# (NCR_15) Coral Reef and Seagrass Protection and Restoration

## Sector(s) Impacted

Natural and Cultural Resources, Water, Economics, Municipalities, CPCB, Public Buildings, Housing, Health and Social Services, various infrastructure

## Issue/Problem Being Solved

Coral reefs have an average economic value of nearly $1.1 billion per year and provide an average of 97-percent wave attenuation which provides storm protection. Corals also provide habitat and recreational services. Seagrass is habitat for multiple commercially important marine species and supports a wide range of recreational activities. Hurricanes Irma and Maria had a severe impact on coral reefs and seagrasses. Storm damage disturbances negatively affected the ecosystem services that corals and seagrasses contribute to protecting coastal infrastructure, including the reduction of wave energy and surface currents and soft bottom sediment stabilization.

## Short Description of COA

This COA would restore five impacted coral reef sites to enhance protection of coastal communities, human safety, health and invigorate the economy. Main activities include establishing coral farms/nurseries to grow and outplanting corals to severely impacted reefs sites, helping reefs recover significantly faster than naturally (i.e., 5 years compared to more than 20 years). Outplanting live corals would prevent further erosion of the reefs and create habitat for important reef fishes, as well as provide additional reef height and increased coastal protections as the corals grow to one meter tall over five years. This COA would be implemented by NOAA, DNER, and NGOs on five sites chosen for high levels of damage and probability of success.

This COA would protect and restore seagrasses by creating new marine benthic habitat maps from high-resolution imagery, conducting field assessments and a long-term monitoring program to determine seagrass health, density, diversity and area, and implementing recovery actions that protect or restore seagrass habitats damaged by hurricane-related vessel groundings, coastal erosion, sedimentation, and enhanced pollution, among other causes.

## Potential Benefits

Coral reefs provide storm protection through an average 97-percent wave attenuation; reef restoration is cost-effective and much less expensive than constructed breakwaters. This COA would directly create 29 jobs and contribute to many more (e.g., boat manufacturing, maintenance). Reefs also provide an important and highly biodiverse habitat for multiple species and also enhance the fishery, tourism, and recreation economies.

Seagrasses are a facet of Puerto Rico's strong ocean-dependent socioeconomic activities, which are a key coastal economic driver. A better understanding of seagrass distributions, monitoring of the habitats post-hurricane, and recovery of lost seagrass will help ensure the sustainability of their economic and ecological contributions to human and coral communities, provide data for marine and emergency planning, and recover lost seagrass ecological services.

## Potential Spillover Impacts to Other Sectors

Reef restoration supports other sectors through coastal protection and averted flood inundation. Restoration also benefits Puerto Rico's $1.1 billion coral reef–associated economy, including tourism and fisheries. Imagery and habitat maps to support seagrass restoration can support various sectors' activities. Pollution

reduction and coastal community restoration coordinated across multiple sectors can also support other COAs' goals, especially when it comes to the ocean and visitor economy.

## Potential Costs

Total cost for this COA is $13.5-14.5 million. Estimated costs for mapping, monitoring and assessments and restoration for seagrasses total $4.7 to $5.7 million. Estimated costs for coral reef restoration are $8.9 million over seven years, depending on labor and site approval ($22 million labor is included in NCR_33 BlueShore Workforce Development).

## Potential Funding Mechanisms

NOAA, EPA, USCG, USFWS. Additional funding for these ecosystems to support sea turtle habitat and food sources (through nonprofits, international agencies or the federal government) may exist.
FEMA Disaster Relief Fund,Hazard Mitigation; USACE Investigations fund, and Construction fund; future appropriations to FEMA, USACE, or NOAA.

## Potential Pitfalls

Coral reefs are sensitive ecosystems that may be damaged by ocean acidification, thermal stressors, pollutants, additional storm and wave impacts, and human impacts, such as anchor drops or high tourist traffic. Long-term success may depend on putting in place plans and protections, such as creating a marine protected area or marine management areas although this may reduce the social and economic value of the restoration sites if access is restricted. Onshore pollution prevention will also increase likelihood of success.

Seagrasses may be damaged further by land-based pollution or high levels of sedimentation. Increased biodiversity might increase human traffic, which could cause vessel damage to seagrasses. Seagrasses are linked to other coastal habitats, such as corals and wetlands, and thus their success depends on the successful restoration of these other habitats as well.

## Likely Precursors

Planning, such as evaluation of methods and site selection for monitoring, and design of restoration.

Lower cost estimate for coral restoration is dependent on labor availability from Blue Shore Workforce Development (NCR_33).

**Note:** It is recommended that coral reefs/seagrasses, beaches/dunes and wetlands are restored in tandem. While each of these systems is technically a separate ecosystem, the benefits for coastal protection, biodiversity and commercial fishing, and recreation are all increased if all three systems are healthy and functional. When considering coastal protection, for example, wetlands provide water filtration services which help keep corals and seagrasses healthy; healthy corals and seagrasses are larger and denser and provide more wave attenuation, thus protecting wetlands from storm damage. Tourism is improved if tourists can expect to enjoy intact beaches, wildlife on live reefs and seagrass beds, and healthy bioluminescent wetlands all on the same trip. These three systems work in symbiosis and there are many benefits that are multiplied if restoration to these three systems is done simultaneously.

This justification is organized with the justification for seagrass restoration first, followed by the justification for coral reefs. These two systems are separate but restoration should be performed in tandem.

# Seagrass COA Justification

## Sector(s) Impacted

NCR, Water, Economics, Municipalities, Capacity Building

## Issue/Problem Being Solved

Hurricane Maria had severe impacts seagrass communities at varying intensities and extents island-wide. Post-hurricane rapid assessments found a wide distribution of disturbances to seagrass due to hurricane-related vessel groundings, sedimentation, and coastal erosion. Disturbances to seagrass negatively affects the ecosystem services they contribute to the marine environment and people of Puerto Rico. A better understanding of seagrass distributions, monitoring of the habitats post-hurricane, and recovery of lost seagrass will help ensure the sustainability of their economic and ecological contributions to the human and coral communities and the associated ocean-dependent socioeconomic activities and coastal economy in Puerto Rico.

Additional Information:

Rapid assessments completed post-hurricane provide evidence that seagrass habitats were directly damaged via sediment burial, physical uprooting, and scouring as well as stressed by degraded water quality conditions related to Hurricane Maria. Assessments found a wide distribution of disturbances to seagrass due to hurricane related vessel groundings, sedimentation, and coastal erosion. The assessments were unable to provide a detailed comprehensive status of seagrass resource impacts for all coastal waters but instead used proxy measures of water quality as an estimate. It is important to understand the extent of hurricane disturbance to seagrass as it negatively affects the ecosystem services seagrass contribute to the marine environment and the people of Puerto Rico. Like coral reefs, seagrass habitats help reduce wave energy and surface currents and stabilize soft bottom sediments, which assists in natural protection of infrastructure along the coast. Seagrass is habitat for multiple commercially important marine species and supports a wide range of recreational activities, including SCUBA, snorkeling, kayaking, and swimming.

The COA addresses the needs to: 1) update mapping of the benthic marine environment around Puerto Rico, 2) establish a seagrass monitoring program to conduct localized field assessments of seagrass conditions in prioritized areas and assessing seagrass density, diversity and area, and 3) implement recovery actions that protect or restore seagrass habitat damaged by hurricane related actions like vessel groundings and coastal erosion. Seagrass is an important feature in the larger tropical reef ecosystem and plays a major role in marine food webs, blue carbon sequestration, and cycling of nutrients to provide clear coastal waters. Seagrass beds are habitat that support commercially important fisheries and managed species in the Caribbean such as conch, snappers, sea turtles, and manatees. A broad scale review of pre and post hurricane imagery sought to characterize hurricane related physical disturbance to seagrass by identifying changes in seagrass habitat to un-vegetated sediment. The assessment found widely distributed evidence of physical disturbance to seagrass thought to be due to hurricane related vessel grounds, land-based sedimentation, and coastal erosion. Over 200 instances of disturbance were detected indicating physical removal or burial of plants due to sedimentation. This cursory level assessment also determined that existing marine habitat maps produced by NOAA in 2001, 2010, 2012, and 2015 are outdated or inaccurate in some areas. It is recommended that more refined data be collected and produced in order to more thoroughly assess large-scale hurricane impacts to seagrass.

## Short Description of CoA: Address landscape-scale seagrass data gaps and restore degraded habitats

Actions will address seagrass data gaps as well as protect and restore seagrasses by creating new marine benthic habitat maps from high-resolution imagery, by conducting field assessments and a long-term monitoring program to determine seagrass health, and by implementing recovery actions that protect or restore seagrass habitats damaged by hurricane-related vessel groundings, coastal erosion, etc.

This course of action addresses deficiencies in marine benthic habitat maps and seagrass ecological data and implements cross cutting projects to recover seagrass habitat while creating local labor needs and providing benefits to coastal communities. The three general actions include: 1) creating post-hurricane marine benthic habitat maps of seagrass, macro-algae, and corals in the waters of Puerto Rico, Vieques, and Culebra using high-resolution imagery, 2) establish seagrass monitoring program(s) to conduct localized field assessments of seagrass conditions in high priority areas, and 3) implementing recovery actions that protect and restore seagrass damaged by hurricanes, vessel groundings, coastal erosion, and land-based pollution runoff. Restoration may include protection-based activities such as shoreline stabilization projects, sediment reduction projects, and environmental awareness outreach for dock owners and boaters.

New marine benthic habitat maps will be generated from high-resolution satellite or aerial imagery locating the extent and distribution of seagrass, corals, macro-algae, and other relevant habitats. Where appropriate and available, the new mapping effort will incorporate additional innovative technologies such as drone low-altitude imagery collection and LiDAR for prioritized areas. Imagery will be used to identify and delineate the distribution of seagrass and other benthic habitats, post-hurricane. The in-field monitoring will include one-time localized

assessments in seagrass habitats of the north, east, south, and west Regions of Puerto Rico. In addition, a long-term seagrass monitoring program will be established for the NOAA designated Northeast Marine Corridor and Culebra Island Habitat Focus Area https://www.habitatblueprint.noaa.gov/wp-content/uploads/2017/05/Puerto-Rico-HFA-May16.pdf. All in-field monitoring will require assistance by local entities to conduct boat-based field verifications of newly generated habitat maps and collect seagrass community health data to track the status of the resources and how they changed. Biological data on species richness, percent cover, shoot density, and possible growth parameters will be collected. Additional environmental parameters such as sediment accretion depths and sediment movement data will seek to increase our knowledge of physical disturbance mechanisms related to hurricane-induced wave energy. Filling data gaps and improving our knowledge of the distribution of seagrass and other marine habitats will benefit the human community immediately upon completion. Implementation of marine benthic habitat map creation and establishment of a seagrass field monitoring program will be led by NOAA with DNER support. The various restoration project implementation may involve NOAA, EPA, USACE, USFWS, and DNER. Other important stakeholders, collaborators and partners may include academia, NGOs, and private businesses.

Based on findings by preliminary seagrass impact and disturbance evaluations, Fajardo-Culebra, Salinas, and Vieques experienced pronounced changes to seagrass and will be the focus of initial restoration activities and elements of the field assessments described above. Implementation of restoration activities will seek to improve existing seagrass density and cover in degraded habitats and to encourage recruitment and regrowth in areas of loss. Traditional transplanting and in-the-ground seagrass restoration techniques will be implemented in appropriate locations. Restoration may also include protection-based activities such as shoreline stabilization projects, sediment reduction projects, and environmental awareness outreach for dock owners and boaters.

Additional example recovery projects to implement include:

1. Build boat ramps and erosion control systems in high traffic areas, such as San Jacinto, where improvised ramps are a source of sediments negatively affecting nearby seagrass beds. This may connect with the economics sector as it deals with the fishery disaster declaration by the Department of Commerce in February of 2018.
2. Install storm drain traps to minimize debris entering coastal waters and seagrass habitats in locations such as Guanica Bay.
3. During permitting and post-hurricane rebuilding efforts, promote the use of different materials and dock designs (e.g. gratings) to reduce dock-shadowing effects on seagrass.
4. Establish mooring fields and management services for mooring fields in Salinas and Culebra.
5. Pilot control techniques for management of the invasive sea vine, *Halophila stipulacea*.

The likely time scale to realize project benefits will vary depending on the specific action. Actions such as ecological monitoring and assessments can provide benefits in the short-term (<1 year) by informing scientists and resource management agencies through data sharing. Habitat mapping products are expected to be completed within 2 to 3 years. Restoration work can begin independently of the new data collection and habitat map creation. Physical impacts to seagrass could be addressed immediately with small-scale seagrass re-establishment in propeller scars and shallow nearshore beds. Restoration efforts are expected to produce benefits, depending on the magnitude and scale of the projects, within 3 to 5 years. Restoration and protection projects that involve managing the invasive Sea vine, *Halophila stipulacea* are anticipated to take longer (approximately 5 to 10 years).

## Potential Benefits

This will provide data for marine planning and recover lost seagrass ecological services.

Additional Information:

Post-hurricane marine debris clean-up efforts by the Army Corps of Engineers and multiple entities involved in hurricane preparedness planning or resource management protection will benefit from new benthic marine habitat maps that fill current data gaps. Improving our knowledge of the distribution of seagrass and other marine habitats and the imagery collected for mapping can be used by various sectors for other natural assessments, community and transportation planning, etc. Project examples proposed earlier describe a wide breadth of activities that will protect seagrass habitat by removing pollutants and stressors to the environment while providing amenities and benefits to local communities, their waterfronts, and local tourism economy. These various actions seeking to monitor and protect seagrass habitat will create local labor needs and providing benefits to coastal communities by investing in possible community improvement projects like boat ramps and mooring fields as well as pollution reduction projects. Recovering disturbed and degraded seagrass will also provide important benefits to multiple small businesses that depend on seagrass conditions for their operations (eco-tourism, fishing).

The report referenced below provides support for the COA's recommendation to update Puerto Rico's marine habitat maps and makes additional suggestions for seagrass restoration actions that will strengthen seagrass resources in order for them to continue to provide valuable ecosystem services.

http://www.nfwf.org/whatwedo/idea/seagrassfund/Documents/Puerto_Rico_Seagrass_Initial_Assessment.pdf

Otero, E., Y. Detres, R. Armstrong, S. Williams, W.J. Hernandez Lopez, 2015. Puerto Rico Seagrass Fund – Initial Assessment: Integration of Field, Aerial Photography and Water Quality Measurements for the Assessment of Anthropogenic Impacts and Stressors in Southern Puerto Rico. Final Report. January 26. 58 p.

## Potential Spillover Impacts to Other Sectors

Imagery and habitat maps can support various sectors' activities. Pollution reduction and coastal community restoration coordinated with multiple sectors can achieve this and others COAs' goals.

Additional Information:

It is expected that several sectors will initiate land-based pollution reduction projects and efforts to restore coastal communities (including human infrastructure and natural vegetation). These activities can be coordinated during implementation in order to provide complementary benefits to this COA and others originating from different sectors. Products resulting from this COA such as satellite and aerial imagery collections can support various activities outside of this COA for other sectors such as transportation. Capacity building will benefit from having newly updated distribution maps of important natural resources for emergency planning, disaster reponse, and marine management planning efforts. Economics and Municipalities will benefit from restoration or protection-based projects that require local workforce labor for

implementation and any resulting amenities such as additional removal of trash or public boat ramps that would result from projects.

## Potential Costs

Estimated costs for mapping, field assessments, and restoration total $5,660,000.
Additional Information:

1. High level cost estimates for creating a comprehensive island(s)-wide benthic marine habitat map is $2-3M. To accommodate funding availability, mapping can be completed in phases, prioritizing areas of special concern and marine reserves. Field assessment monitoring costs will vary based on the number of locations selected for evaluation and intensity of sampling. Allocating approximately 8 days for sampling during a one-time post-hurricane assessment within four regions of Puerto Rico will cost an estimated $110,000. Data compilation, analysis, and report writing costs are an additional $50,000.
2. Restoration project planning (feasibility and project design) for in-the-ground restoration and additional protection-based projects is estimated at $500,000.
3. Using a cost estimate of $100,000 per acre (0.4 hectares) for in-the-ground restoration of tropical seagrass habitat, the COA seeks to restore 5 acres (up to 2.02 hectares) at an estimated cost of $500,000.
4. Activities proposed for the Fajardo-Culebra area that focus efforts in the Northeast Marine Corridor and Culebra Island Habitat Focus Area would cost an additional $1,500,000 for restoration as well as establishment of a minimum 5-year seagrass in-field monitoring program.

## Potential Funding Mechanisms

Federal agencies that would partner in this COA include: NOAA, EPA, ACOE, USCG, and USFWS.

## Potential Pitfalls

Encountering adverse environmental or weather conditions during data collection and restoration. Additionally, transplants may fail to survive or thrive.

## Likely Precursors

Planning such as evaluation of methods and site selection for assessments and restoration are likely.
Additional Information:
Prior to implementation, identification of high quality imagery available for mapping should be investigated. An evaluation of all possible imagery acquisition methods and sources will also be conducted to determine the most effective and cost efficient methods for implementation given the unique constraints for capturing data island(s)-wide. Additional analysis and interpretation of FEMA-generated seagrass assessments and other available data will be conducted to develop location specific data collection and restoration needs. Feasibility, engineering design, and permitting will be required for some types of projects proposed. In addition, in-the-ground restoration would require identifying donor plant sources.

# Coral COA Justification

## Sector(s) Impacted

Infrastructure (Transportation, Public buildings, Communications, Public Buildings, Power, Water); Housing; Economics; Municipalities; Health and Social Services; Natural and Cultural Resources; Capacity Building.
Coral reefs provide crucial coastal protection services that significantly reduce wave energy and flood inundation for all coastal communities' infrastructure, building, utilities, and services. Coral reefs also serve as habitat for commercially and recreationally important fisheries and as a focus for tourism and recreation; thus they are major contributors to Puerto Rico's economy. Finally, this COA will produce 29 jobs, increasing local capacity, but more indirect jobs could be expected in the tourism and recreation economic sectors.

## Issue/Problem Being Solved

Hurricanes Irma and Maria had a severe impact on coral reefs, which are natural infrastructure that provide an average of 97% wave attenuation and protection to coastal infrastructure (Ferrario et al. 2014). They are like nature's seawall. Coral reefs are also the habitat for commercially important marine species and have an average economic value of nearly $1.1 billion per year (Brander and Van Beukering, 2013) and are crucial for the sustainability of a long term strong ocean dependent economic activities.

Globally, coral reefs are facing significant threats from climate change, unsustainable fishing, and land-based sources of pollution, which have led to dramatic declines in coral abundance and their ability to create and maintain major reef structures (Hughes et al., 2018). Coupled with this decline, Caribbean corals are also experiencing low reproduction and low levels of successful recruitment (Edmonds et al., 2018), which would help to replace the corals that are dying. Thus, the coral reef system was already compromised and experiencing slow recovery prior to Hurricanes Irma and Maria affecting Puerto Rico.
Overall, an average of 11% of Puerto Rico's corals were damaged by the hurricanes; however, the damage at each location was variable and some sites experienced severe damage (up to 100%). The major reef-building and Endangered Species Act (ESA) listed corals were the most severely impacted species. The Northeast (including Culebra), North, Vieques, and West regions showed the highest levels of damaged corals, as might be predicted by the highest wave energies experienced in these regions due to the paths of the hurricanes.
Triage activities salvaged thousands of at-risk corals; however, thousands more are still likely at-risk. Further, in many cases, the fragments or loose colonies were removed completely from the reef site by the waves and are lost from the system. Thus, some sites would benefit from replanting the reef with propagated corals from nurseries to restore, or potentially enhance the protective services the reefs provide. These activities would help these sites recover in approximately 5 years.

<u>Additional Information:</u>
This COA specifically addresses the recovery of severely damaged coral reef sites so they can maintain and increase their coastal protection services to socioeconomically-important communities. Currently, these reefs have reduced capacity to provide coastal protection to the

over 500,000 people and associated properties residing in coastal communities due to the loss of the complexity and reef height the corals provide. In particular, elkhorn coral was one of the most impacted species (average of 45% of all elkhorn corals were damaged.). Thus, restoring impacted coral reef sites will enhance protection of coastal communities, human safety, health, and invigorate the economy.

## Short Description of CoA: Protect coastal communities by restoring volume and function of coral reefs

*What does the CoA do?*
By 2025, increase protection of approximately 30 km of coastline by increasing the reef height by 1 meter with 1 million corals in areas that have large populations and significant economic activity importance, including San Juan, Fajardo, Culebra, Aguadilla, and Arecibo.
The COA will establish coral farms/nurseries to grow and outplant the corals to these severely-impacted reefs sites. The reefs will recovery significantly faster than naturally. Outplanting live corals will prevent further erosion of the reefs immediately, and then provide additional reef height and increased coastal protections as they grow to 1 meter tall over 5 years.

*Who is implementing the CoA?*
NOAA, DNER, & NGOs.

*How are they implementing the CoA?*
**RESTORATION**
A coral reef restoration program will be established to restore approximately 1 $km^2$ of coral reef habitat at 5 priority locations around Puerto Rico. The duration of the program is 7 years, including restoration activities and success monitoring. Elkhorn coral is the focus species due to its relatively fast growth rate, robust and complex structure, growth on reef crest so it will increase overall reef height, and ease and success of propagation. The program will repair and help with recovery of severely damaged reef sites within 5 years after outplanting.
Five coral reef sites have been identified as priorities for restoration. These sites were selected based on the following criteria: (1) Sustained severe damage from the hurricanes; (2)Habitat is suitable for restoration (e.g., substrate is stable, good water quality); and (3) Protect valuable coastal communities.
The same methods will be used at each restoration site.

1. **Establish coral nurseries/farms near each restoration site**: Nurseries will be established proximate to the selected restoration sites. Most farms will be established in situ; however, an ex situ facility may be considered to maximize operational time, particularly in areas of challenging field conditions such as the North Coast. Floating arrays will be constructed and secured to the seafloor to serve as the structure on which the corals will be propagated.

2. **Collect broodstock:** Elkhorn coral fragments (~5 cm diameter) will be collected from local populations to serve as broodstock. Fragments from numerous genetic individuals will be collected to maximize genetic diversity within the nurseries and at restoration sites.

3. **Propagate corals:** Coral fragments will be placed on the pre-constructed floating arrays. Divers will periodically perform maintenance at the nursery to remove any fouling organisms and ensure the structures are sound. Fragments will be grown to ~15 cm in maximum linear dimension after approximately 6 months in the nursery. A subset of fragments will remain in nursery and be sub-fragmented to serve as continuous broodstock. This process will be repeated approximately every 6 months for the duration of the program.

4. **Outplant corals**: Once coral fragments have achieved the 15-cm size, they will be collected from the floating arrays and transferred to the restoration site, approximately every 6 months. The fragments will be outplanted at density of 1 coral/$m^2$ to maximize the potential for growing into dense thickets, providing the highest level of coastal protection. Outplants will also be arranged to maximize potential for natural reproduction, further increasing the abundance of the species at restoration sites and on adjacent reefs. Over the duration of the program, approximately **1.03M** corals will be outplanted.

5. **Ensuring success:** These methods of coral restoration are extremely successful and will include monitoring for adaptive management. Coral survival is over 90% and outplanting strategy has taken this mortality into account such that at the project's end, the 1-million coral target will be met. The regulatory framework already exists to provide protection of the investment (i.e., Puerto Rico Law 147 of 1999, Marine Protected Areas).

*What is the likely time scale to see benefits?*
Benefits will begin immediately upon outplanting. The outplanted corals will protect the reef from further erosion and contribute to complexity, which increases friction, and reduces wave energy. The outplanted corals will also immediately provide complex habitat for commercially important reef fishes. The full benefits of the restoration will be realized within 5 years based on the time it will take for the corals to grow to 1-m in height.

*Location (if any) of CoA.*
The restoration sites are distributed around the coast of Puerto Rico based on areas of severely damaged reefs and their potential to provide significant coastal protection when restored. Table 1 lists the 5 sites, their location, and area to be restored.

**Table 1. Location and size of Restoration Sites**

| Map Label | Restoration Site | Latitude | Longitude | Restoration Area* ($m^2$) |
|---|---|---|---|---|
| **1** | Aguadilla | 18.44 | -67.16 | 2,522 |
| **2** | Arecibo | 18.49 | -66.66 | 84,502 |
| **3** | San Juan | 18.46 | -66.04 | 331,385 |
| **4** | Fajardo/NE Reserves | 18.35 | -65.58 | 403,447 |

| | | | | |
|---|---|---|---|---|
| **5** | Culebra | 18.28 | -65.25 | 187,703 |
| | TOTAL | | | **1,009,559** |

## Potential Benefits

Puerto Rico is an archipelago of islands that is surrounded by coral reefs almost entirely; however, these reefs were severely damaged by the hurricanes. Puerto Rico has 700 miles of coastline and a coastal population of 525,305. Sixty one (61%) of Puerto Rico's population lives within 1 kilometer of the coastline, and most of Puerto Rico's economic activity and critical infrastructure is located within the 44 coastal municipalities (DNER Office of Coastal Management and Climate Change). Coral reefs buffer coastlines from erosion and inundation, providing important protective services. These natural coastal systems reduce risk to people and infrastructure from wave damages and flooding. This COA will provide crucial coastal protection services to important coastal communities by restoring live corals to the reef and increasing the reef height by 1 meter. It will directly create 29 jobs and contribute to many more (e.g., boat manufacturing and maintenance). It will also enhance fishery, tourism, and recreation economies.

Additional Information:

Recent studies have shown the success and cost-effectiveness of using natural infrastructure for coastal protection (Calil et al. 2015; Reguero et al. 2018, Narayan et al. 2018). Coral reefs have the highest overall potential to reduce wave energy (Narayan et al. 2018). Healthy coral reefs have been shown to reduce up to 97% of wave energy (Ferrario et al. 2014). Natural infrastructure has an average cost benefit ratio of 3.5 (Reguero et al. 2018) and are more cost effective than constructed structures (e.g., breakwaters). Constructed breakwaters average $19,791 per linear meter (Ferrario et al. 2014); whereas, this coral restoration COA averages less than $1,000 per linear meter.

Changes in reef height significantly affect the amount of protection that coral reefs provide. Preliminary analyses show that just in the San Juan-Metro area, existing (pre-hurricane) coral reefs would avert $122M in flood damages from a 100-yr storm event as compared to a reduction of just 1-m in reef height, as was observed post hurricanes (Beck and Storlazzi, unpublished data). Conversely, the increase in reef height of the one-meter proposed at the 5 restoration sites in this COA has the potential to avert significant additional damages by preventing flooding. These findings make a strong case for enhancing Puerto Rico's coral reefs to restore and enhance the coastal protection services the damaged reefs provide.

The particular restoration sites were selected specifically to provide coastal protection to the important coastal communities of San Juan, Fajardo, Culebra, Arecibo, and Aguadilla.

Puerto Rico's coral reefs and associated ecosystems have an average economic value of nearly $1.1 billion per year, including tourism, diving, snorkeling, and fisheries ((Brander and Van Beukering, 2013). The five restoration sites, the San Juan metro area, Fajardo, Aguadilla, Arecibo, and Culebra, are some of the top tourism destinations. Puerto Rico's tourism contributes 12 % to the National Domestic Product and is one of the few economic sectors demonstrating sustained growth. This COA will directly contribute to and enhance these vital economies.

## Potential Spillover Impacts to Other Sectors

*Brief description on how the CoA could positively or negatively impact other sectors, with attention to considerations for implementation*

Because this COA provides coastal protection to the five communities in which the restoration sites are located, it positively impacts the following sectors: Infrastructure (Transportation, Public buildings, Communications, Public Buildings, Power, Water); Housing; Economics; Municipalities; Health and Social Services; Natural and Cultural Resources; Capacity Building

Coral reefs provide crucial coastal protection services that significantly reduce wave energy and flood inundation for all coastal communities' infrastructure, building, utilities, and services. Coral reefs also serve as habitat for commercially and recreationally important fisheries and as a focus for tourism and recreation; thus they are major contributors to Puerto Rico's economy. Last, this COA will produce 29 jobs, increasing local capacity.

## Potential Costs

**Error! Reference source not found.** is a summary budget for the CoA assuming that labor is provided by the Blue Shore Workforce Development Initiative (COA 33). A detailed budget is provided in Appendix 2.

Note: Budgets assume seven year timelines: 5 years of active restoration, 2 years of monitoring.

**Table 2. Summary of costs excluding labor.**

| | |
|---|---|
| Vessel lease and charter | $4,158,900.00 |
| Land facility and storage | $882,000.00 |
| Supplies and equipment | $1,800,000.00 |
| Subtotal | $6,840,900.00 |
| Project Management | $1,120,000.00 |
| Travel | $750,000.00 |
| Contract Processing Fee (2%) | $159,218.00 |
| **TOTAL** | **$8,870,118** |

**Table 3. Summary of costs including labor by location.**

| Recovery Site | Cost |
|---|---|
| San Juan | $10,324,473 |
| NE Reserve | $12,569,616 |
| Culebra* | $5,847,984 |
| Arecibo* | $2,632,713 |

| | |
|---|---|
| Aguadilla* | $77,032 |

* The budget was built assuming the economy of scale of a large project. The costs for Culebra, Arecibo, and Aguadilla are only valid if the San Juan and/or NE Reserves portion were implemented as well.

Additional Information:
The costs are based on the particular sites, area proposed to be restored, and the number of corals required. The costs provide above are scalable based on actual area to be restored, or number of sites restored. However, costs are not directly proportional to area restored or number of corals outplanted due to critical infrastructure and labor to establish the program.

## Potential Funding Mechanisms

Federal - February 2018 Supplemental Appropriation: FEMA Disaster Relief Fund ($23.5B), Hazard Mitigation; US Army Corps of Engineers –: Investigations fund ($135M), Construction fund ($15B) or future appropriations to FEMA,USACE, or NOAA.

Potential Implementers:
PR Department of Natural and Environmental Resources (DNER), US Department of Commerce (DOC) National Oceanic and Atmospheric Administration (NOAA)

## Potential Pitfalls

*Where the CoA could fail for reasons outside of the CoA. Dependencies that exist with other sectors or subsectors.*
Coral reefs worldwide are subject to stressors associated with climate change, including thermal stressors, ocean acidification and increased storm activity. Increased tourism can add physical damage (such as anchor drops or swimmer/snorkeler/SCUBA breakage). Pollution events or spills can occur from the land or from at-sea vessels.

## Likely Precursors

*Brief description of the precursors required for the COA.*
Requires NCR_33 BlueShore Workforce Development for labor costs.
This COA is ready to be implemented upon receipt of funding. This project may be more successful if long term plans and protections are put in place, such as creating a marine protected area (MPA) or marine management are (MMA), but also may have lower social and economic value if access is restricted. Onshore pollution prevention will also increase likelihood of success. This project can be successful without these actions but restoration work will be more likely to be protected and resilient if these policies and plans are enacted.

## References

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# Appendix 1: Detailed Budget for Coral Reef Restoration

Note: Budget does not take into account labor provided by BlueShore (NCR_33).
This budget is for seven years. Five years of active restoration, two years of monitoring.

| | | | | | |
|---|---|---|---|---|---|
| **Contractual** | | | | | |
| | | **Loaded Hour Rate** | **Day Rate** | **Person Days** | **Total** |
| **Contract Personnel** | Project Manager | $85.00 | $680.00 | 2066 | $1,405,152.00 |
| | Senior Scientist | $75.00 | $600.00 | 2066 | $1,239,840.00 |
| | Scientific Divers | $60.00 | $480.00 | 6199 | $2,975,616.00 |
| | Senior Field Techs | $60.00 | $480.00 | 5092 | $2,444,256.00 |
| | Field Techs | $48.00 | $384.00 | 20369 | $7,821,619.20 |
| | Dive Masters | $60.00 | $480.00 | 4133 | $1,983,744.00 |
| | Vessel Captains | $60.00 | $480.00 | 5092 | $2,444,256.00 |
| | Deck Hands | $45.00 | $360.00 | 5092 | $1,833,192.00 |
| | | | | | **$22,147,675.20** |
| | | | | | |
| | | **Day Rate** | **Travel Days** | | |
| | Travel | $150.00 | 5000 | | **$750,000.00** |
| | | | | | |
| | | **Purpose** | **Day Rate** | **Resource Days** | **Total** |
| **Lease and Charter** | Vessel Charter | Outplanting | $1,400.00 | 990 | $1,386,000.00 |
| | | Nursery Operations | $1,200.00 | 990 | $1,188,000.00 |
| | | Prep/Monitoring | $1,000.00 | 1386 | $1,386,000.00 |
| | Vehicle Lease | Outplanting | $45.00 | 1300 | $58,500.00 |
| | | Nursery Operations | $45.00 | 1300 | $58,500.00 |
| | | Prep/Monitoring | $45.00 | 1820 | $81,900.00 |
| | | | | | **$4,158,900.00** |
| | | **Monthly Lease Rate** | **Months** | | |
| | Land Facility & Storage | $10,500.00 | 84 | | **$882,000.00** |
| | | | | | |
| | | **Annual Cost** | **Years** | | **Total** |
| **Supplies and Equipment** | Nursery Supplies | $20,000.00 | 5 | | $100,000.00 |
| | Nursery Equipment | $50,000.00 | 5 | | $250,000.00 |
| | Facility Supplies | $15,000.00 | 7 | | $105,000.00 |
| | Facility Equipment | $25,000.00 | 7 | | $175,000.00 |
| | Outplanting Supplies | $100,000.00 | 5 | | $500,000.00 |

| | | | | | |
|---|---|---|---|---|---|
| | Outplanting Equipment | $15,000.00 | 5 | | $75,000.00 |
| | Monitoring Supplies | $10,000.00 | 7 | | $70,000.00 |
| | Monitoring Equipment | $10,000.00 | 7 | | $70,000.00 |
| | Monitoring Data Processing | $65,000.00 | 7 | | $455,000.00 |
| | | | | | **$1,800,000.00** |
| | | | | | |
| | | | | **Contractual Total** | $29,738,575.20 |
| | | | | Contract Processing Fee (2%) | $594,771.50 |
| | | | | | |
| | | | | CONTRACT TOTAL | **$30,333,346.70** |
| | | | | | |
| | | **Loaded Annual Rate** | **Years** | | |
| **NOAA Project Management** | Term Project Manager Labor | $140,000.00 | 7 | $980,000.00 | **$1,120,000.00** |
| | Travel | $20,000.00 | 7 | $140,000.00 | |
| | | | | | |
| | | | | | |
| | | | | **Project Total** | **$31,453,346.70** |