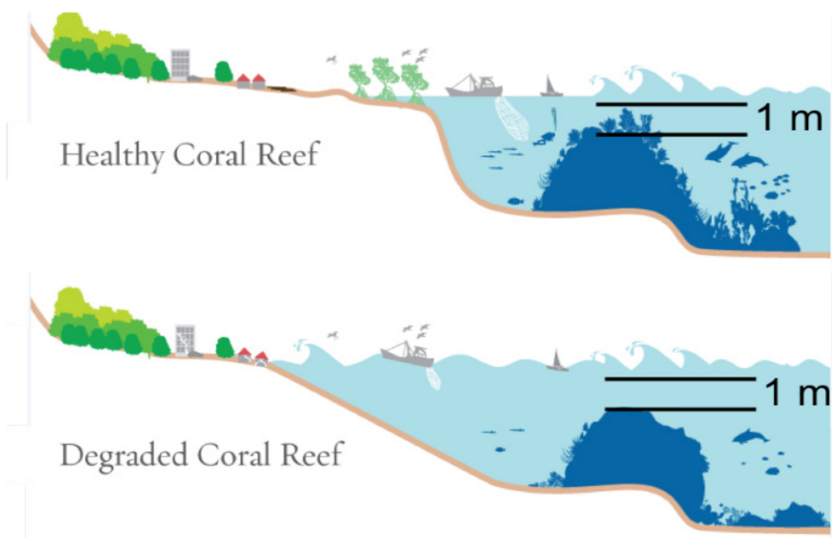

Figure 19. The loss of the top 1 m of reef has the potential to result in significantly increased flooding onshore. Credit: TNC.

Estimating Project Costs

Currently, few studies estimate project cost data for a CR4 project (Beck et al. 2022; Braithwaite et al. 2022), but many entities (e.g., engineering firms) can develop cost estimates based on analogous projects such as low-crested submerged breakwaters. Several studies review the costs of coral outplanting from nurseries, also referred to as coral gardening (Bayraktarov et al. 2019). In most instances, nursery plantings will be at least one part of CR4 costs.

In 2014, Ferrario et al. (2014) reviewed the published cost of structural restoration projects and identified a median structural reef restoration cost of $1290 per meter. A more recent pilot project in Grenada was estimated to cost $3600 per meter (Reguero et al. 2018, 2019); this project involved structural restoration with sections higher than the 1-m considered by Ferrario et al. (2014). The project proponents noted that initial costs for this 30-m Grenada pilot project were likely significantly greater than expected final project costs as larger implementation would offer some economies of scale (Reguero et al. 2018).

Figure 20. A hybrid CR4 structure installed in Grenada to reduce wave energy. Photo credit: TNC.

Project proponents can work with local coral restoration practitioners and environmental/coastal engineers to get specific cost estimates for the region in which they plan to implement their project. Local environmental/coastal engineers can provide approximate costs for a submerged breakwater structure that might be used in a hybrid approach where corals are attached to a structural restoration component. For nursery-grown coral restoration, most cost estimates are typically for smaller-scale restoration projects. However, local coral restoration practitioners can provide local cost estimates for nursery-grown or other coral fragmentation methodologies. Then, the project proponent can use those local costs as the basis for the cost approximation for FEMA's BCA. Long-term maintenance and monitoring cost estimates are also limited for large-scale coral restoration projects and CR4 projects in particular. The largest comprehensive estimate of coral restoration costs, including maintenance and monitoring, to date is from the Florida Keys Mission Iconic Reefs project. However, the monitoring and maintenance costs associated with the Mission Iconic Reefs project are for monitoring ecological outcomes, not risk reduction. Thus, it is more appropriate to estimate monitoring and maintenance costs for a CR4 project based on the local monitoring and maintenance costs for a subtidal submerged breakwater rather than an ecological coral restoration project.

Step 4. Developing a Project Proposal
The process of developing and submitting a CR4 project proposal takes time and engagement from a broad array of stakeholders and experts. FEMA BRIC capability and capacity building (C&CB) funds can be used to support the facilitation and coordination of the team's effort for project scoping, regardless of the ultimate CR4 project funding source. Note that the state or territory manages all FEMA HMA funding, so it is vital to get in touch with the local emergency management agency or SHMO early to establish cross-sector project interest and prioritization. The SHMO will also help guide the application creation and submission process. Specific project proposal requirements, priorities, and contact information will be available in the FEMA, or other federal agency, grant program NOFO(s). For non-grant funding, the appropriate program manager in the local/regional agency office can be contacted to learn more.

Conclusion
There is promising interdisciplinary interest in the use of NBS for coastal flood risk reduction, particularly as NBS are identified in federal hazard mitigation funding opportunities such as FEMA BRIC. CR4 projects will rely on multiagency collaboration throughout the process of obtaining data, designing a project to reduce flooding, developing BCAs, and gaining support and permits from management agencies. There is growing evidence that coral reef restoration could be a technically and financially effective approach for coastal protection with supporting interest from stakeholders in local communities, territorial and state agencies, and businesses ranging from engineering contractors to insurance. However, challenges remain as there are only a few CR4 demonstration projects on which to inform the design and proposal development. Cooperative parties are actively working to overcome these barriers. The potential to integrate CR4 projects into the suite of hazard mitigation strategies for coastal communities will continue to grow as critical questions are answered, and interagency partners work together to advance CR4 as an attainable NBS.

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