Management Action Plan for the Guánica State Forest Marine Extension

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NOAA Coral Reef Conservation Program

Puerto Rico Department of Natural and Environmental Resources

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Acronyms

BMP	Best Management Practice
CDOM	Colored Dissolved Organic Matter
CELCP	Coastal and Estuarine Land Conservation Program
CFMC	Caribbean Fisheries Management Council
CRCP	Coral Reef Conservation Program
DDT	Dichlorodiphenyltrichloroethane
DNER	Department of Natural and Environmental Resources
DOS	Dark Object Subtraction
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
FMP	Fishery Management Plan
GBW	Guánica Bay Watershed
GPS	Global Positioning System
GSF	Guánica State Forest
IDDE	Illicit Discharge Detection and Elimination
LBSP	Land Bases Sources of Pollution
MD	Marine Debris
ME	Marine Extension
MPA	Marine Protected Area
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NRP	Nutrient Reduction Practices
NTU	Turbidity
PAHs	Polycyclic Aromatic Hydrocarbons
PAR	Photosynthetic Active Radiation
PCBs	Polychlorinated biphenyls
PDC	Protectores de Cuencas Inc.
PR	Puerto Rico
PRPB	Puerto Rico Planning Board
SLR	Sea Level Rise
TSS	Total Suspended Sediments
TW	Treatment Wetlands
UPRM	University of Puerto Rico Mayagüez
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

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Acknowledgements

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We also acknowledge all the people who voluntarily reviewed the drafts at different stages and offered us valuable comments, especially Dr. William J. Hernández of Environmental Mapping Consultants, Ernesto Díaz of the Puerto Rico Climate Change Council, Tania Metz, and Dr. Miguel Canals.

Executive Summary

The Management Action Plan for the Guánica State Forest (GSF) Marine Extension (ME) was developed to identify threats to shallow-water benthic communities and how these relate to anthropogenic activities in the region. The purpose of this plan is to establish a framework for the management of these important ecosystems and the protection of threatened and endangered species, as well as for the management of recreational and economic opportunities for local communities and visitors.

A comprehensive characterization of the marine extension was completed using remote sensing satellite imagery and field campaigns to analyze the current conditions of benthic communities. A literature review was also conducted to support the creation of this plan. Literature such as scientific articles related to the area, management plans for other Marine Protected Areas (MPAs), reports from the Department of Natural and Environmental Resources (DNER) and the National Oceanic and Atmospheric Administration (NOAA), were reviewed to understand past management strategies and historical threats in the ME. Stakeholders including residents, community leaders, non-governmental organizations, municipal officials, and business owners were also involved in the creation of this plan. Based on this information, this plan provides a list of integrated management actions with the potential to minimize the effects of current threats while ensuring the protection and conservation of these important marine ecosystems.

The following areas are identified as important for strategic management:

a) *Expansion of the Marine Reserve*

   The GSF ME is located south of the eastern section of the GSF, but it does not include the area south of the Guánica Bay and Las Pardas. This area has been found to be a critical area for coral reefs and an expansion of the GSF ME would provide protection to these benthic habitats west of Guánica Bay and connectivity to the Guánica Forest area in Punta Brea.

b) *Improvement of navigational aids*

   The GSF ME is home to a resident population of the West Indian Manatee (*Trichechus manatus*), but this species is threatened by use of high-speed watercrafts that can cause serious injury and death. Furthermore, benthic populations such as seagrass can also be

damaged by propellers. Improvement of navigational aids, such as the installation of mooring buoys or signs, would alert users of the ME of the proper use of the area and would help ensure the safety of marine life as well as users.

c) *Pollution Prevention*

Guánica Bay is a priority watershed where there are ongoing restoration and implementation projects to control land-based sources of pollution throughout the watershed. Due to proximity of the ME to the bay, land-based sources of pollution arriving to the bay can affect benthic habitats within the ME. To address existing and future sources of pollution, it is imperative to first identify and evaluate pollution hotspots. Potential hotspots include agricultural lands, landfills, municipal public works yards and marinas, sewage systems, among others. Once evaluated, specific interventions and activities can be recommended to address pollutants depending on the source, pollutant load, and location. Evaluating community sectors El Pitirre and San Jacinto, located just north of the Caña Gorda Cays, could be a first step towards the identification of pollutant sources.

d) *Establishment of a no-take zone for Cayo Coral*

Cayo Coral is an emergent reef located between Punta Ballena and the mouth of Guánica Bay. Surveys within the cay have identified a total of 22 stony corals, a total of 79 fish species and many other algae and invertebrate species. Due to its richness and diversity, Cayo Coral is operated as a coral benthic nursery and restoration site supported by the NOAA Restoration Center, DNER, and HJR Reefscaping. The nursery mainly manages elkhorn coral (*Acropora palmata*) and staghorn coral (*Acropora cervicornis*) which are used for outplanting at restoration sites. Several areas in Cayo Coral have also been restored using species from this nursery site. In addition, Sea Ventures, the DNER, and HJR Reefscaping are leading efforts in Cayo Coral to treat affected coral colonies for stony coral tissue loss disease. Due to its importance in research and restorative projects, the designation of a no take zone for this cay should be considered to preserve spawning areas of many aquatic species and the overall health of the coral reef.

e) *Establishment of the Blue Economy*

Puerto Rico's close to 2.4 million people live close to coastal areas, and locations like the GSF ME draw tourists from around the world and support jobs that can generate significant earnings annually. Challenges such as sea level rise, fish stock declines, *Sargassum* inundations, and land-based sources of pollution impacts to coastal ecosystems can have a detrimental effect on the blue economy potential. Structured management action plans can provide the information baseline of available resources, current uses of the coast, threats, and how to provide best management practices that align with a sustainable economic approach on the use of the resources. In addition, blue economy strategies like co-management of the marine reserve and protected areas can provide a socio-economic and sustainable benefit in the use of natural resources.

f) *Fisheries Management*

In Puerto Rico, fisheries management is regulated by various levels of authority including state and federal agencies such as the Puerto Rico DNER, Caribbean Fisheries Management Council (CFMC), NOAA, and the U.S. Department of Commerce. They are all responsible for developing fishing management strategies. All these agencies collaborate with fishermen and other stakeholders to create management plans and secure the conservation of these important ecosystems. Still, discrepancies in management arise (e.g., seasonal closures) that can confuse the public and that complicate the enforcement of regulations. Considering these discrepancies, the CFMC is currently trying to shift from a U.S. Caribbean-wide Fishery Management Plan to an island-based plan that provides a plan tailored to Puerto Rico's unique characteristics.

Marine fisheries in MPAs are generally managed to conserve, protect, and/or increase fish populations and prevent overfishing. The establishment of this new FMP would help identify potential management actions tailored for MPAs in Puerto Rico, including the GSF ME. The level of fisheries management selected for GSF ME should consider the biological, ecological, and socio-economic data characteristic of the area to determine what type of management would work best to reach fisheries goals. The involvement and approval of the community is recommended to ensure the success of new management actions as identified by a survey conducted by PDC that found that, 86% of surveyed respondents of the GSF do not support the establishment of a no take zone (PDC Data 2022).

g) Best Management Practices

Best management practices are described in this management action plan with the intention of highlighting potential strategies that help conserve the integrity of the ME. Suggested best management practices fall under the following categories: stormwater treatment practices, nutrient reduction practices, soil stabilization practices, and pollution prevention practices. All these practices range in complexity and cost and agencies looking to implement them should consider the availability of space and funds.

Introduction

The Federal Department of Agriculture proclaimed the Guánica Dry Forest as an Insular Forest in 1919. Later on, jurisdiction passed to the local government. In 1981, UNESCO, under the "Man and the Biosphere" program, declared it an International Biosphere Reserve. The Guánica State Forest (GSF) is the most biodiverse forest in Puerto Rico and its marine extension (ME) has over 1,200 documented species including complex coral reef communities and seagrasses. All seven federally threatened coral species in the Caribbean, including *Acropora cervicornis* and *A. palmata*, are present; mammals such as the Antillean manatee, four species of sea turtles, and other species of concern are dependent on the good quality and health of the benthic ecosystems present in the ME.

The GSF ME extends 8.9 km along the coastline from the eastern corner of the Guánica Bay to Punta Ventana and 1.6 km offshore from Punta Jacinto (Figure 1). In this marine component, the Caña Gorda Cays ecosystem is the largest coral reef system in the ME, from which Cayo Aurora (also known as *Gilligan's Island*) was historically the most intensively used area for recreation. Cayo Aurora is a mangrove islet of 3.75 ha, of which about 0.50 ha. are sandy beaches. Mangrove and coral reefs are vital for the ecosystem services as important nurseries and habitat for fish and marine invertebrates. The Caña Gorda Cays ecosystem is an important source of larvae and juveniles of many marine species that replenish adjacent areas of economic importance for local fisheries. Local and federal agencies have identified this ME as a priority area for conservation due to the presence of federally listed species and to the effects of local and climate change stressors (Commonwealth of Puerto Rico & NOAA Coral Reef Conservation Program, 2010).

The GSF receives high volumes of visitors annually looking for outdoor recreational activities as the area is home to rich and diverse aquatic ecosystems including seagrass beds, coral reefs, and mangrove forests. Many of these visitors frequent the GSF's coastal areas to enjoy the sandy beaches, snorkeling, surfing, boating, and other aquatic activities. The area is also an important case study for scientific research carried out by universities as well as state and federal agencies. However, these natural communities located within the GSF ME are being threatened by constant demand for recreation and the illicit overuse of the area, especially by harmful boating practices. The Puerto Rico Department of Natural and Environmental Resources (DNER), along with the local community, agree that there is an urgent need to develop a management plan that describes the status of ecosystems in the ME, identify threats to help prioritize management actions, and establish strategies for public policies.

In September 2017, hurricanes Irma and María caused disturbances to inland and marine ecosystems. The inland ecosystems and vegetation in the GSF are still recovering, but adverse circumstances restrict the recovery and stabilization of coasts and cays in the ME. Particular attention has been given to Cayo Aurora by the DNER and adjacent communities given the severe erosion after the 2017 hurricanes. Illicit overuse was preventing natural succession of the coastal vegetation from occurring. High loads of sediment and land-based sources of pollution reached nearshore coral reefs and associated ecosystems at an accelerated rate, affecting the ecological integrity of this area. These impacts decrease light availability in the water column and increase smothering, reducing coral growth rates and cover, and susceptibility to disease, which can increase coral mortality (Sturm et al., 2012; Whitall et al., 2014). Until 2019, the DNER had established regulations in the ME for a daily maximum of 250 people on Cayo Aurora, an estimated carrying capacity for the recreational areas on the Cay. Additionally, private boat owners could anchor close to the cays, but these activities can result in anchoring and propeller wash scars on seagrass beds. These actions posed a direct threat to seagrasses and puts at risk the security of the visitors and the community.

After the passing of the 2017 hurricanes, the use and management of Cayo Aurora was once again drastically changed by a seismic sequence on the southern region of Puerto Rico. The first earthquake of this sequence began in southern Puerto Rico on December 28, 2019 and was followed by an increase in the quantity and magnitude of earthquakes in the region during the following weeks. This event indefinitely paralyzed visits to the cay due to the damage caused to the infrastructure used for public access. Since the beginning of the sequence, public access to the cay has been restricted and only DNER personnel have access to it. Additionally, on March 11, 2020, the World Health Organization declared the COVID-19 pandemic as a Public Health Emergency of International Concern (Cucinotta & Vanelli, 2020). This prompted the Puerto Rican government to impose strict curfews and order the restriction of outdoor activities in response to the rapid spread of the virus. Both events drastically changed visitation to Cayo Aurora and thus changed the management measures recommended for the area. As of July 2022, the DNER has been evaluating the use of the cay and are in the process of completing a *limit of acceptable change* model to identify appropriate uses by the public.

Protectores de Cuencas Inc. (PDC), a Puerto Rican community and science based non-profit organization, signed a co-management agreement with the DNER in 2015 for the Guánica State Forest. Through PDC and the DNER's experience managing the GSF throughout the natural events, they have identified an urgent need to delineate an action plan for the ME. The goal of this plan is to improve the conservation and management of the ME, a priority habitat that supports ecological hotspots for Endangered Species Act (ESA) listed species including coral reef colonies, the hawksbill (*Eretmochelys imbricata*), green (*Chelonia mydas*) and leatherback (*Dermochelys coriacea*) sea turtles, as well as Puerto Rican crested toad (*Peltophryne lemur*) and the Puerto Rican nightjar (*Caprimulgus noctiterus*), an endemic bird to the Guánica State Forest. Among the ESA-listed flora, Guánica is known to house *Mitracarpus maxwelliae, Catesbaea melanocarpa, Trichilia triacantha, Eugenia woodburyana and Ottoschulzia sp*.

This plan integrates data for the characterization of shallow-water benthic communities (approximate depths of 4 - 8m) and their status after the impacts of hurricanes Irma and María and the effects of the 2019 earthquakes. This plan also provides an analysis of the current threats to these ecosystems and how these relate to current anthropogenic activities in the region.

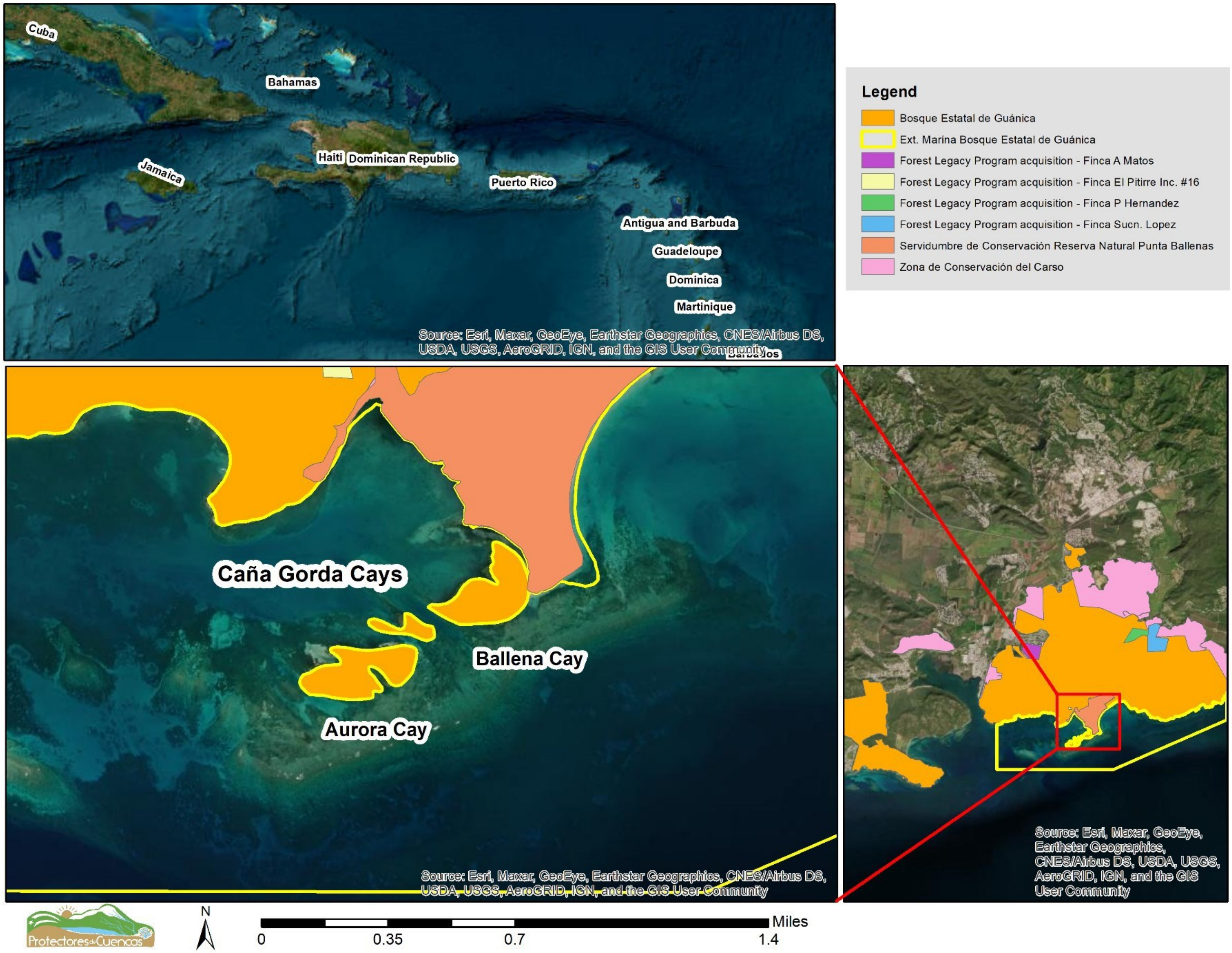


Figure 1. Map of Guánica State Forest marine extension and Cayos de Caña Gorda which include Cayo Aurora and Cayo Ballena.

Marine Protected Area

Marine Protected Area (MPA) is a broad term that includes a variety of conservation and management protocols. In the United States, MPA Executive Order 13158 defines an MPA as: "... *any area of the marine environment that has been reserved by federal, state, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein*. These are designated to protect specific areas within different types of water bodies (e.g., oceans) from excessive long-term anthropogenic use and to aid the conservation of natural reserves. There are many types of MPAs that range from restrictive (no human access) to flexible (e.g., seasonal fishing) and their management differs greatly between nations. As of 2019, only around 7.26% of the world's oceans fall under MPAs (Laffoley *et al.*, 2019).

Oceans cover about 70% of the Earth's surface and are an important component to counteract the effects of climate change. They provide multiple benefits such as production and storage of oxygen, regulating the climate by absorbing heat, as well as providing humans with food resources, employment, and recreational activities. The use of MPAs aids in the protection of sensitive marine ecosystems as pressures from urban expansion are mostly concentrated in coastal areas, including Puerto Rico (Martinuzzi *et al.*, 2009; Salazar-Ortiz & Cuevas, 2017).

In Puerto Rico, marine resources have been protected since the 1840's when the archipelago was under Spanish control. Initially, laws were created to supervise the extraction of timber and firewood from mangrove forests. After the Spanish-American war, the United States declared Puerto Rico its territory, but many of the Spanish laws were conserved for the protection of these valuable ecosystems. In 1918, Arthur Yeager, Governor of Puerto Rico, created the first category of MPA by protecting all the coastal mangrove forests on the archipelago. At present, all MPAs in Puerto Rico are managed by the DNER and the designation of new ones falls under the jurisdiction of the DNER and the Puerto Rico Planning Board (PRPB). First, the DNER identifies and recommends appropriate areas of high ecological value and presents a proposal to PRPB. This agency then evaluates the proposed areas and if approved, issues a resolution to the Puerto Rican legislation. If the resolution is approved, the Governor emits an executive order creating a new reserve (Aguilar-Perera *et al.*, 2006; Castro-Prieto *et al.*, 2019).

Currently, there are 27 MPAs in Puerto Rico (Figure 2), most of which contain and protect important coral reef ecosystems and fisheries from anthropogenic threats such as overfishing, pollution, and destructive anchoring (Castro-Prieto *et al.*, 2019). The Guánica State Forest marine extension covers an area of 14.2 km^2 (1,416 ha) and was designated as an MPA in 1985 (Schärer *et al.*, 2004; Aguilar-Perera *et al.*, 2006; Castro-Prieto *et al.*, 2019). This area extends 8.9 km along the coastline from the eastern corner of the Guánica Bay to Punta Ventana and 1.6 km offshore from Punta Jacinto. The ME encompasses a system of cays called the Caña Gorda Cays which include three cays: Cayo Aurora, Isla Ballena, and Cayo Honda. Historically, these cays have been an important area for locals and visitors looking for recreational opportunities.

Purpose

This plan identifies current threats to the ME, analyzes findings from assessments conducted in the ME, and provides recommended actions to conserve and rehabilitate marine ecosystems based on those findings. The purpose of this plan is to establish a framework for the management of these important ecosystems and the protection of threatened and endangered species, as well as for the management of recreational and economic opportunities for local communities and visitors.

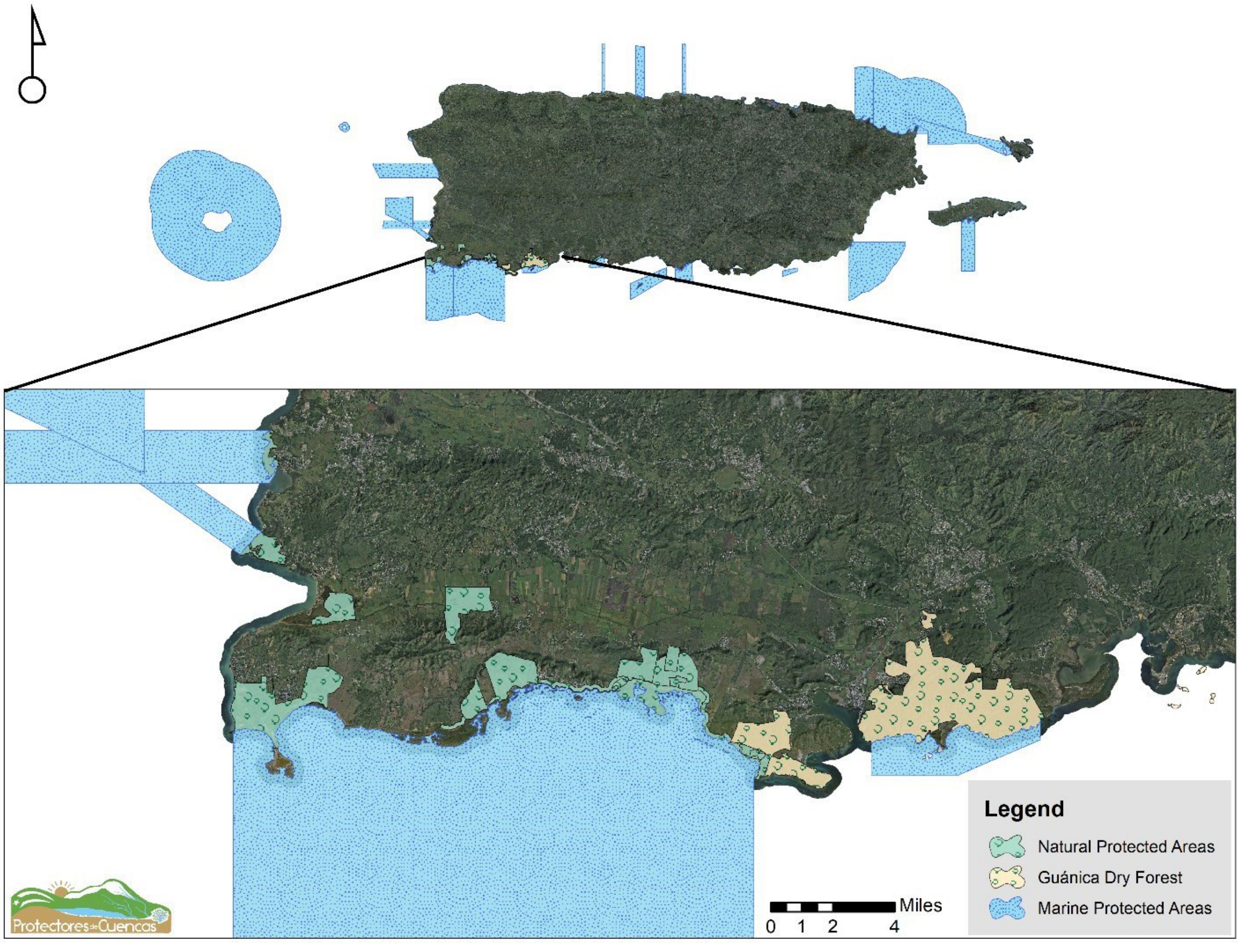


Figure 2. Map highlighting the Marine Protected Areas in the Puerto Rico archipelago, and a close up of the Guánica State Forest Marine Protected Area.

Methods

The GSF and its ME has been a center of many studies from diverse disciplines. To understand the context under which this plan is developed, a literature review was conducted. We evaluated recent scientific articles related to the area, management plans for other MPAs, and reports from the DNER and NOAA that provided valuable data to support this plan. These documents were reviewed and integrated into this analysis.

Additional sources of information that were incorporated into this plan include:

a) Meetings with local businesses, local fishers, visitors, DNER personnel, and researchers to help identify current threats, collect community input and recommendations, and help establish goals for the conservation of the ME.

b) Shallow benthic communities (e.g., corals, algae, other invertebrates, sand, hardbottom) were characterized to determine status after the 2017 hurricanes.

Using all these resources, the project team was able to analyze threats to marine ecosystems (e.g., coral reefs) and how these relate to current anthropogenic activities in the region. The result is an action plan with recommended courses of action to respond to these threats.

Stakeholder Goals

A critical step in the development of management action plans is the involvement of local stakeholders. Stakeholders can help implement management action plans and can be useful in helping to hold public official agencies accountable. As part of this process, stakeholders such as residents, community leaders, NGOs, municipal officials, and business owners were asked to discuss their concerns and to help identify potential management options within the ME.

The following stakeholder recommendations were discussed in these meetings and were considered in the development of this plan.

1. Use the GSF as a model for the conservation of marine extensions.
2. Improve communication between locals, visitors, and management agencies within the GSF and ME.
3. Designate a small portion of the ME as a no take zone.
4. Improve navigational aids (e.g., buoys) to help users identify the appropriate uses within the ME and to delimit the ME.
5. Reduce contamination from sewage and septic systems to marine ecosystems within the ME.
6. Restore marine ecosystems within the ME, including coral reef and mangrove forests.

Guánica State Forest Marine Extension

General Characterization

The Guánica State Forest Marine Extension stretches 8.9 km along the coastline from the eastern corner of the Guánica Bay up to Punta Ventana and 1.6 km offshore from Punta Jacinto (Figure 3). Within this marine extension, *Cayos de Caña Gorda* hosts the largest coral reef system in the Guánica ME. Of these cays, Cayo Aurora, also known as Gilligan's Island, is the most intensively used recreational area. This emergent reef was designated as part of the Guánica State Forest in 1919, as an International Biosphere Reserve by the United Nations in 1981, and officially designated a MPA by the Puerto Rico Planning Board in 1985.

This protected area has a variety of micro-habitats including coral reefs, mangroves, seagrass beds, and coastal lagoons. The conservation of all these ecosystems is incredibly important as they provide important services such as nurseries, and habitats for larvae, corals, fish, and other invertebrates. The *Cayos de Caña Gorda* ecosystem is an important source of larvae and juveniles of marine species, including fish, which replenishes adjacent areas that are of great economic importance for locals. It is estimated that Guánica's marine resources, including estuaries, mangroves, salt flats, lagoons, beaches, seagrass beds, coral reefs, and small cays, attract 300,000 visitors annually, with about 100,000 people visiting the recreational areas of Cayo Aurora. Cayo Aurora is a mangrove islet of 3.75 ha, approximately 0.50 ha of which is sandy beach. Seagrass beds, channels, coral reefs, and submerged sandy patches surround the islet. Cayo Aurora is one of the main attractions within the marine extension of the GSF.

Dating back to 1983, the DNER implemented management strategies that provided recreational enjoyment with conservation of the cays, especially Cayo Aurora. These included a dock, various gazebos, charcoal burners, solid waste disposal sites, composting toilets, and a fishing platform. The public beach area was delineated, mooring buoys were installed, proper signaling was placed, and anchoring areas were designated. In conjunction with federal agencies (NOAA and the US Fish and Wildlife Service [USFWS]), various projects developed over the years including mangrove planting, restoration of seagrass beds, and an educational recreational fishing program. However, after the earthquake sequence that began in December 2019, structures within the cay were affected and deemed unsafe by the DNER. The DNER closed recreational areas due to severe erosion on the cay (Figure 4). As of September 2022, PDC, along with DNER personnel, closed off the dock and removed the charcoal grills and restrooms to deter human use in the cay and allow the natural regeneration of the mangrove (Figure 5).

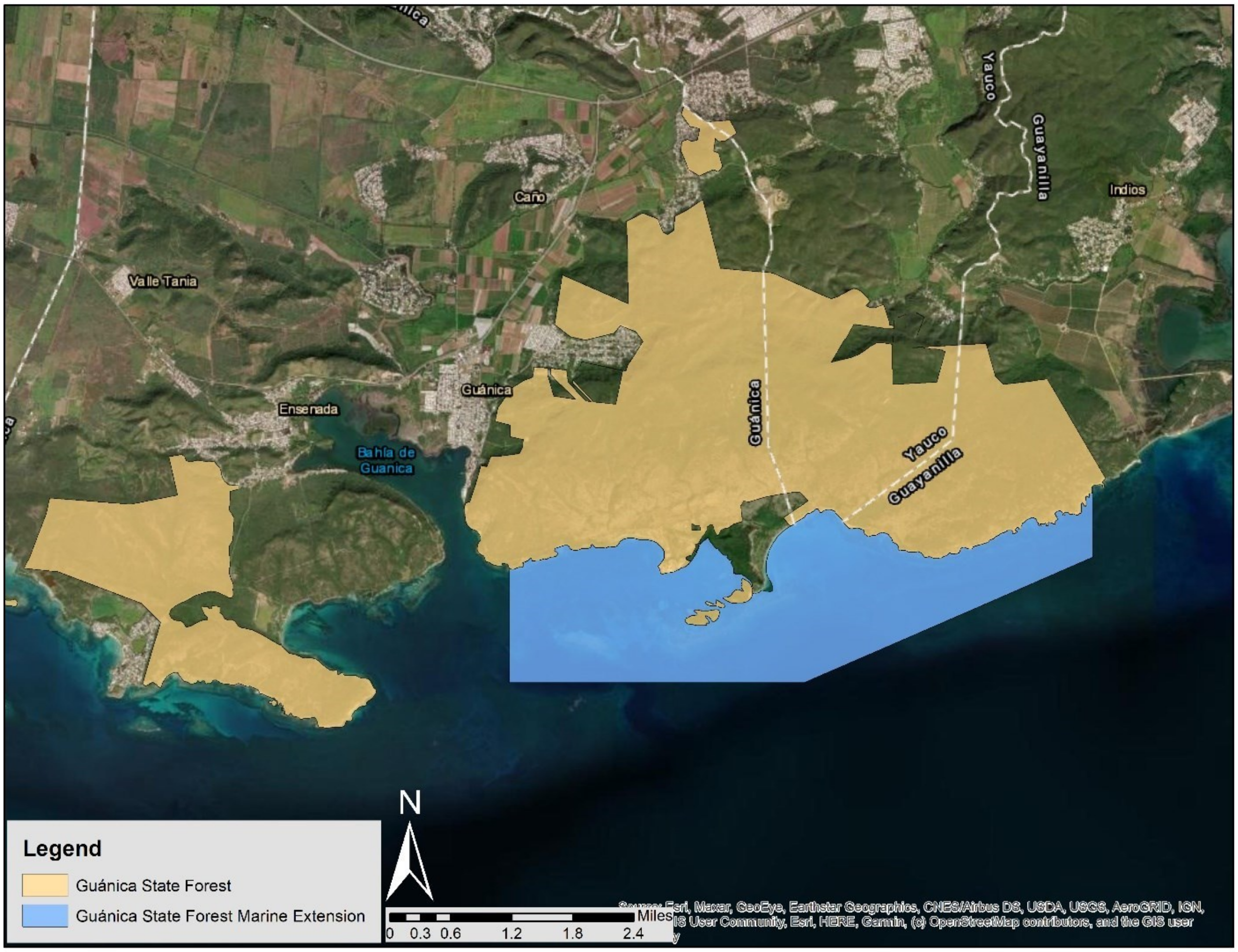


Figure 3. Map of the Guánica State Forest Marine Extension location and the Guánica State Forest. The ME extends over three municipalities: Guánica, Yauco and Guayanilla.

Figure 4. Damage to Cayo Aurora's recreational structures after the beginning of the earthquake sequence in December 2019.

Figure 5. Recreational facilities at Cayo Aurora were removed after the 2019 earthquakes to discourage people from visiting the cay.

Fauna

The ME harbors a diverse benthic reef community that includes at least 22 stony coral species that have been identified along Cayo Coral during benthic characterizations of Ballena Beach and Cayo Aurora. The substrate cover within transects was dominated by benthic algae and stony corals, while the most dominant species of stony coral were *Orbicella faveolata* (Figure 6), *Porites astreoides*, and *Colpophyllia natans* (4.31, 1.89, and 1.86 % substrate cover, respectively) (García-Sais *et al.*, 2019). In 2013, Bauer *et al.* studied Guánica's coral reefs and found that sites with the highest coral cover were located nearshore at a depth of 5m. However, reefs in Guánica have been significantly degraded over the last few decades. Reductions in the percent cover and diversity of stony corals were observed in 2005 after a massive bleaching event (Ballantine *et al.*, 2008; García-Sais *et al.*, 2019). In addition, Guánica's coral reefs have been affected by the arrival of the stony coral tissue loss disease in early 2022[1]. At a local (e.g., land-based sources of pollution) and global scale (e.g., climate change and ocean acidification), stressors have exacerbated these losses. The loss and degradation of coral reefs in Puerto Rico is influenced by high levels of terrigenous sediment (Sherman *et al.*, 2013; Whitall *et al.*, 2014). Coral reefs in Guánica are not exempt and have been affected by increased sediment loads from urban expansion and poor agricultural practices (e.g., dirt roads) in the mountains. Many coral reefs in Guánica are not found within the limits of the GSF ME and are located near the mouth of the Guánica Bay. Guánica Bay was found to have high levels of terrigenous sediments (Sherman *et al.*, 2013), potentially affecting their long-term resiliency and survival of coral reefs in the area (Figure 7).

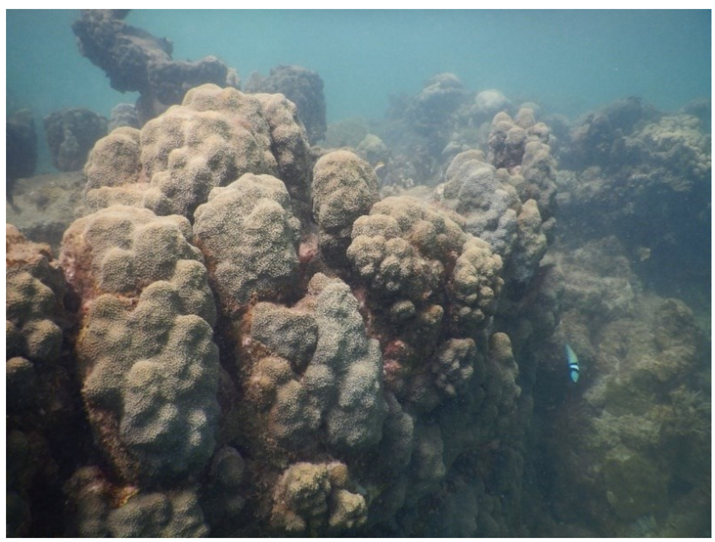


Figure 6. An *Orbicella faveolata* colony in Cayo Coral.

[1] https://www.drna.pr.gov/coralpr/enfermedades/

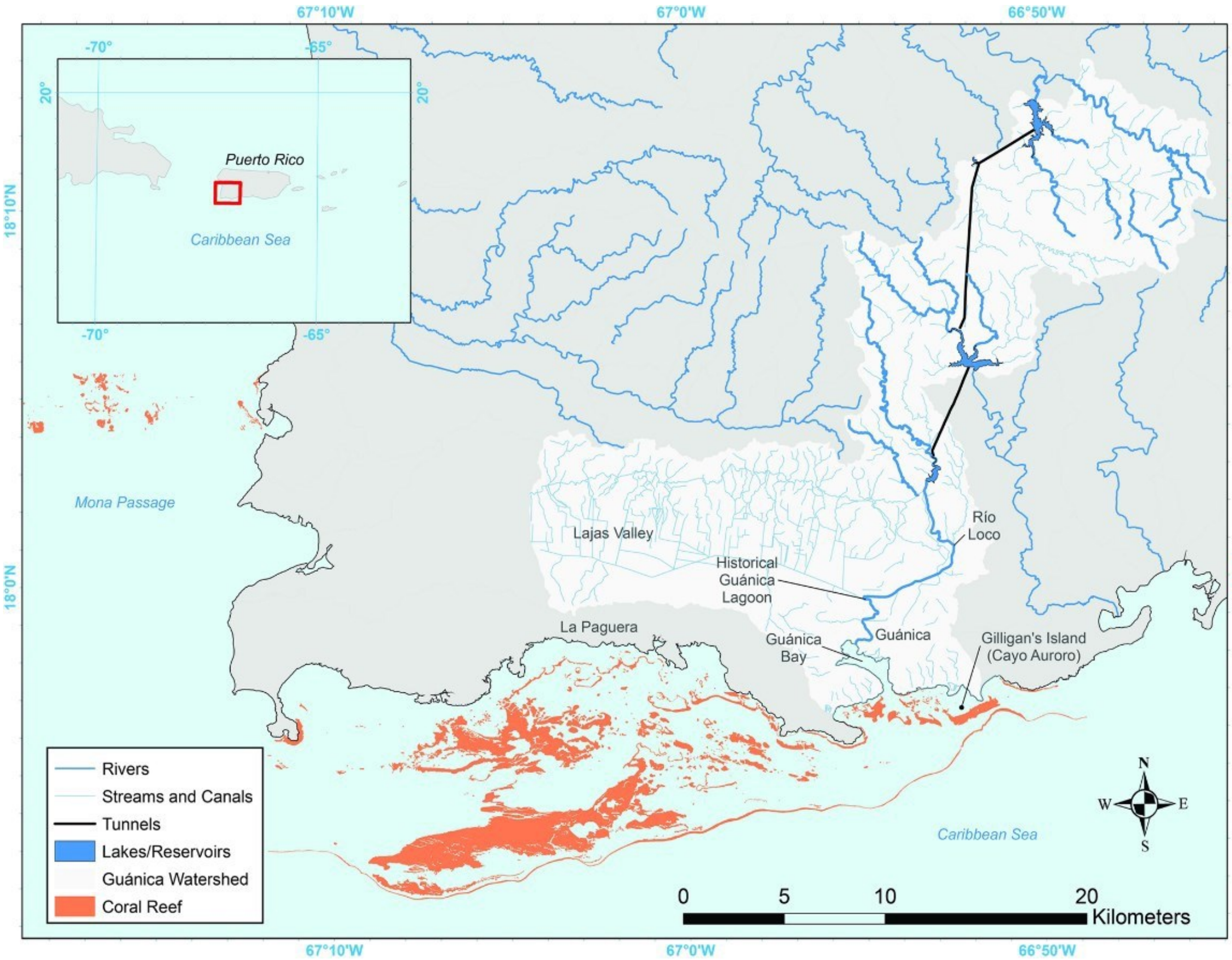


Figure 7. Map of the Guánica Bay Watershed and its associated coral reefs. Figure from Gibbs *et al.*, 2021.

The GSF ME was designated an Essential Fish Habitat, Habitat Area of Particular Concern by the Caribbean Fisheries Management Council. This ME is home to at least 36 taxonomic families and 119 fish species, including *Thalassoma bifasciatum*, *Chromis cyanea*, *Scarus iseri*, and *Gobiosoma evelynae*, among others (Bauer *et al.*, 2013). Fish species richness, biomass, and mean density are higher in hardbottom habitats, followed by mangrove and unconsolidated sediments habitats. Herbivores and diminutive opportunistic invertivores compose most of the biomass and density of fish in the area (García-Sais *et al.,* 2005; Bauer *et al.,* 2013). Fish species in the area include pelagic predators (Piscivores) such as Great Barracuda (*Sphyraena barracuda*) and cero mackerels (*Scomberomorus regalis*) (García-Sais *et al.,* 2019). Some of the motile megabenthic invertebrates found in the area are cleaner shrimp (*Periclimenes pedersoni*), banded coral shrimp (*Stenophus hispidus*), and flamingo tongue (*Cyphoma gibbosum*).

Bird watching is one of the main attractions for visitors to the GSF. At least 185 species of birds have been recorded at GSF, including marine and coastal species that can be found within the ME (Arendt *et al.*, 2015). Endemic birds such as the Puerto Rican woodpecker (*Melanerpes portoricensis*), Puerto Rican flycatcher (*Myiarchus antillarum*), and the yellow-shouldered blackbird (*Agelaius xanthomus*) can be found year-round. Resident species such as the brown pelican (*Pelecanus occidentalis*), Wilson's plover (*Charadrius wilsonia*), killdeer (*Charadrius vociferus*), ruddy turnstone (*Arenaria interpres*), sanderling (*Calidris alba*), laughing gull (*Leucophaeus atricilla*), and cave swallow (*Petrochelidon fulva*) are also present in coastal habitats within the ME.

Flora

The mangrove structure at Cayo Aurora is typical of the southern coast of Puerto Rico, characterized by low rainfall patterns and lower wave energy than the northern coast and low freshwater runoff. The cay is part of the fringe mangrove forests characteristic of the south coast and is mainly composed of the red mangrove (*Rhizophora mangle)* (Figure 8). These red mangrove forests sit over shallow plate forms and are influenced daily by rising tides, low leaf litter, low growth rates, and low variability in salinity content (Cintrón *et al.*, 1978). These structures are important as they provide protection against hurricanes and rising tides, while providing breeding grounds to marine organisms and habitat for shorebirds and migratory species. The forest within Cayo Aurora is mainly composed of white, black, and button mangroves (*Laguncularia racemosa*, *Avicennia germinans,* and *Conocarpus erectus*, respectively). Other species such as sea grape (*Cocoloba uvifera*) and saltwort (*Batis maritima*) are also present in the cay (Carrubba & Torres, 2006).

Figure 8. Typical growth of mangrove forests composed of the red mangrove (*Rhizophora mangle*).

Seagrass beds are an essential component of the marine environment as they are primary producers[2] with high rates of carbon sequestration (Hemminga & Duarte, 2000). They also play an important role in the functionality of marine food webs by providing food and nursing grounds to legally protected species such as manatees. In the Caribbean, seagrass beds are principally composed of two species, *Thalassia testudinum* and *Syringodium filiforme* (Harborne *et al.*, 2006) (Figure 9). To survive in fully submerged marine environments, they have developed unique mechanisms and adaptations and require high amounts of light to photosynthesize. Most seagrass populations develop over sandy or muddy substrates that facilitate the penetration of roots (Hemminga & Duarte, 2000). In Guánica, these seagrasses are frequented by a resident population of the West Indian Manatee (*Trichechus manatus*) but these are impacted by human activities such as boating that can cause scarring, especially in shallow areas (Otero-Morales *et al.*, 2015).

Figure 9. A seagrass bed containing species *Thalassia testudinum* and *Syringodium filiforme*.

Marine Extension Characterization

The ME is constantly under pressure from anthropogenic sources and natural events such as hurricanes. To analyze the current conditions of seagrass and benthic communities in the ME, it was necessary to review new and previously collected *in situ* data with high resolution remotely sensed imagery. Dr. William J. Hernández from Environmental Mapping Consultants and Dr. Juan L. Torres-Perez from Bay Area Environmental Research Institute completed an in-water characterization of benthic components in January 2020 and data analysis during 2020-2021.

Benthic surveys

Dropcam video waypoints were collected for the selected sites using a Delta Vision HD camera with digital video recorder (DVR). A Trimble R1 sub-metric GPS receiver was used to collect the locations of the drop camera sites. A one-minute video was recorded at each original waypoint and

[2] Organism capable of producing organic compounds from light energy or chemical energy.

used as a video transect for benthic cover analysis. Initial plans included diver-based video transects surveys in the Guánica/Guayanilla area, however, these were not completed due to the occurrence of a 6.4 magnitude earthquake in the Guánica region and the subsequent aftershocks.

Depending on the complexity of the site (some sites were predominantly sand), 3-10 video frames were used for each waypoint and analyzed for benthic cover using Coral Point Count with Excel extensions (CPCe). One-hundred random points were generated and analyzed for a total of 300-1,000 random points for each GPS waypoint. The original waypoints were indicative of the start and end of underwater transects and for the purpose of the analysis these were still treated as such. Data was also collected at random waypoints in two of the study regions (Ballena Beach and Cayo Aurora) for additional information. Video data and photographic frames were collected as above. A one-minute video was collected while the boat was maintained at a fixed position and GPS coordinates were recorded. A total of 40 dropcam video waypoints were collected in areas of coral reef, sand, mud, seagrass beds, and colonized hardbottom (Figure 10).

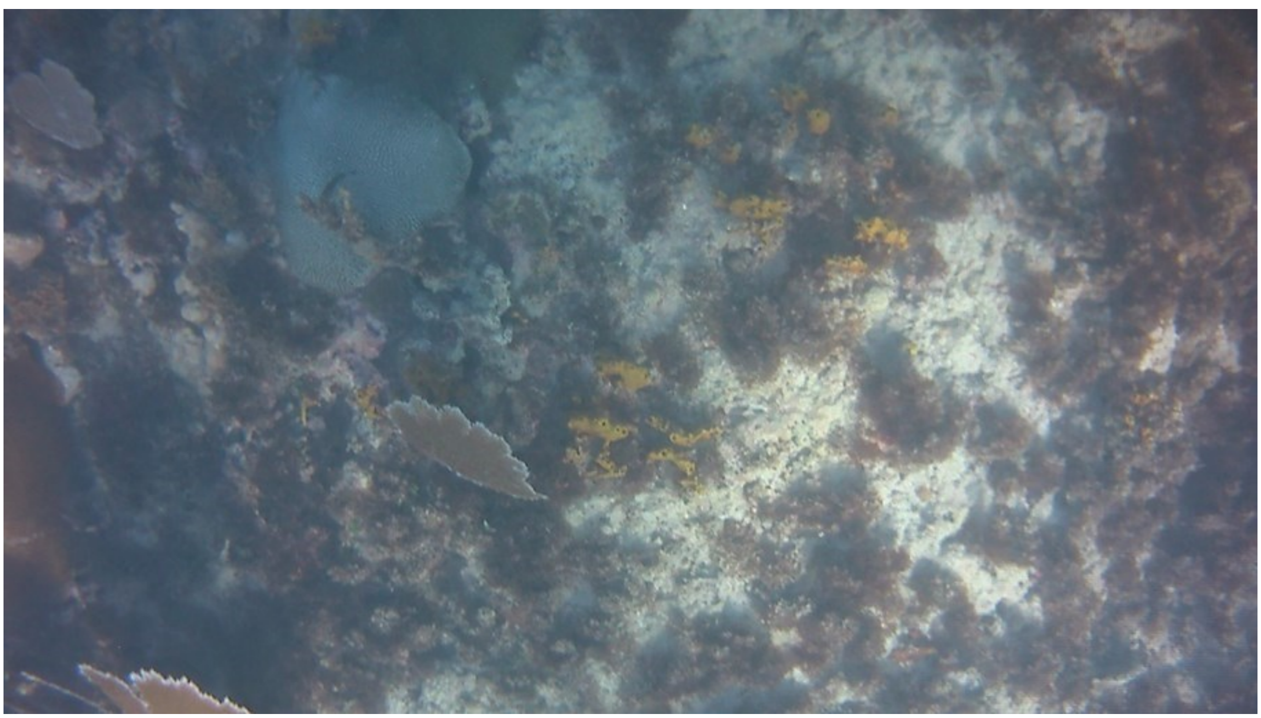


Figure 10. Snapshot of dropcam video survey showing coral reef cover in GSF ME. January 2020. Photo credit Dr. William J. Hernández.

For each photographic frame, benthic cover was characterized in terms of major category groups (Percent Coral, Octocorals, Gorgonians [sea fans], Sponges, Macroalgae, Seagrass, Zoanthids, other live organisms [echinoderms, anemones, etc.], Coralline algae, and a General Bare Substratum category [sand, pavement, rubble, benthic areas covered with algae]). Major categories were further sub-divided into species or main groups, if applicable. For example, for corals, taxonomic identification was performed to the species level, whereas sponges were sub-divided into *Cliona* sp. and "Other species." Appendix A contains detailed results obtained from sites surveyed.

The photo quadrats were analyzed by the software CPCe which relies on the random distribution of several points onto an underwater photographic image and the visual identification of each feature lying under each point (Kohler & Gill, 2006). The result is an unbiased estimate of benthic composition. The presence or absence of health parameters such as bleaching or diseases in reef corals were also considered. Benthic composition includes percent cover by all groups (e.g., corals, algae, other invertebrates, sand, hardbottom). The results of the benthic characterization are presented based on the location of the underwater video transects and random waypoints as shown in

Figure **11**. For specific transect and random waypoints see Appendix B.

Results from South of Guánica Bay

Transect depths ranged from 6-8m. The benthic community south of Guánica Bay is characterized by a hardbottom-type formation dominated by a combination of bare or macroalgae-covered substratum (Figure 12 & Figure 13; Appendix A). Coral cover on average varied from 0.5-8.2% and were dominated by sporadic colonies of *Pseudodiploria* (both *P. strigosa* and *P. clivosa*), *Porites astreoides*, *Siderastrea siderea*, and several colonies of *Acropora cervicornis* and *Orbicella faveolata*. Small sized colonies of the hydrozoan *Millepora alcicornis* (fire coral) were present in all transects within this region. The octocoral community was dominated by *Gorgonia* species (sp.) and sea rod species (unidentified). Notably, a few of the encrusting sponge *Cliona* sp. were present covering dead coral colonies and other hard substrata. Macroalgal cover in this region is dominated by benthic *Sargassum* sp. and *Dictyota* sp., with a minor component of the calcareous *Halimeda* sp. and *Udotea* sp. Bare substratum was mostly pavement with intermingled coarse sand areas.

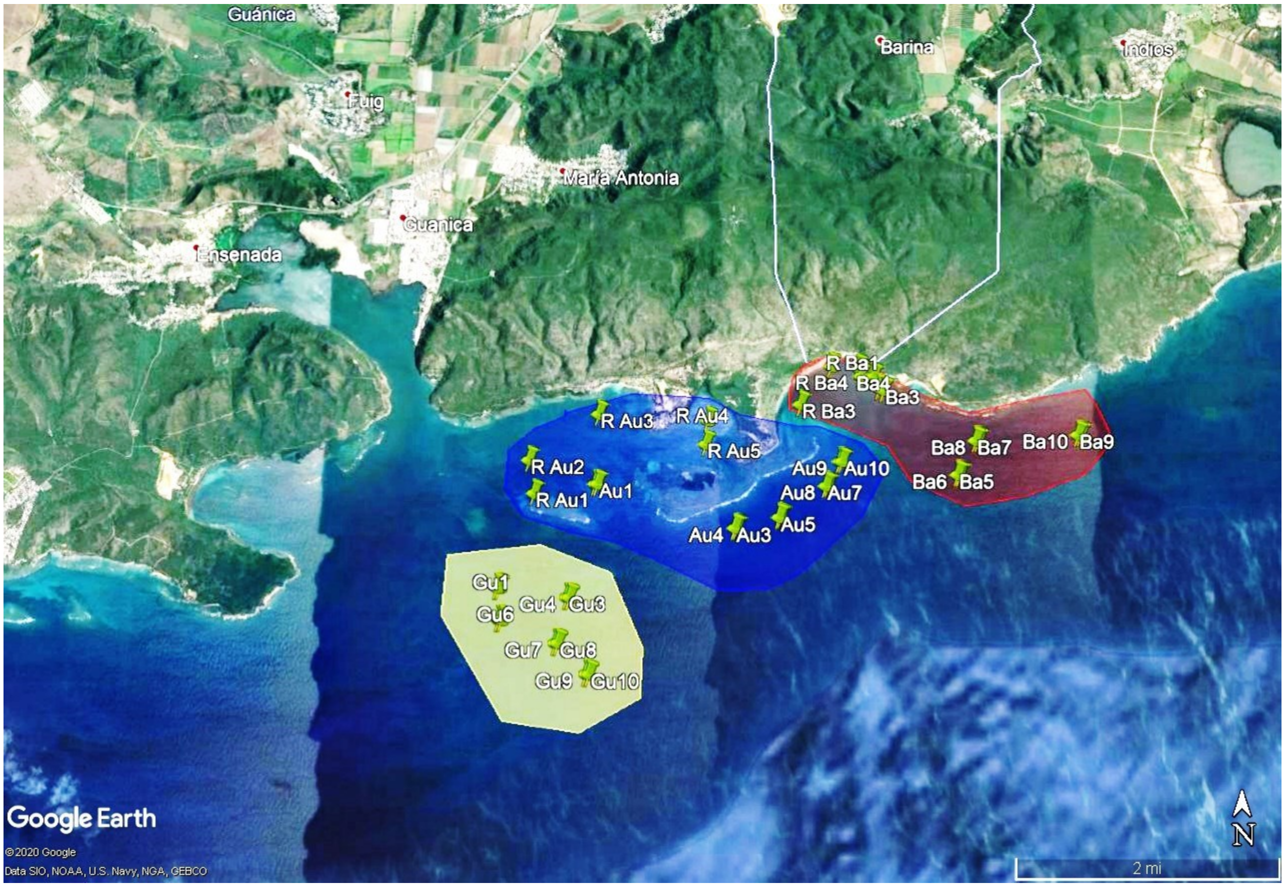


Figure 11. Google Earth image of study sites. Polygon colors indicate the study regions within the greater Guánica Bay reef platform: Yellow = south of Guánica Bay; Blue = Cayo Aurora; Red = Ballena Beach. Specific transect and random waypoints are indicated within each polygon.

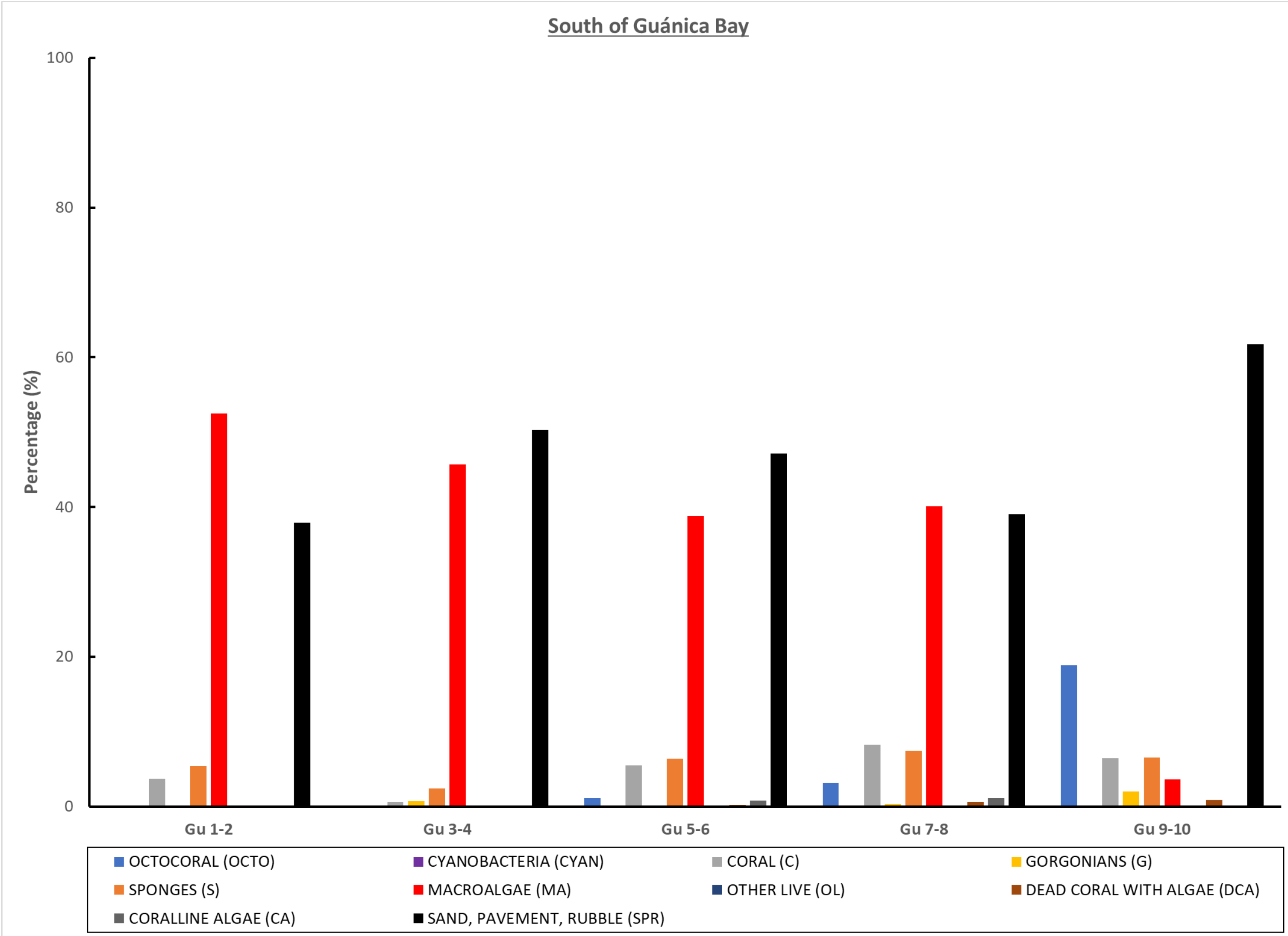


Figure 12. Benthic composition within the studied region south of the Guánica Bay entrance. X-axis represents the sampled transects names.

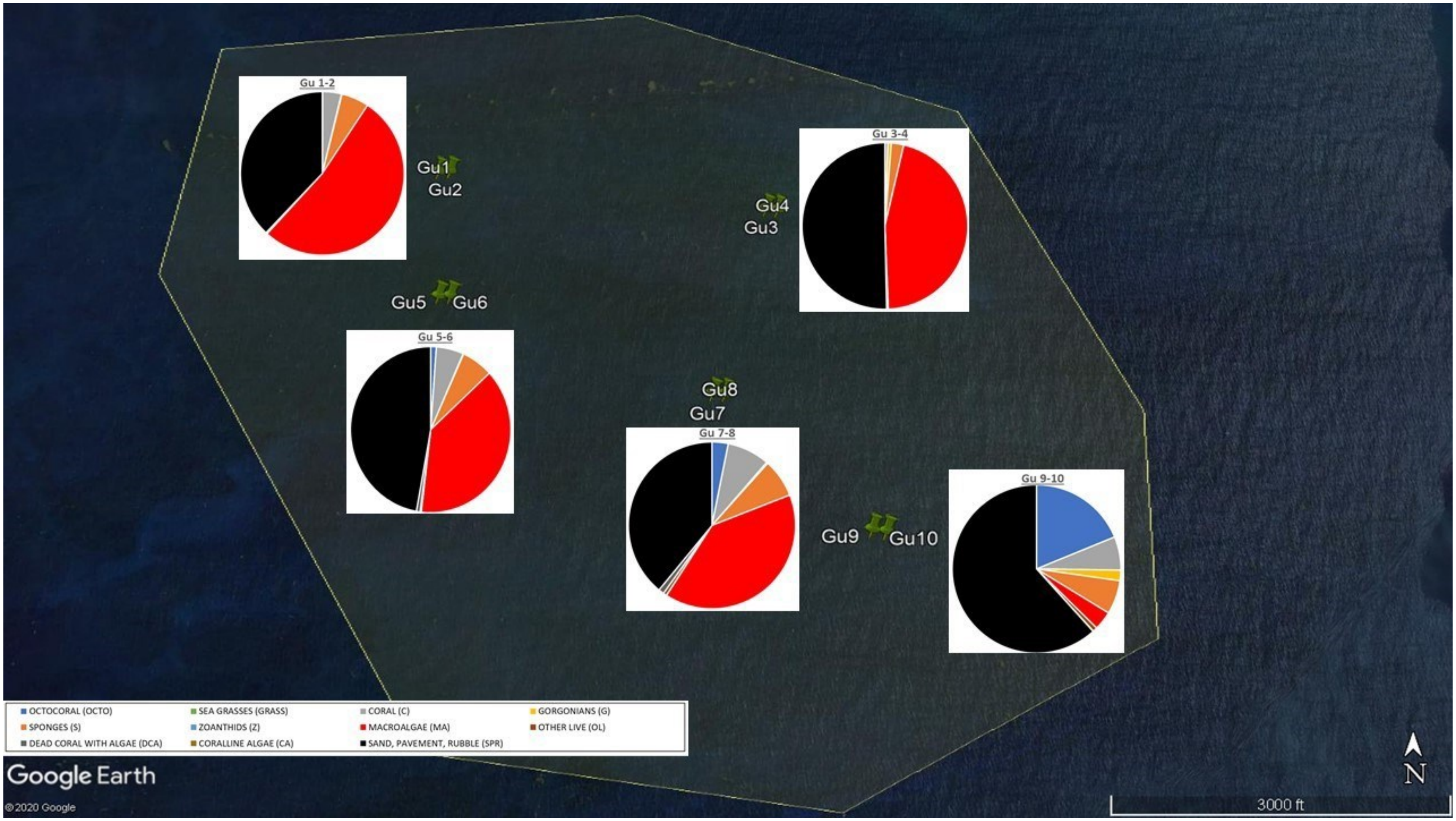


Figure 13. Percent benthic composition per transects at the south of the Guánica Bay region.

Results for Cayo Aurora

Transect depths ranged from 4-7m. The benthic community around Cayo Aurora is characterized by a hardbottom-type formation dominated by a combination of bare or macroalgae-covered substratum on the fore-reef zone (Figure 14 & Figure 15; Appendix A). Coral cover in the fore-reef zone on average varied from 1-18.2 %. Areas with low coral cover were dominated by sporadic colonies of *Pseudodiploria* (both, *P. strigosa* and *P. clivosa*), while those with higher cover show a much higher diversity with *Porites astreoides*, *P. porites*, *Siderastrea siderea*, *Acropora cervicornis*, *Montastraea cavernosa*, and *Orbicella faveolata*. Small sized colonies of the hydrozoan *Millepora alcicornis* (fire coral) were present in all transects within this region except for transect Au9-10. The octocoral community was dominated by sea rod species (unidentified) and a few colonies of *Gorgonia* sp. The encrusting sponge *Cliona* sp. was only seen in transect Au 1-2. Macroalgal cover in this region is dominated by benthic *Sargassum* sp. and *Dictyota* sp., with a minor component of the calcareous *Halimeda* sp. and *Udotea* sp. Bare substratum was mostly pavement with intermingled coarse sand areas. The back-reef area, as shown by the data collected in the random waypoints, is a mix of sand, seagrass and macroalgae (mostly *Dictyota* sp.).

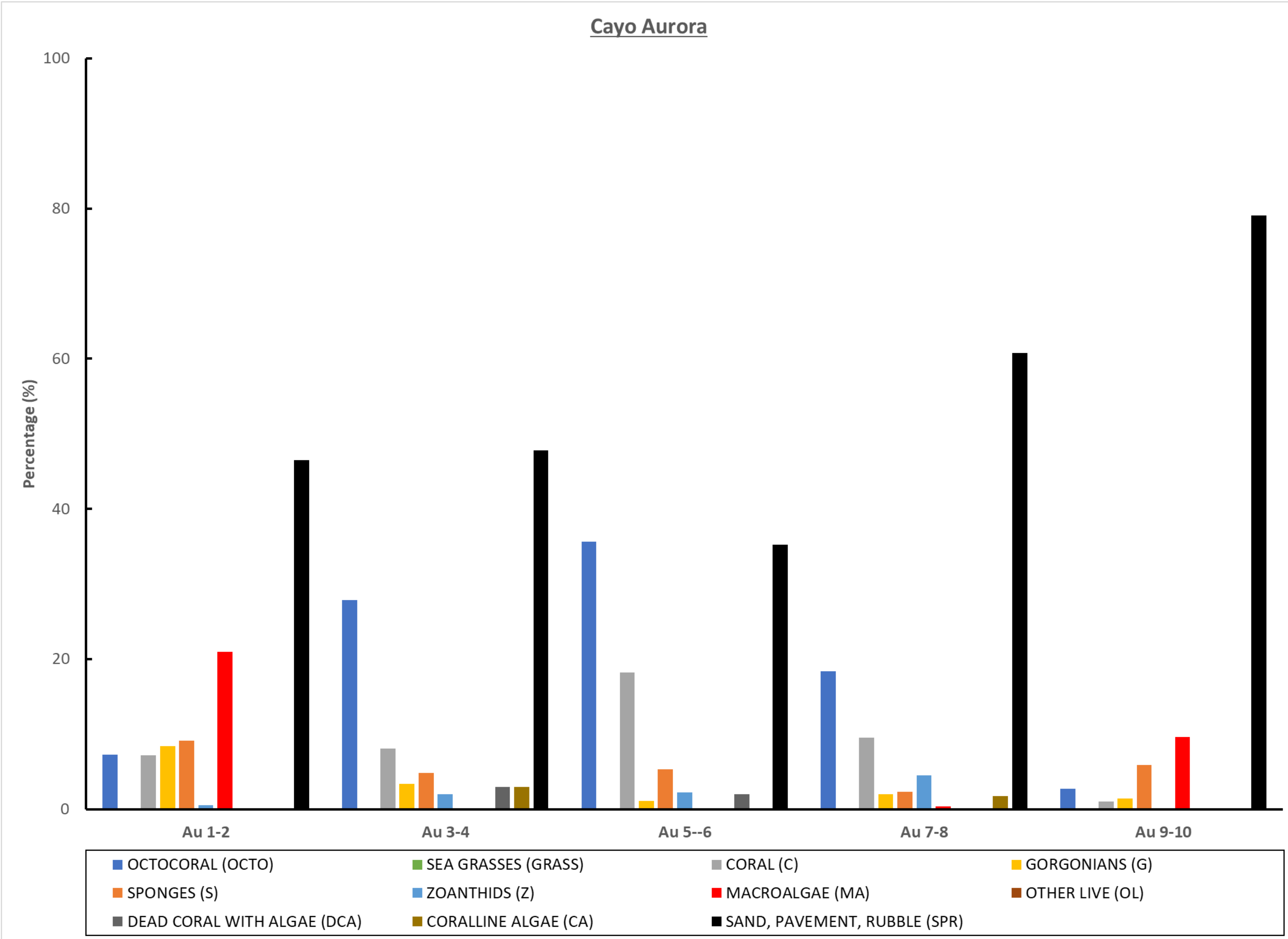


Figure 14. Benthic composition at transects located in the fore-reef zone of Cayo Aurora. X-axis represents the sampled transects names.

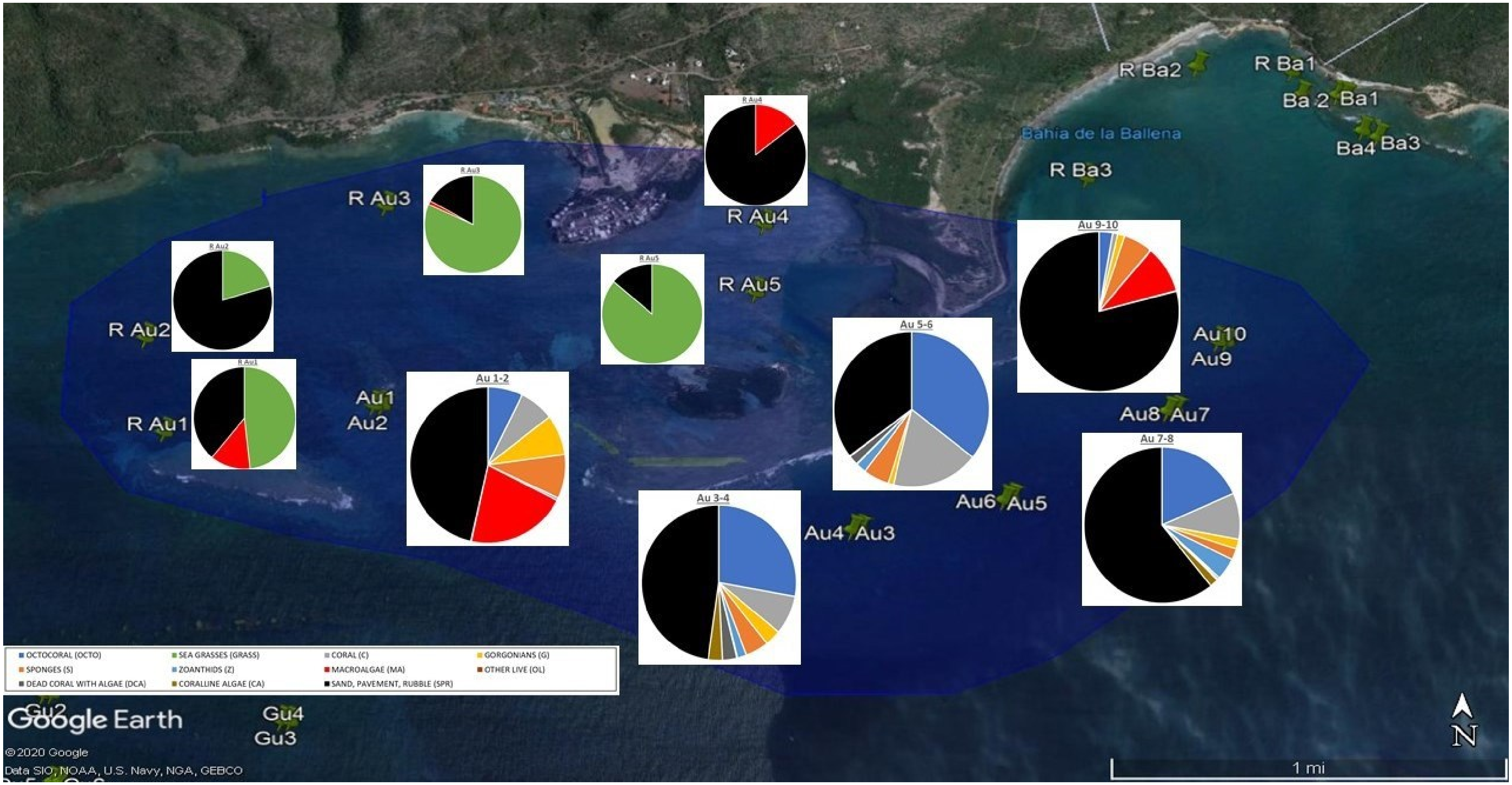


Figure 15. Percent benthic composition per transects and random waypoints in Cayo Aurora.

Results for Ballena Beach

Transects at this site ranged in depth from <0m in the beach area to 6m towards the east of the beach (transects Ba 5-10). Due to safety issues, data was not collected at the transect Ba1-2. The benthos east of Ballena Beach is dominated by a hardbottom with sporadic coral colonies, mostly *Pseudodiploria clivosa*, *P. strigosa*, *P. astreoides*, and *Siderastrea siderea*, and the hydrozoan *Millepora alcicornis* (Figure 16 & Figure 17; Appendix A). Notably, one transect was dominated by pavement covered by the brown algae *Dictyota* sp. Transects and random waypoints located closer to the beach were dominated by either 100% sand or a mix of sand and boulders covered by algae or small coral colonies (both hard and soft).

General Findings

The description of these study sites complements those already provided during the previous NOAA-CRCP Domestic Funds project (2017-2018) and expands to additional sites, particularly at the south of Guánica Bay and Ballena Beach. Further, it adds more data at Cayo Aurora, particularly in the back-reef and fore-reef zones. Underwater data collection was limited by the occurrence of a series of earthquakes near the established field campaign dates. Nonetheless, the data presents that while most sites present a hardbottom-type seafloor in shallow-intermediate depths (4-8m), these sites show substantial cover by important threatened coral species as well as other sessile invertebrates such as sponges and octocorals. The results support the importance of promoting the extension and conservation of the marine regions within the Guánica State Forest.

Benthic Composition Map

A Maxar Worldview 2 very high-resolution satellite imagery was acquired to serve as baseline imagery for the benthic composition map updates. This multi-spectral image from February 2019 contained 8-bands and provided 50cm spatial resolution (Figure 18). The image was radiometrically corrected, and a Dark Object Subtraction (DOS) was applied to correct for atmospheric effects (Hernández and Armstrong 2016), and a landmask was also applied to the imagery to reduce land influence in the classification. A supervised classification was performed to the satellite imagery to provide an updated benthic composition map of the area. The dropcam waypoints collected during the benthic surveys were used to train the classifier in the classification process. Additional waypoints from a diver-based benthic survey were also used as reference sites (CRCP Domestic 2017-2018).

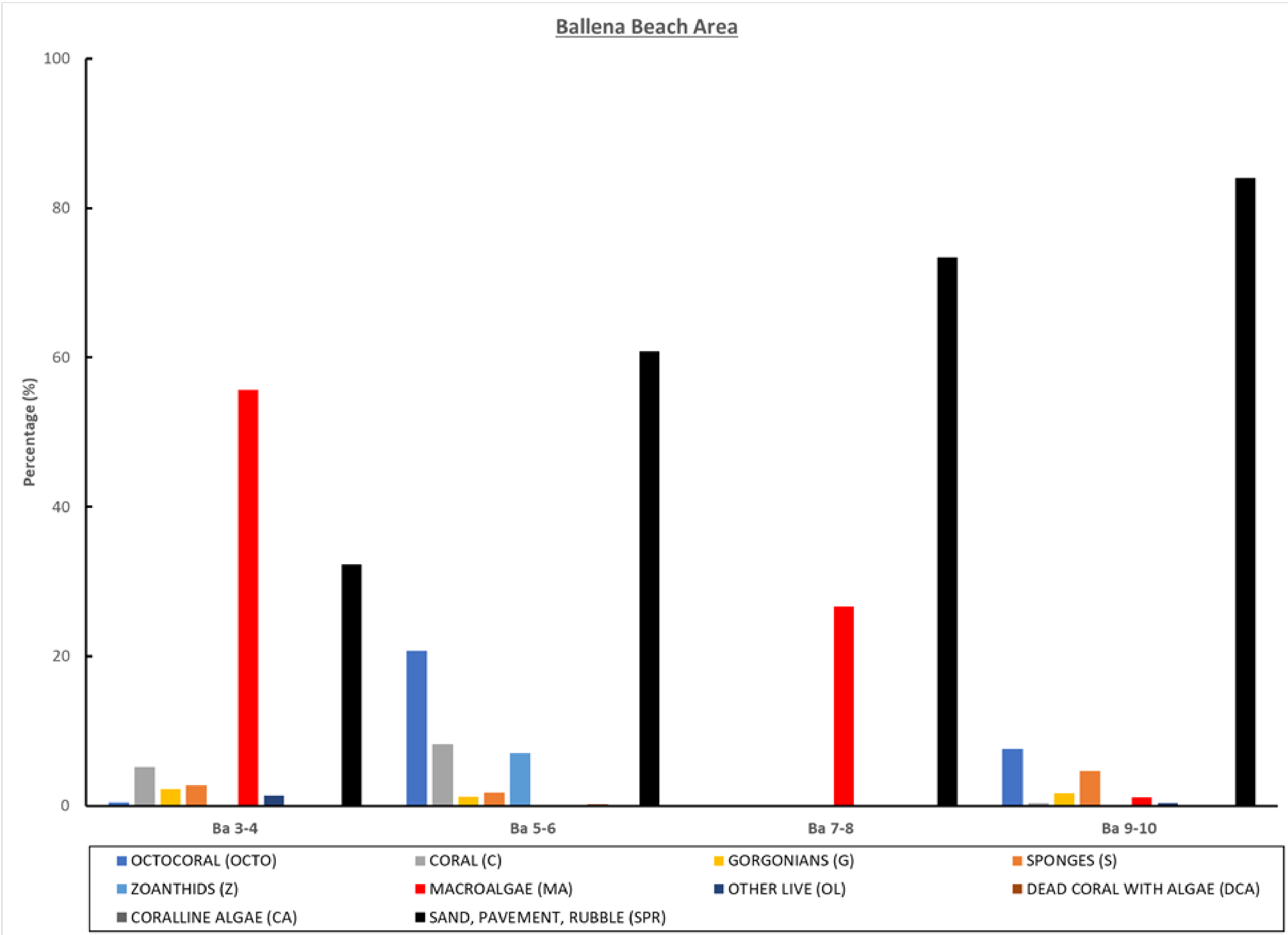


Figure 16. Benthic composition at transects located in the Ballena Beach region. X-axis represents the sampled transects names.

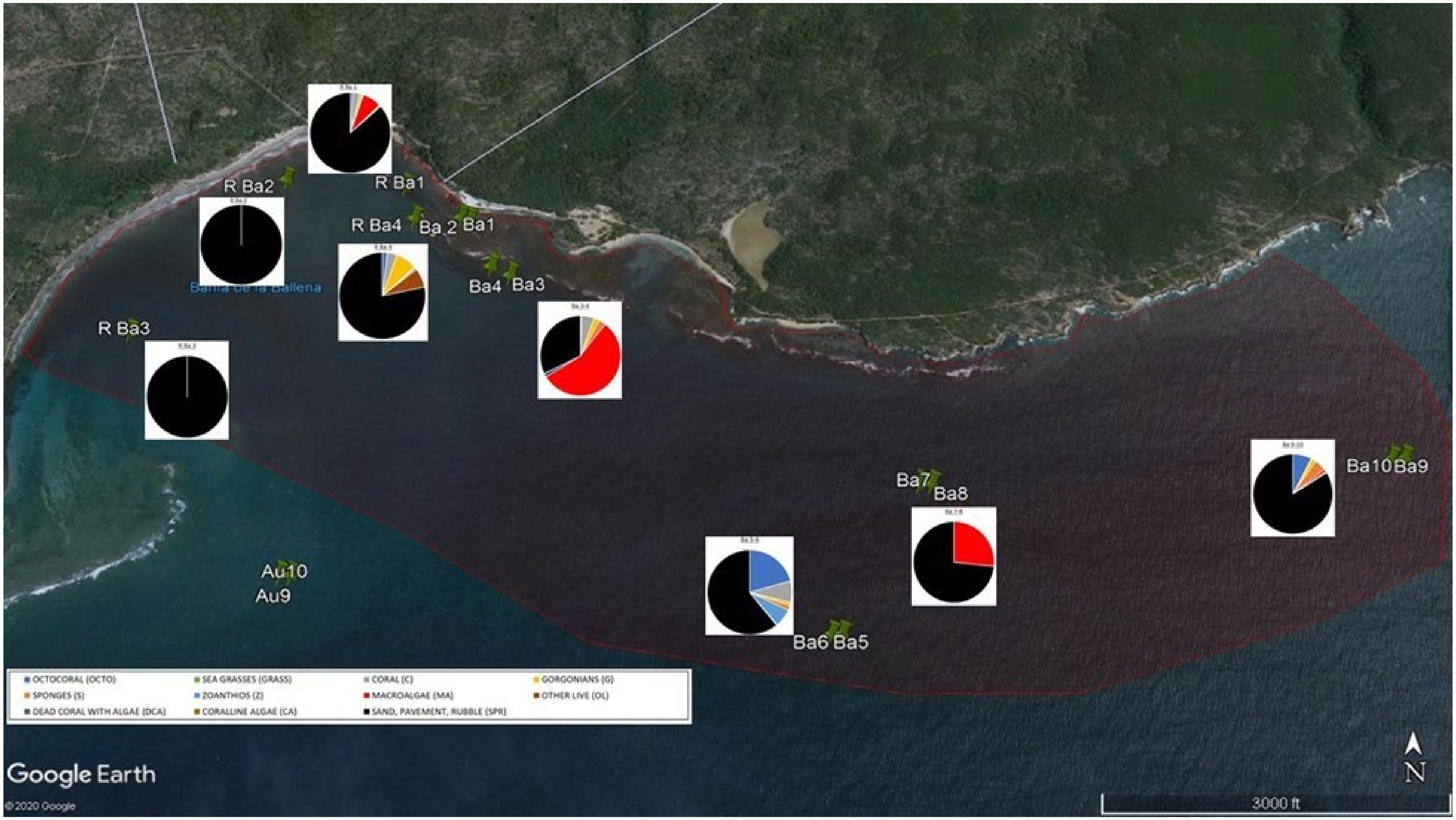


Figure 17. Percent benthic composition per transect and random waypoints in Ballena Beach.

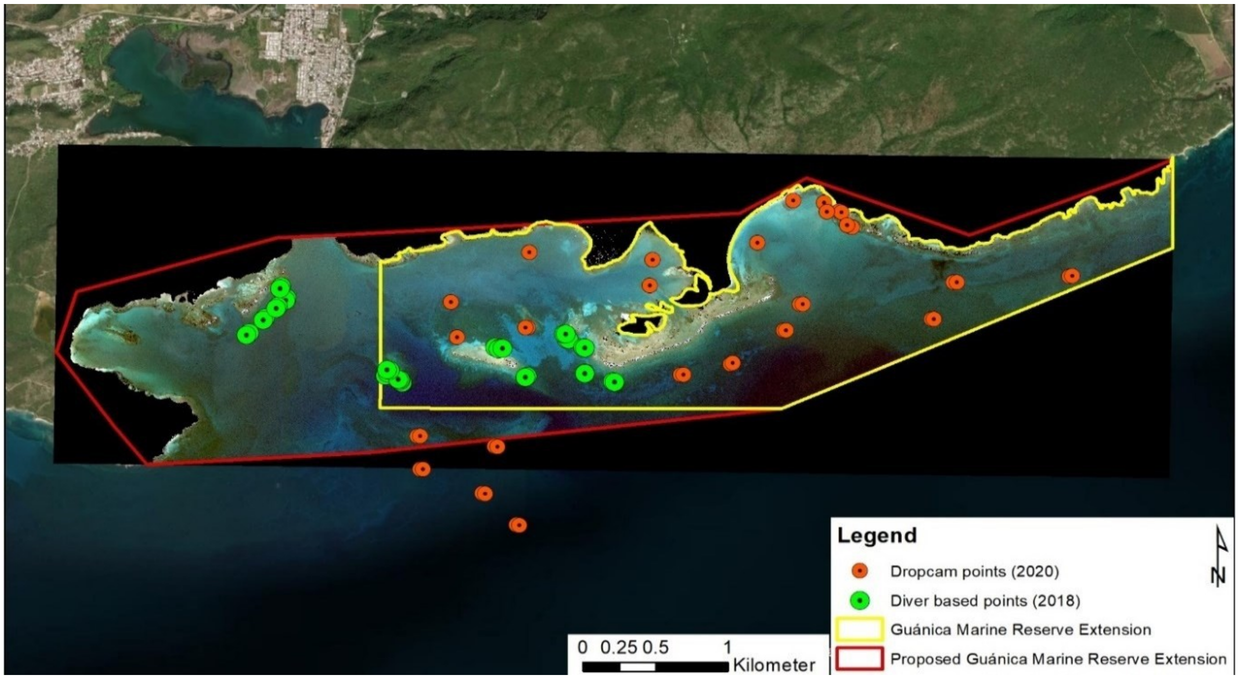


Figure 18. Multi-spectral image from February 2019 with dropcam points used in 2020 and diver-based points used in 2018.

The latest NOAA Benthic Habitat Maps (Kendall *et al.* 2001, Bauer *et al.* 2011) were used to obtain the benthic class criteria. The classification was based on the geomorphological structure types and major cover as presented by Bauer *et al.* (2011) (Table 1).

After the classification, the Major Cover (Algae, Seagrass, Live Coral) attributes were estimated based on the photo transects analysis from the benthic surveys. The benthic map from NOAA was based on satellite imagery from 2010 and it's included for reference (Figure 19). A final benthic composition map was developed after the classification process for the GSF ME (Figure 20). A "Deep water" class was used to designate areas too deep to classify, and an "Unknown" class was added to classify benthic areas covered by surface sediments or not distinguishable. The dominating class was "Sand with Seagrass" with 3.5 km^2, followed by "Pavement" with 2.58 km^2, also due to the presence of plumes and turbid waters, the "Unknown" total area was 2.70 km^2 (Figure 21).

Table 1. Classification of geomorphological structure types as presented by Bauer *et al.* (2011).

Major Classes	**Detailed Classes**
Coral Reef and Hardbottom	Rock/Boulder Spur and Groove Individual Patch Reef Aggregated Patch Reef Aggregated Reef Reef Rubble Pavement Pavement with Sand Channel Rhodoliths
Unconsolidated Sediments	Sand Mud Sand with Scattered Sand and Coral
Other Delineations	Artificial Land
Unknown	Unknown

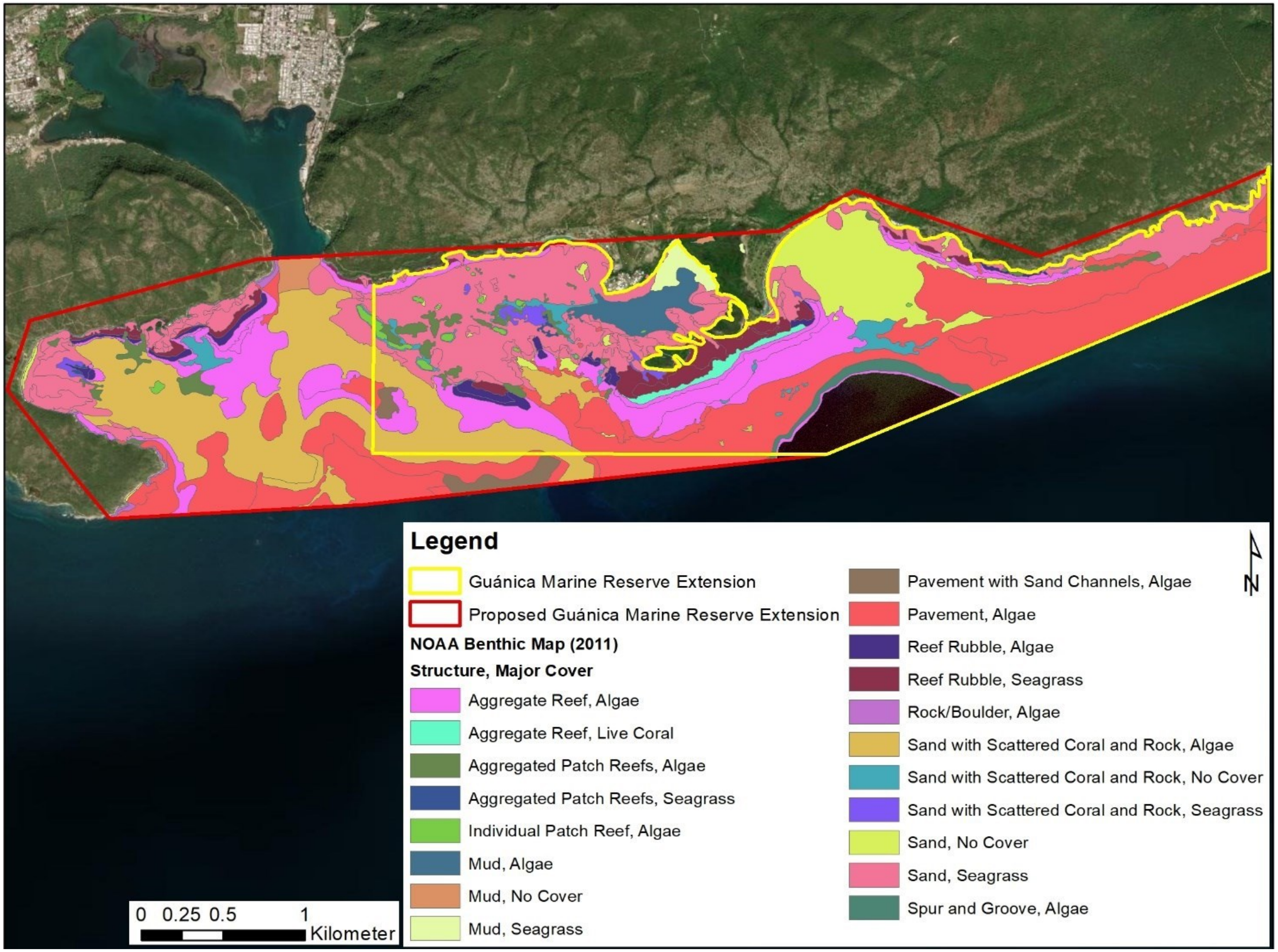


Figure 19. Benthic composition map from NOAA (Bauer *et al.*, 2011) for the Guánica Marine Extension showing the various benthic classes.

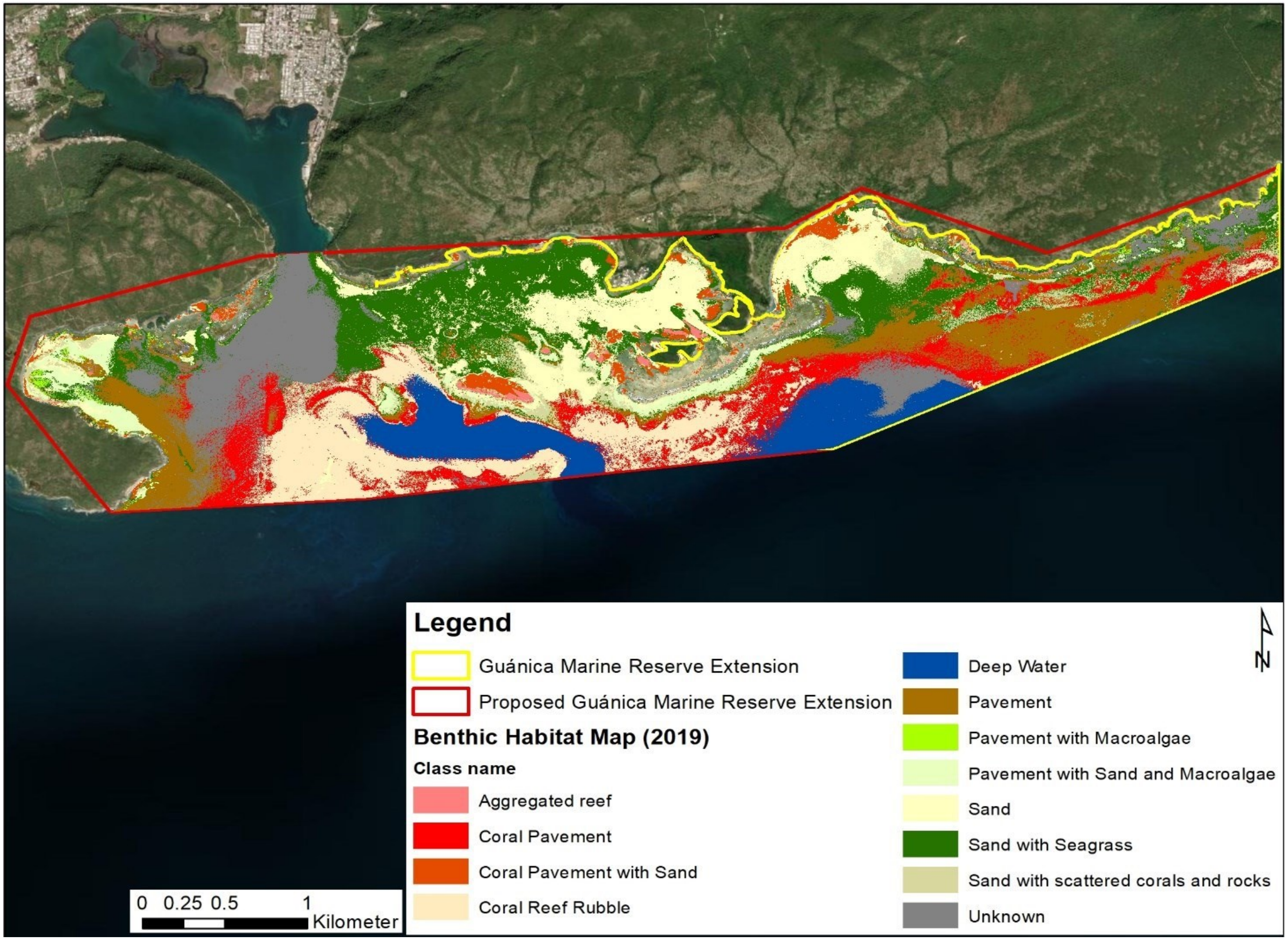


Figure 20. Benthic composition map from a 2019 satellite image for the Guánica Marine Extension showing the various benthic classes.

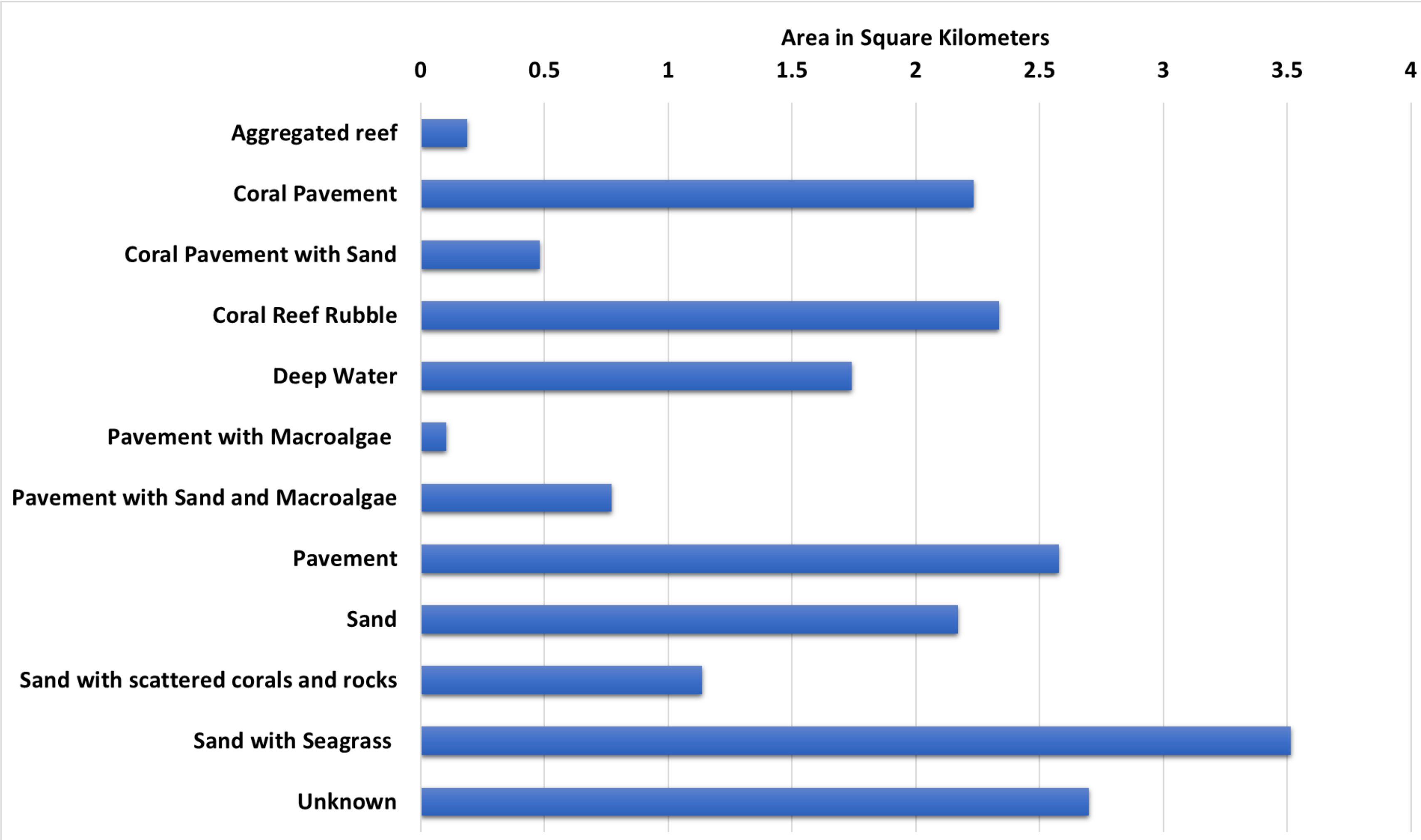


Figure 21. Total area in square kilometers of each benthic composition class in the 2019 Benthic Composition Map.

Current Use

Commercial fishing

Commercial fishing near the GSF is small scale and artisanal with fishermen using multiple types of gears such as *cordeles*, *nasas*, nets (also known as *tarrayas, filetes, mallorquines* and *chinchorros*) to dive fishing (Valle-Esquivel, 2011). Waters near the cay are productive all year round and sustain a small fishing community, with at least 14 fishers regularly visiting the area. From 2000 to 2014, data for the fishing villages in Guánica compiled by the Caribbean Fisheries Management Council (CFMC) shows an average yearly reported catch of 59,025.35 lbs. and an average yearly reported income of $167,480.98. The maximum values reported were in the year 2000, with a reported catch of 247,913 lbs. and a reported income of $473,395 (Figure 22 & Figure 23). However, the zone has seen a steep decline in fishers, reported pounds fished, and reported income that could be related to the 2019 earthquake sequence and the COVID-19 pandemic (Table 2). Few fishers remain as some left the island after the earthquakes, while others retired.

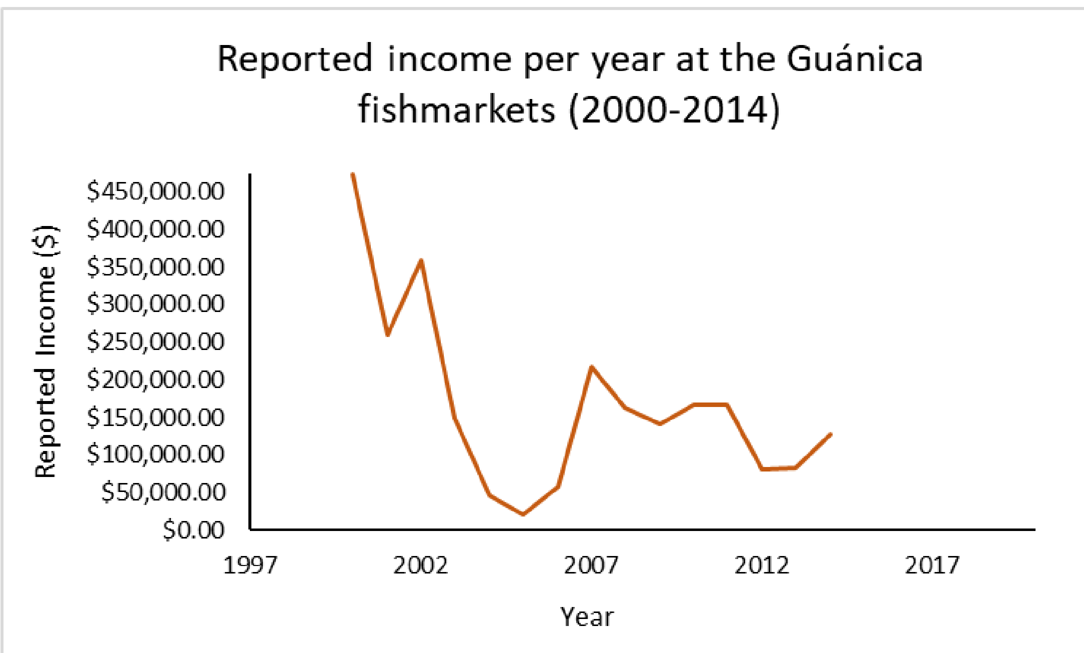


Figure 22. Total reported income from local fish markets in Guánica from 2000 to 2014.

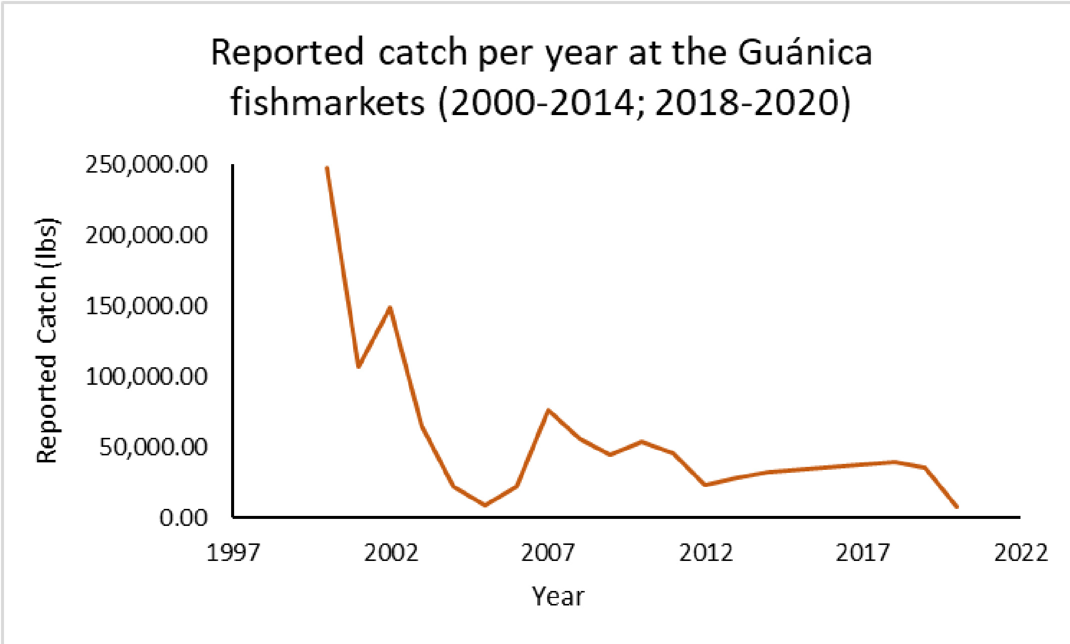


Figure 23. Total reported catch (lbs.) from local fish markets in Guánica from 2000-2020.

Table 2. Total reported landings by fishers in Guánica from 2018-2020. Data was provided by the DNER Fishing Research Laboratory.

Commercial Fishing Reporting Landings 2018-2020 from the Guánica Municipality

Year	Fishers Reporting	Total Pounds (lbs.)	Total Trips
2018	24	39,401	792
2019	17	35,515	814
2020	14	7,407	249

Fishing is part of the cultural identity of the ME and is one of the main uses for locals and visitors alike. Although in recent years the number of commercial fishers has declined, there is still an active group concentrated on the Guánica Bay, specifically in the fish market *Pescadería Bahía Guánica*. Beaches such as Atolladora and Tamarindo are frequently used for shore fishing as they are accessible and shallow (Figure 24).

Figure 24. Fishers at Atolladora Beach during the summer of 2022.

Recreational activities

The ME provides ample opportunities for recreational activities including swimming, water sports, boating, and diving, among others. One of the most attractive areas for recreation within the ME is Cayo Aurora. Past management strategies implemented included controlling the maximum daily capacity of visitors on the cay to ensure the security of visitors and the protection of the cay. This management strategy was first used in Puerto Rico at Cayo Aurora and was then successfully replicated in other natural reserves. Initially, a daily limit of 200 people was established. Afterwards, composting toilets were installed on the islet and the daily limit was raised to 300 during the summer, the season with the highest visitor's traffic. Originally, the DNER granted a concession of 200 people to San Jacinto Restaurant, who previously transported visitors. An additional 100 visitors arriving on their private vessels were allowed. Later, in 2002, the concession to San Jacinto was increased to 275, and concessions granted to Mary Lee's by the Sea (2003) and Hotel Copamarina (2009) were established at 20 and 50, respectively. Consequently, the maximum number of visitors was raised to accommodate 325 visitors per day and leaving no "legal" space for visitors in their private means of transportation. However, as of 2020, access to Cayo Aurora has been restricted. This was due to the aftermath of an offshore earthquake in the southwestern region on January 7, 2020, which caused damages to the cay. As of 2022, DNER personnel are evaluating the future of the cay, as it is important for tourism in the area and it sustains livelihoods, including those of fishers and tour operators. Their next steps include completing the *limit of acceptable change* model to identify appropriate uses by the public within Cayo Aurora.

Survey data shows at least 64% of surveyed people visit the GSF ME for recreational purposes (PDC Survey Data 2022). Many visitors spend the day on beaches such as Jaboncillo, Caña Gorda, Ballena, Tamarindo, Atolladora and Los Congres. Furthermore, another 12% visit the area for lunch or dinner in nearby restaurants. Based on the survey data, almost half of the visitors (49%) to the GSF ME visit the area at least once a week. Data compiled shows that more than 59% of surveyed visitors at the GSF were unaware that the area included a protected ME.

Research

The Guánica Bay area has been a priority area of scientific research, especially focusing on the benthic ecosystems in the region due to the coral reef ecosystems diversity on the insular shelf offshore and west of Guánica Bay. Research has been conducted on reef zonation and sediment impacts in southwest Puerto Rico, including the Guánica and La Parguera areas, westward of Guánica Bay (Acevedo *et al.*, 1989).

The Guánica Bay area and the Río Loco watershed were identified by the U.S. Coral Reef Task Force as a priority location for watershed initiatives to reduce impacts of anthropogenic runoff to nearby coral reef ecosystems (Whitall *et al.*, 2013). These initiatives included research studies on the status of reef ecosystems and current stressors (García-Sais *et al.*; 2008; Ryan *et al.*, 2008; Warne *et al.*, 2005), sediments sources and transport (Sherman *et al.*, 2013; Takesue 2019; Takesue *et al.*, 2022) and chemical and organic contaminants (Pait *et al.*, 2008a; Whitall *et al.*, 2014). In addition, research has focused on that water quality conditions using satellite remote sensing and field water quality data, especially after extreme rain events like hurricanes (Hernández *et al.*, 2020; Ortiz-Rosa *et al.*, 2020; Geiger *et al.*, 2021).

A coral benthic nursery and restoration site is currently operated in the Cayo Coral area and supported by the NOAA Restoration Center, DNER, and HJR Reefscaping. The nursery mainly manages elkhorn coral (*Acropora palmata*) and staghorn coral (*Acropora cervicornis*) which are used for outplanting at restoration sites. Several areas in Cayo Coral have also been restored using species from this nursery site. In addition, Sea Ventures, the DNER, and HJR Reefscaping are leading efforts in Cayo Coral to treat affected coral colonies for stony coral tissue loss disease.

Current threats

Land-based sediments

Coastal and marine ecosystems in Puerto Rico have been severely impacted by land-based anthropogenic activities for decades (Larsen and Webb, 2009). These impacts include increased sediment loading rates (Larsen and Webb, 2009), and eutrophication and microbial pollution from improperly treated sewage (Hernández-Delgado *et al.*, 2006). These impacts decrease light availability in the water column and increase smothering affecting coral growth rates and cover, and susceptibility to disease (Acevedo and Morelock, 1989; Torres, 2001; Torres and Morelock, 2002). Several studies have used ocean color satellite remote sensing as a tool to evaluate short and long-term exposure of degraded water quality to coral reef areas (Hernández *et al.*, 2020; Torres-Pérez *et al.*, 2021)

A detailed water quality study using remote sensing was conducted for several priority coral reef sites in Puerto Rico, including the Guánica Bay area (Environmental Mapping Consultants for NOAA CELCP, 2019)2F[3]. These sites included Cayo Coral West/East (close to Cayo Aurora) and Andrea near the shelf edge (Figure 25). The water quality products derived from both moderate resolution (1km) and high-resolution (10-30m) satellite data included the water attenuation coefficient at 490nm (K_d490) and the chlorophyll-a concentration. The K_d490 is an important parameter for water quality because it provides a measure of "turbidity" (measure of the total organic and inorganic matter held in solution and suspension) in the water column and can be used to quantify light availability for benthic organisms (i.e., coral reefs and seagrasses) (Hernández *et al.*, 2020). The chlorophyll-a concentration provides a measurement of the phytoplankton biomass and nutrient status (i.e., productivity) and can be used as an index of water quality.

After analyzing the data, the Cayo Coral East and West showed an average value for K_d490 that exceeded the 0.1 m-1 threshold, while the Andrea site represented more oceanic values below this threshold (Figure 26). K_d490 values above the 0.1m-1 threshold are considered areas exposed to turbid water by other jurisdictions (e.g. Hawaii, Australia). Also, the Cayo Coral West site showed higher values when compared with Cayo Coral East site, which suggests the potential influence of the Guánica Bay plume track in the observed values. For the chlorophyll-a concentration, Cayo

[3] Sponsored by NOAA Coral Reef Conservation Program (Grant #NA19NOS4820129)

Coral West site presents the highest values for the region, where peaks are observed in 2010 and 2017, and values nearly double from the dry to the rainy season (Figure 27).

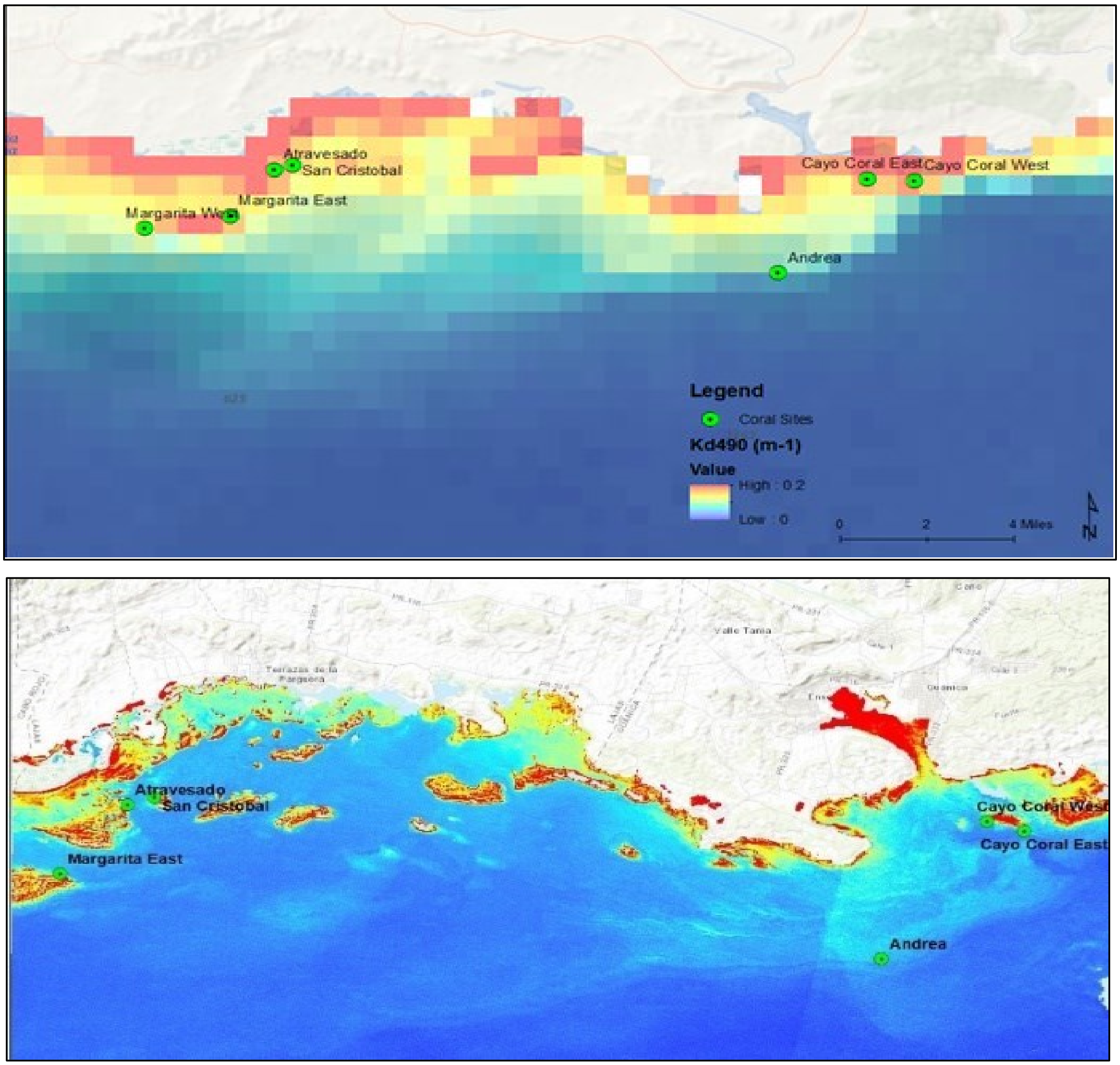
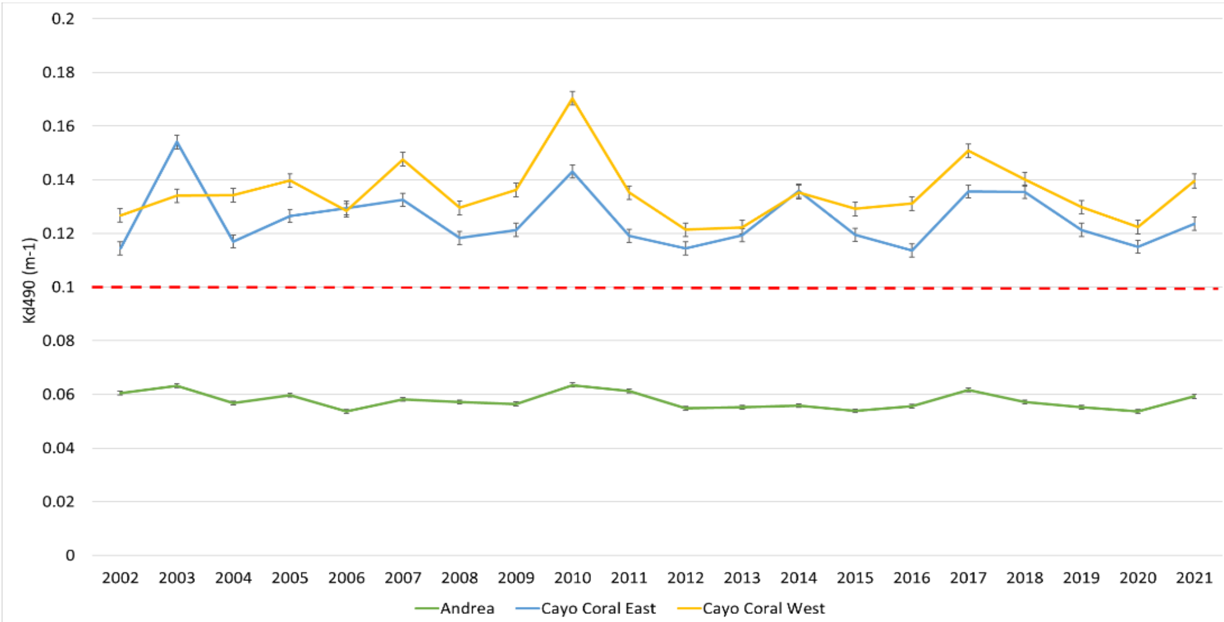


Figure 25. K_d 490 (turbidity) products for the moderate resolution sensor (top) and the higher resolution sensor (bottom) for the Guánica Bay area.



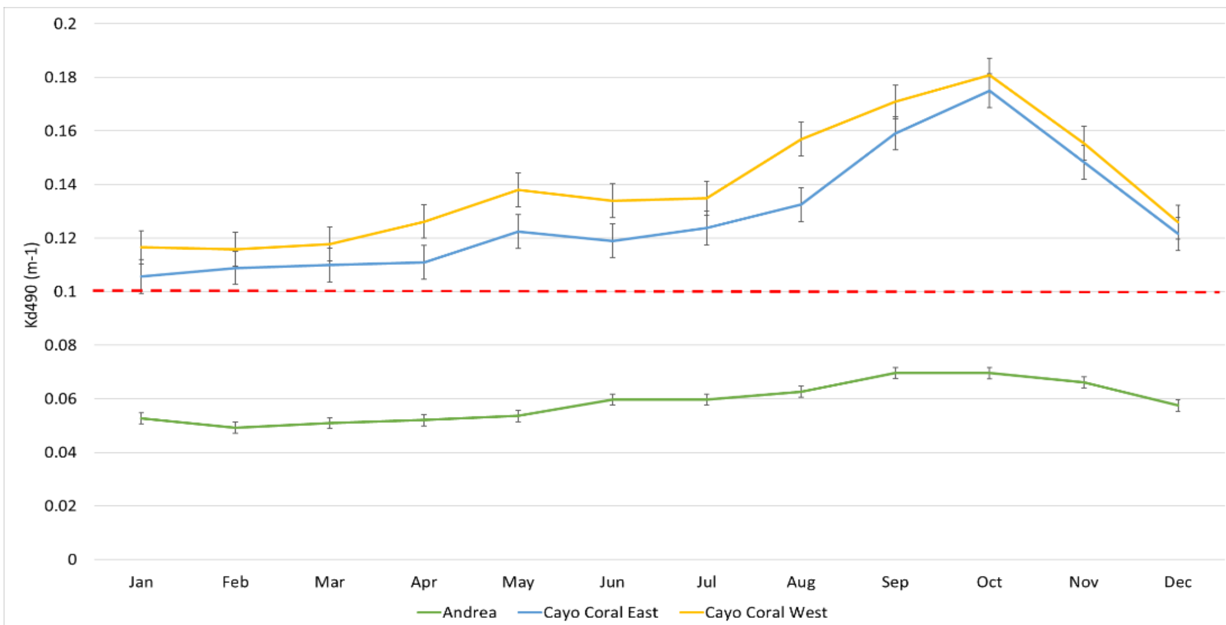
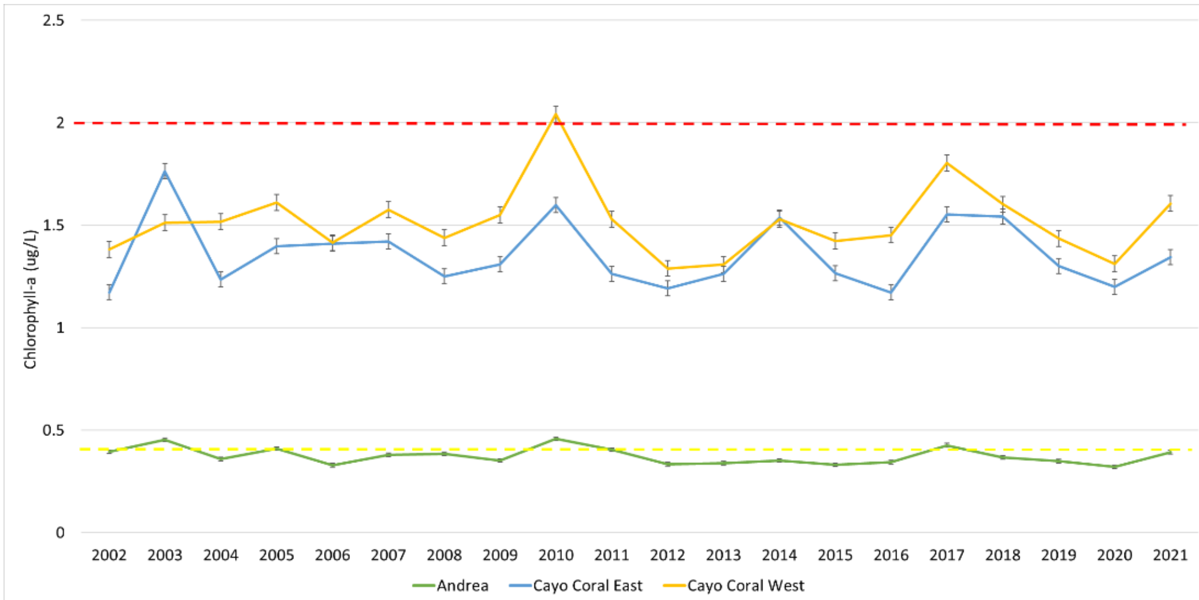


Figure 26. Yearly averages from 2002-2021 of Kd490 values for Guánica region (top). Monthly averages from 2002-2021 of K_d490 values for Guánica region (bottom). The threshold of 0.1 m-1 (red-dashed line) is included for reference.



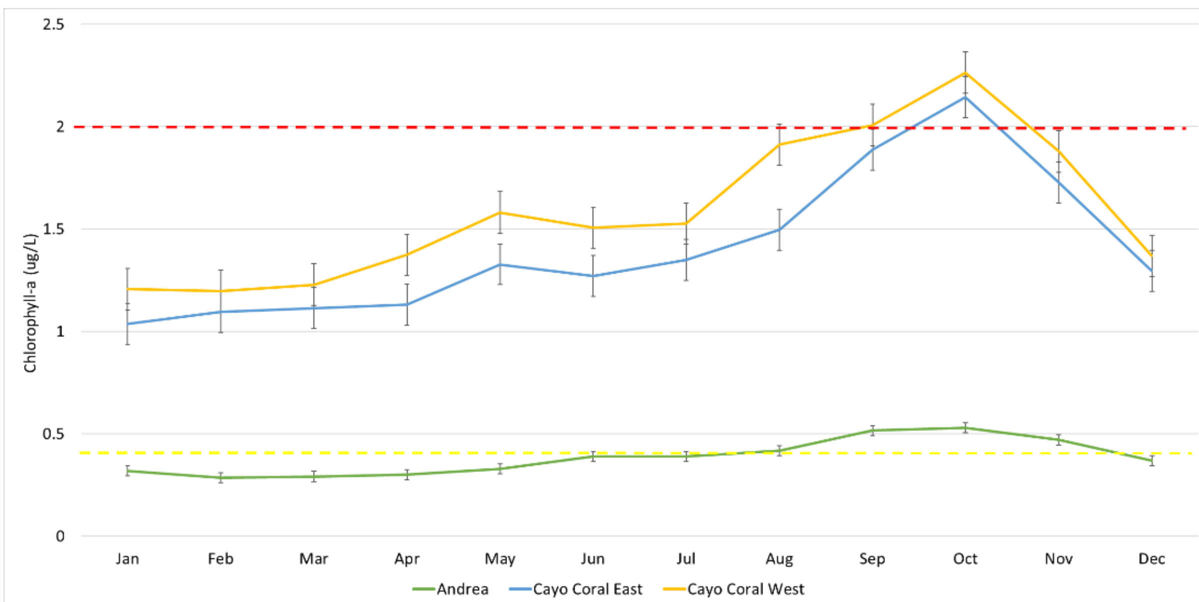


Figure 27. Yearly averages from 2002-2021 of Chl-a values for Guánica region (Top). Monthly averages from 2002-2021 of Chl-a values for Guánica region (Bottom). The thresholds of 0.45 ug/L (yellow-dashed line) and 2 ug/L (red-dashed line) are included for reference.

The water quality time-series analysis shows that most of the sites show chronic exposure to turbid waters that exceed current water quality thresholds established by other jurisdictions. Also, the higher values of both K_d 490 and chlorophyll-a concentration suggest that the extent of the plume from Guánica Bay has a direct impact on the coral reef nursery and restoration sites located here. These water quality impacts should be considered when prioritizing restoration and management of coastal resources, including Cayo Aurora, to avoid adding additional sources of disturbance and sedimentation to these sites.

Sargassum blooms

Sargassum is a floating seaweed that can be found in the Intra-Americas Sea (including the Gulf of Mexico and the Caribbean Sea) and the Atlantic Ocean and provides an important marine ecosystem in oceanic waters (Witherington *et al.* 2012). In Puerto Rico, *Sargassum natans* and *Sargassum fluitans* are the two most common species of this seaweed. Since 2011, there has been a sudden increase in *sargassum* biomass in the tropical Atlantic and Caribbean Sea and consequently, massive accumulations of *sargassum* have been reported in the coasts of the Eastern and Western Caribbean and Florida (Gower *et al.* 2013), including Puerto Rico. *Sargassum* impacts in coastal environments, include alterations to coastal and wetland biochemistry, release of toxic products due to its decomposition, fish mortality, and beach accumulations that impact sea turtles and other important species in coastal and marine reserves. In addition to these physical and chemical effects, *sargassum* beaching events also have economic impacts on coastal communities, including tourism (Franks *et al.* 2012). These events drive tourists away from beaches and dramatically increase costs to communities and tourist resorts to remove *sargassum* mats from beaches.

In the Guánica Bay area, the large *sargassum* patches are carried by the surface currents and winds and from satellite and local observations accumulate primarily in the Las Pardas and Ballena areas (Figure 28). The accumulation at these locations persists throughout the *sargassum* season, limiting the use of these coastal resources in these areas and impacting the nearshore coastal and benthic communities. No long-term accumulation of *sargassum* has been documented in the Cayo Aurora area, however, even transient events can limit tourism and the use of the coastal resources in the area. Also, the effects of *sargassum* accumulation in Ballena and its decomposition products can reach Cayo Aurora with currently unknown consequences (Figure 29).

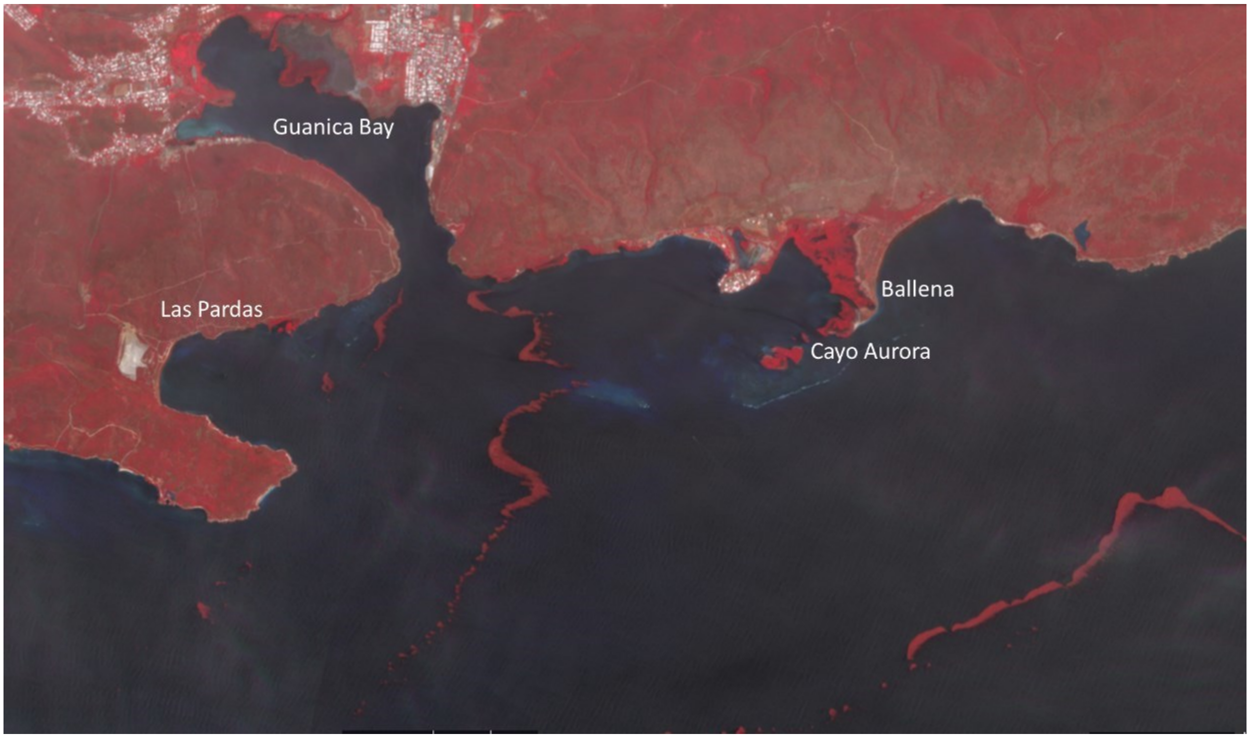


Figure 28. False color enhanced Sentinel 2 MSI (10m) image showing large *sargassum* patches (in red) in the Guánica Bay area.

Figure 29. *Sargassum* accumulated in Playa Ballena during the summer of 2022.

Geomorphological Changes

On December 28, 2019, an earthquake sequence began on the southwestern coast of Puerto Rico. This sequence peaked the morning of January 7, 2020, when a 6.4 magnitude earthquake caused severe damage all along the southern coast especially on the municipalities of Guánica, Guayanilla, and Yauco, Peñuelas, among others. In response to these events, an interagency collaboration began between NASA Earth Applied Sciences Disasters Program, the Federal Management Agency (FEMA), the United States Geological Survey (USGS), the University of Puerto Rico in Mayagüez, and other state and federal agencies[4]. NASA scientists used satellite data to help federal and local agencies identify areas damaged by the earthquakes and to identify the changes in the ground surface. The data was acquired by comparing synthetic aperture radar (InSAR) interferometry data collected on January 9, 2020, with data collected on December 28, 2019, by the Copernicus Sentinel-1A satellite. Scientists were able to map where, how much, and in what direction the changes occurred (Figure 30).

In February 2020, scientific personnel from the DNER and NOAA agencies along with academics from the University of Puerto Rico visited Cayo Aurora to validate the information collected by the satellites of the National Aeronautics and Space Administration (NASA), which determined the subduction of Cayo Aurora. These agencies validated field data with the data that was collected through satellite measurements. During the same month, the NOAA Restoration Center and Sea Ventures Marine Response Unit completed a pre-assessment report for earthquake damages to coral reefs along the southern coast of Puerto Rico (Griffin *et al.*, 2020). Cayo Aurora was surveyed at three sites and Cayo Aurora was surveyed at three sites and found around 250 fragments of *Acropora palmata* scattered along the base of colonies. It was observed that most of the fragments were in good condition with healthy tissue and were candidates for triage[5] to avoid tissue loss. However, due to the government implemented mandatory restrictions in response to the COVID-19 pandemic, these restoration practices could not be completed. Many of the geomorphological changes are still under review by scientists as the sequence is still active as of 2022. Many communities in Guánica and surrounding municipalities are still recovering from the effects of these earthquakes. Future management strategies must consider the possibility of future earthquakes and their effects on the southern region of Puerto Rico.

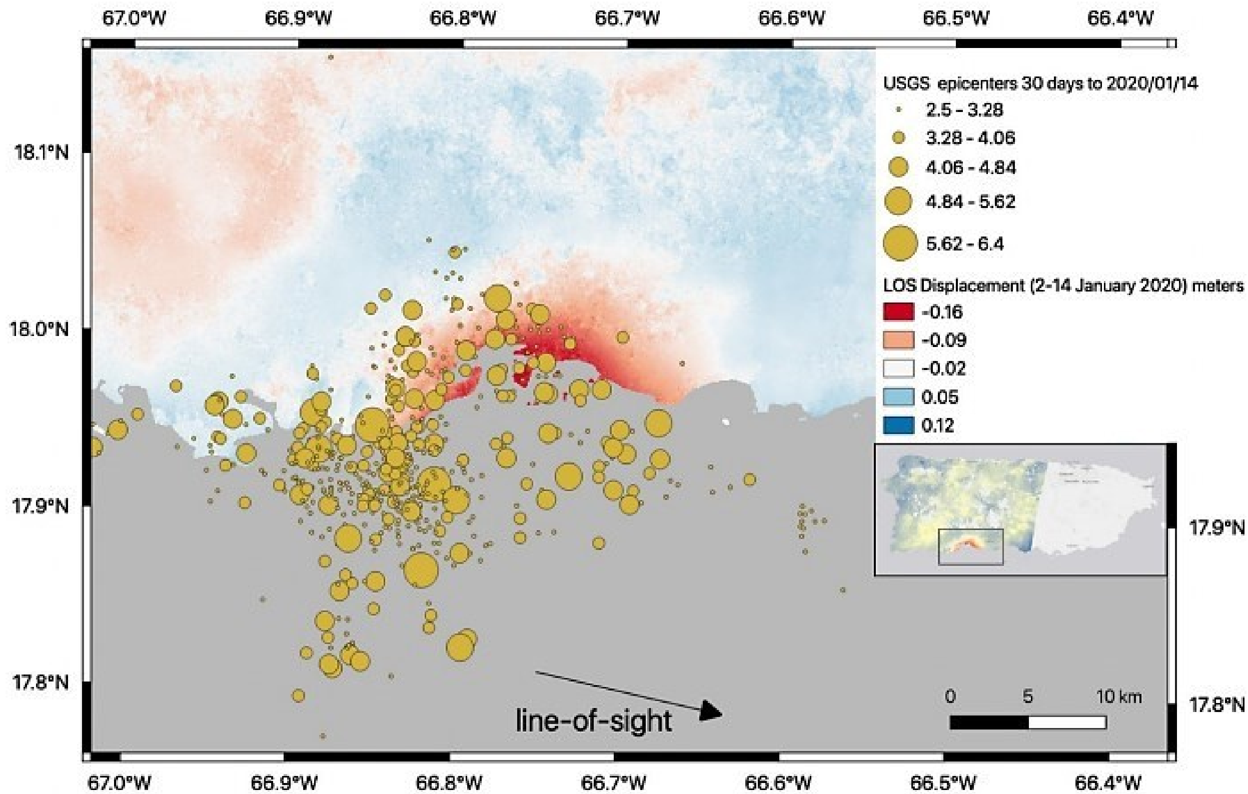


Figure 30. Map generated by NASA to demonstrate the surface displacement and the changes in elevation caused by the Puerto Rico Earthquakes between January 2 and 14, 2020. This estimates around 6 inches of surface lowering centered on the Guayanilla Bay in the southern region of Puerto Rico. The gray area is the ocean. Credit: NASA, JPL-Caltech, ESA

Anthropogenic Pressures

Marine pollution

Marine pollution, one of the main stressors of marine life, was defined by the 1982 United Nations Convention on the Law of the Sea as "*the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water, and reduction of amenities*" (UNCLOS, 1982).

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[4] https://appliedsciences.nasa.gov/our-impact/news/nasa-disters-program-responds-2020-puerto-rico-earthquakes

[5] The process of stabilizing and/or readjusting damaged, broken, or fragmented corals to the substrate.

The Guánica Bay has been a central study area for multiple projects wanting to understand land-based sources of pollution such as chemical contaminants found in sea floor sediments. A study by Pait *et al.* (2009), found levels of Polycyclic aromatic hydrocarbons (PAHs), Dichlorodiphenyltrichloroethane (DDT) and Polychlorinated biphenyls (PCBs) above the accepted levels by NOAA's National Status and Trends (NS&T). Another study by Whitall *et al.*, (2014) found that chemical contamination at Guánica Bay is much higher than other areas in Puerto Rico with multiple potential sources. The presence of these chemical contaminants is the result of human activities such as industrial factories and agricultural practices and could potentially have detrimental effects on humans and marine ecosystems.

One type of marine pollution is the presence of plastics that can be transported long distances and that are damaging to marine life. In Puerto Rico, the Caribbean Marine Pollution Assessment and Control Program identified fishing equipment as a principal source of marine pollution (Coe *et al*., 1997). A beach cleanup completed in 1994 identified plastics as the most abundant item and accounted for 44.5% of the total of materials collected (Coe *et al.*, 1997). A NOAA funded project titled *Assessment of Pathways and Degradation of Marine Debris within the Guánica Watershed and Surrounding Region of Southwest Puerto Rico* was initiated in 2022 to conduct a regional assessment of the Guánica Watershed by analyzing upstream sources of marine debris and transport to downstream areas of coastal deposition, and by conducting field and laboratory degradation experiments. As a collaboration between Villanova University, Alelí Environmental, Inc. and Protectores de Cuencas Inc., this partnership is an opportunity to conduct scientific experiments that will help identify the influence of marine debris in the region, while providing opportunities to connect with the local community and stakeholders.

Marine debris characterizations and beach cleanups are conducted twice a year in Ballena Beach (Figure 31) and Las Pardas beach (Figure 32), once during the wet season and once during the dry season. Preliminary results coincide with data collected by Coe *et al.*, 1997. During the dry season, at Las Pardas Beach, more than 23% of marine debris collected was related to fishing practices. Plastic was also the principal type of marine debris observed in all the study sites (Figure 33). Although Las Pardas is not part of the ME, this beach is close to the ME and marine debris originating from this area can influence marine life in the area.

Results from this study will assist agencies, scientists, and stakeholders in understanding plastic pathways within the watershed and identify best practices to intercept debris such as plastics from entering our oceans. Marine pollution is a multiscale problem that requires the involvement and collaboration of private and public sectors. Long-term solutions require time to tackle the sources of pollution, while implementing educational campaigns involving local communities as they are the main users.

Figure 31. Photos of debris at Ballena Beach on October 8, 2022. The left photo shows debris accumulated on the beach. The middle and right photos are debris removed from transects on Ballena Beach for further characterization and laboratory degradation experiments. Photos from NOAA funded project *Assessment of Pathways and Degradation of Marine Debris within the Guánica Watershed and Surrounding Region of Southwest Puerto Rico.*

Figure 32. Photos of Las Pardas beach (left and middle) and a subset of the debris removed and characterized (right) on November 26, 2022. Photos from NOAA funded project *Assessment of Pathways and Degradation of Marine Debris within the Guánica Watershed and Surrounding Region of Southwest Puerto Rico.*

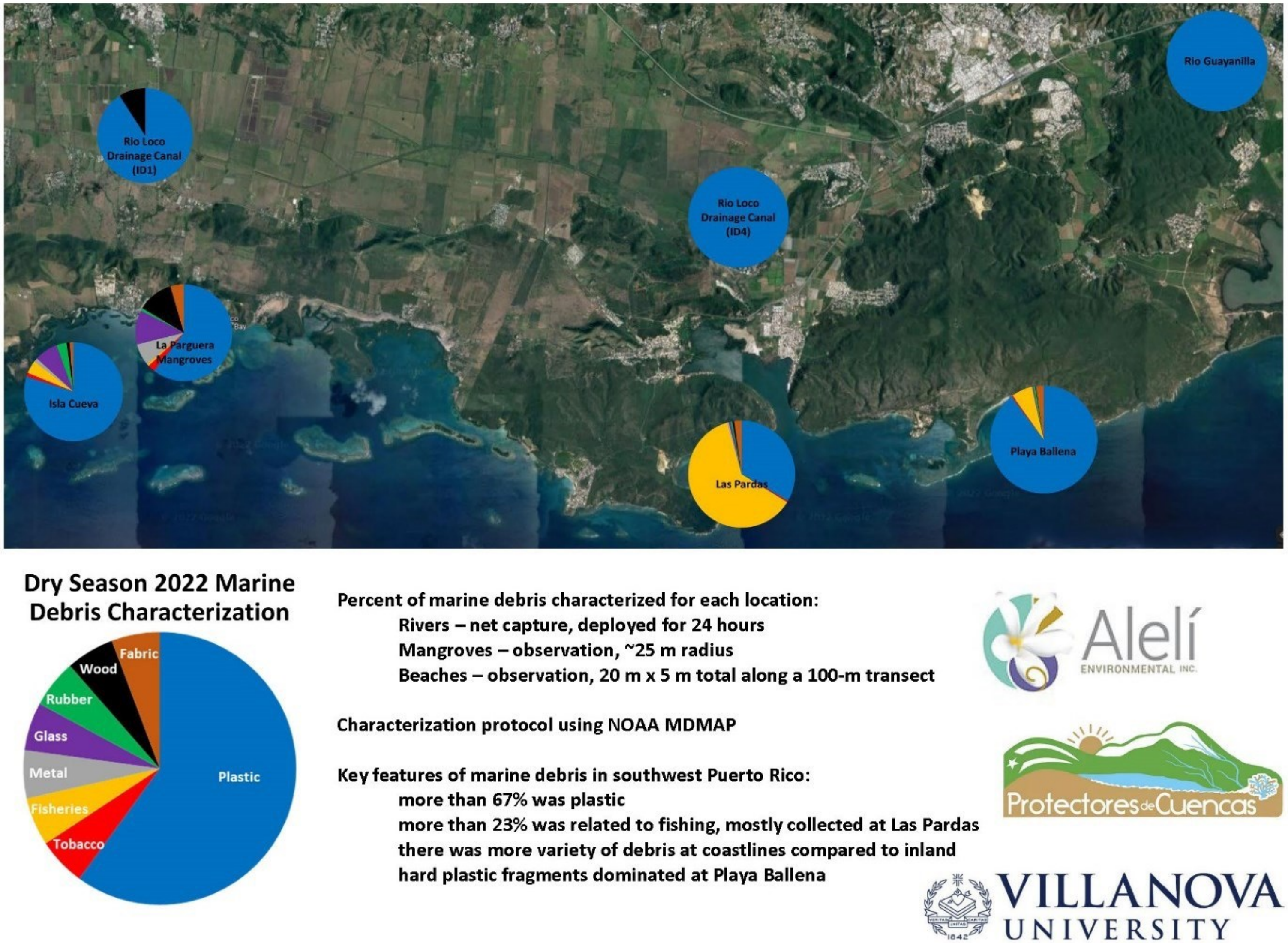


Figure 33. Preliminary results from NOAA project Assessment of Pathways and Degradation of Marine Debris within the Guánica Watershed and Surrounding Region of Southwest Puerto Rico. Plastic is the main type of MD found in the southwest of Puerto Rico.

Climate Change

Global warming

A rise in temperatures due to global warming has implications to both land and marine livelihoods. Khalyani *et al.* (2016) examined the potential effects of climate change on ecological life zones, increasing energy demands, and drought indices in Puerto Rico from 1960 to 2099 using a suite of statistically downscaled global circulation models. These results predict a gradual linear increase in drought intensity and extremes with the end of the century, with consequences that could include water supply deficits. Also, the projected warming in the same period was 4.6°–9°C depending on the geographic location and emission scenarios and climate change may alter the life zones of the island with shifts from rain, wet, and moist zones to drier zones.

In addition, warming in the ocean has occurred over the last decades resulting in coral bleaching events and associated coral reef mass mortalities (Hoegh-Guldberg, 1999). Caribbean reefs have been on average by 0.18°C per decade during the latest decades, while if this linear rate of warming continues, these already threatened ecosystems would warm by an additional ~1.5°C on average by 2100 (Bove *et al.*, 2022). In addition to the warming of the oceans, land-based sources of pollution, overfishing, and diseases augment the impacts to these ecosystems. The Guánica Bay watershed was designated as a priority restoration site for the US Coral Reef Task Force due to the important coral reef ecosystems located in the area. Loss of coral reef ecosystems has a direct effect on the primary productivity in the coastal oceans including coastal protection from storms, decline in fish stock, and tourism with direct impacts to ocean dependent communities.

Sea Level Rise

Sea level rise (SLR) is an increase in the level of the world's oceans because of global warming. The warming of the ocean causes its expansion resulting in SLR. A SLR of about 2 feet (0.6 meters) along the U.S. coastline is increasingly likely between 2020 and 2100 because of emissions to date (Sweet *et al.*, 2017). The south coast of Puerto Rico is particularly vulnerable to SLR, storm surges and waves due to their relatively low relief and highly exposed coastlines (Khalyani *et al*., 2016). This vulnerability has increased over the past decades because of the change in climate such as the increased occurrence of extreme events like hurricanes and SLR, and a reduction in rainfall events but an increase in rainfall intensities resulting in bigger freshwater flooding impacts (Gould *et al.* 2018). Some effects of SLR along the coastline includes reduction in coastal protection and increase erosion of the coastal areas that promote a higher exposure of local communities to coastal inundation (PRCCC, 2013). In addition, SLR effects include changes in the migration and structure of mangrove forests with consequences on the flora and fauna associated with these, loss in habitat connectivity, and deepening of coral reefs not able to keep up with the increase in SLR (Gould *et al.*, 2018).

The NOAA's Sea Level Rise Monitoring Program provides a Sea Level Rise Viewer[6] that allows users to model various impacts of SLR scenarios. A projected 0.6m increase in SLR will submerge both Aurora and Ballena Cays, inundate most of Ballena, San Jacinto, coastal beaches, and the low-lying areas of downtown Guánica (Figure 34). These SLR scenarios do not consider current subsidence and inundation of cays and coastal areas in the marine extension due to seismic activity, so these SLR effects may occur sooner than expected.

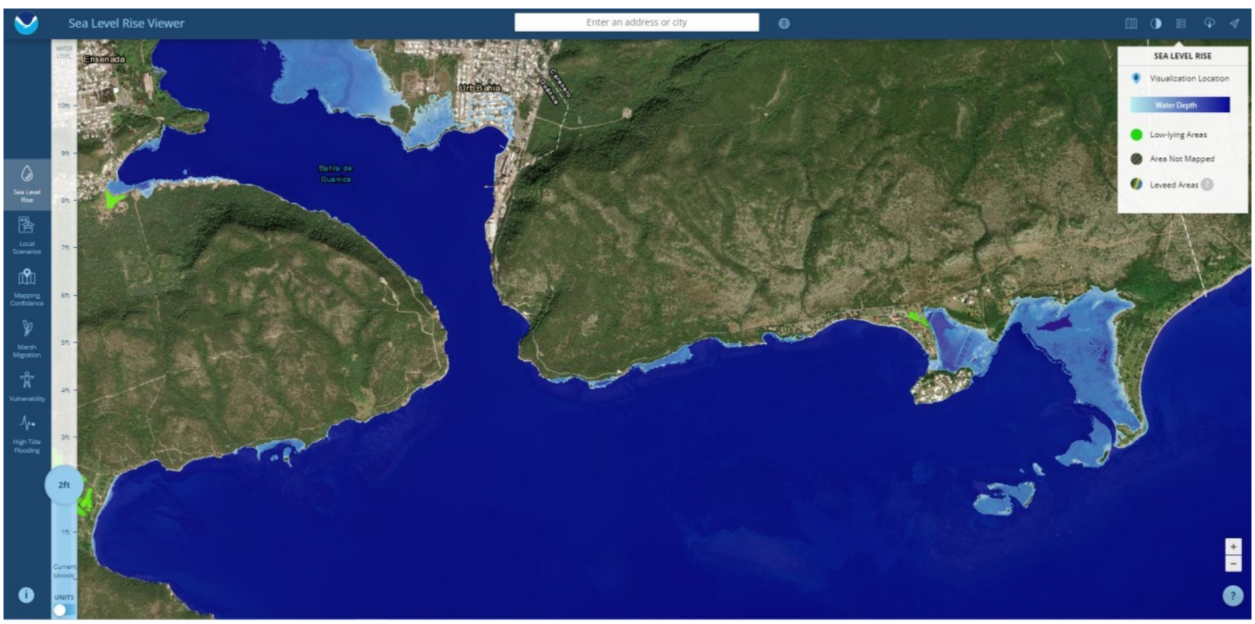


Figure 34. Sea Level Rise Viewer modeled impacts with a projected 2 feet (0.6m) SLR in Marine Extension of the Guánica State Forest.

[6] https://coast.noaa.gov/slr/

Potential Management Actions

Management Action Plans are useful for the conservation of marine ecosystems as they provide a clear path for the types of uses allowed in an area, minimize conflicts between users and agencies, and aid in the establishment of sustainable conservation practices. Adequate use of an ME is especially important for the conservation of threatened species and to ensure the sustainability of the ecosystem.

A list of management opportunities for the GSF ME were identified through fieldwork, literature review and through discussions during meetings with stakeholders. These opportunities are detailed below.

Expansion of the Marine Reserve

A study conducted by PDC and sponsored by the NOAA Coral Reef Conservation Program, entitled *Benthic community structure characterization and assessment of turbidity impacts of the north (Manatí and Vega Baja) and south (Guánica) coasts, Puerto Rico*, involved conducting a benthic characterization of various sites in 2018. The sites of Corona La Laja and Punta Pescadores were included as part of this study and video transects were collected to estimate coral, submerged aquatic vegetation, and benthic substrate types. The site for Corona La Laja south is a submerged key south of Guánica Bay which is partially included in the current GSF ME. This site was mainly dominated by sand, hardbottom with algae, pavement, and rubble but included approximately 8% of hard coral cover and close to 35% of soft corals (octocorals). The site of Punta Pescadores is located west of the Guánica Bay entrance, and it is currently not included in the GSF ME. This site was also mainly dominated by sand, bottom with algae, pavement, and rubble but included approximately 10% of hard coral cover and close to 40% of soft corals (octocorals). The observations show a dominance of gorgonian plains in most reefs in Guánica, at least at the sampled depths (4-10m). Reef zones that usually receive higher wave action are dominated by hardbottom with sparse colonies of the threatened *Acropora palmata* and *A. cervicornis* along with small colonies of other important reef-builders (*Orbicella annularis, O. faveolata, Pseudodiploria strigosa, P. clivosa,* and *Montastraea cavernosa*) (Figure 35).

Figure 35. Typical benthic components of reefs associated with the Guánica watershed. a) *Orbicella faveolata* colonies; b, c, e) gorgonian plains; d) hardbottom with sparse Scleractinian and gorgonian colonies; f) *Acropora palmata* colony. Photo credit Dr. Juan Torres-Pérez.

The GSF ME is located south of the eastern section of the GSF but it does not include the area south of the Guánica Bay and Las Pardas. The expansion of the GSF ME is proposed to include important areas for benthic habitats west of Guánica Bay and to provide connectivity to the Guánica Forest area in Punta Brea (Figure 36). This expansion would help reach *Kunming-Montreal Global biodiversity framework* which aims to preserve at least 30 per cent of terrestrial, inland water, and of coastal and marine areas by 2030 (Obura, 2023).These sites present key areas of coral reef cover that are susceptible to the current anthropogenic stressors and should be included in the GSF ME. The expansion of the marine reserve could provide additional protection and management actions to these sites and their coral reef and associated ecosystems.

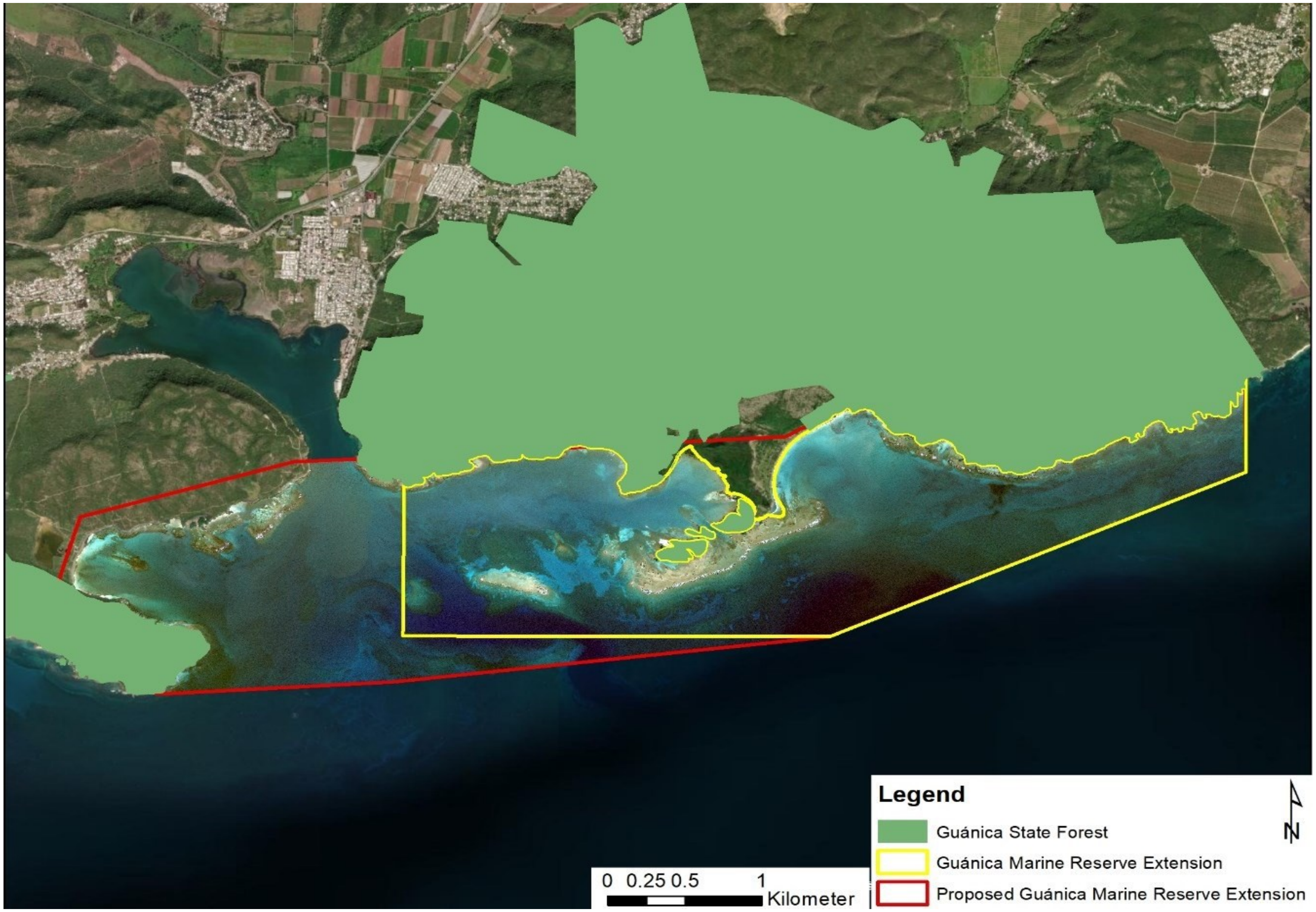


Figure 36. Map delimitating the Marine Extension of the Guánica State Forest and the proposed extension of the area to encompass more ecological sensitive areas.

Improvement of navigational aids

Human activity within the ME can have adverse effects on sensitive ecosystems and important marine life. One of the most detrimental activities is the use of recreational watercrafts at high speeds that can result in injuries to marine life such as manatees and sea turtles. A study by Collazo *et al.* (2019), highlights how population studies of manatees are affected by biased population estimates as their distribution is within large geographical areas, individuals spend time at depths where they cannot be detected and individuals at the surface can be missed. As part of this study, scientists also surveyed the entire coast of Puerto Rico, including offshore cays and islands, to identify manatee populations. One of the main findings was the identification of hotspots along the southern coast of the island, including Guánica Bay. This area is frequented by a resident population of the West Indian Manatee (*Trichechus manatus*) that can be observed within the bay and the ME. This population can fluctuate between 15 to 20 individuals and are usually observed near seagrass beds within the reserve and along the coast (D. López, *personal communication*, November 10, 2022).

The protection of this population is of the utmost importance as this species is listed as an endangered species under the Endangered Species Act of 1973 and protected under the Marine Mammal Protection Act of 1972. As result of this law, in 2012, the DNER released the *Plan for the Conservation and Protection of Manatees in Puerto Rico* to help establish strategies to ensure the protection of this species. The strategies suggested in this plan include: 1) use of navigational buoys within the hotspots identified for manatees that help alert watercraft users avoid collisions, 2) maintenance of installed buoys, 3) and educational campaigns to create awareness among users. A 2021 report completed by the DNER highlights the necessity of adding additional mooring buoys along the ME to protect this population (Figure 37).

Manatee calves in this area are at risk of being separated from their mothers and/or suffering life threatening injuries caused by impacts from watercrafts (e.g., jet skis). In addition, benthic habitats such as shallow seagrasses are impacted by propellers and anchors of watercrafts visiting the cays. To ensure proper use of watercrafts and the wellbeing of marine life, installation of navigational buoys is recommended within the reserve and Guánica Bay to alert users to the speed limits. Also, installation of additional mooring buoys would be beneficial for larger watercrafts used in the area.

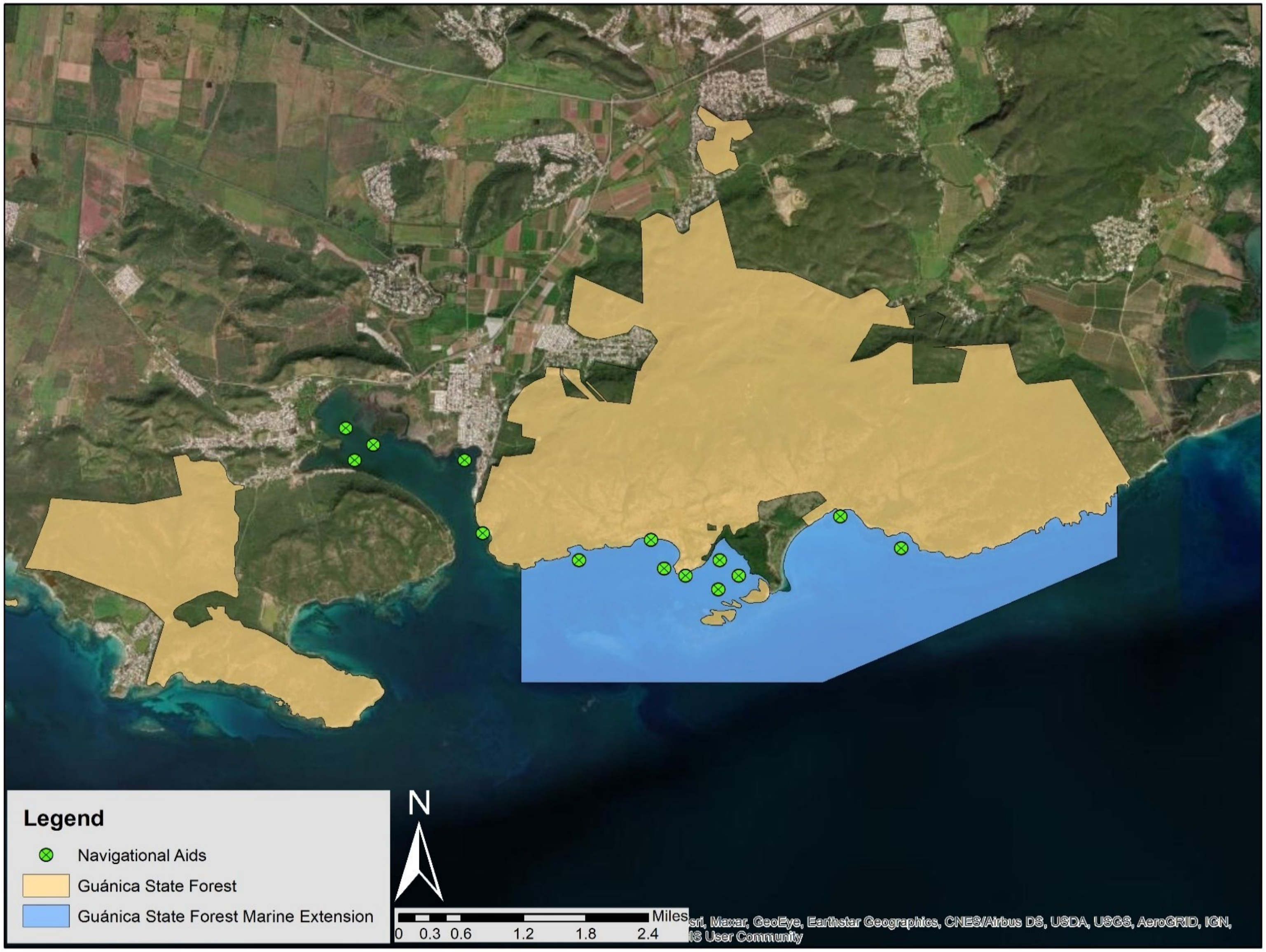


Figure 37. Locations suggested by DNER for the installation and maintenance of buoys in areas inside and near the ME. These buoys would help to identify areas frequently visited by manatees as well as to provide mooring buoys for watercrafts.

Pollution Prevention

Pollution prevention involves addressing existing and future sources of pollution by taking a proactive, preventative approach and working directly with key entities and individuals that may be responsible for the pollution. It is imperative to first identify and evaluate pollution hotspots. Potential hotspots for pollution include agricultural lands, landfills, municipal public works yards and marinas, sewage systems, and re-fueling areas such as gas stations, among others. Evaluations can be done through geospatial and field analyses. Useful field assessments at the watershed scale include 1) evaluation of stream and stormwater outfall conditions; 2) evaluation of stream channel conditions and possible sources of sediment from stream channel erosion; and 3) evaluation of bare soils/unpaved roads and resource extraction or landfill sites.

Once evaluated, specific interventions and activities can be recommended to address pollutants depending on the source, pollutant load, and location. In the Guánica Bay Integrated Watershed Management Plan (*in progress*), specific recommendations for pollution prevention were made and include increased Illicit Discharge Detection and Elimination (IDDE), erosion and sediment control training workshops for local jurisdictions and their developers, and door-to-door surveys in areas with persistent water pollution to determine if homes have proper sewage connection or failing septic systems. Due to their proximity to the ME and location just north of the Caña Gorda Cays, pollutant threat analysis is specifically recommended for community sectors El Pitirre and San Jacinto.

Establishment of a no-take zone for Cayo Coral

Cayo Coral is another important cay located within the GSF ME, roughly 1.6 km offshore from Punta Jacinto. (17°56'18.8" N, 66°53'21.1" W). This cay is an emergent reef located between Punta Ballena and the mouth of Guánica Bay (Figure 38). It has an area of about two km long and lays in the same insular shelf as Caña Gorda Cays. Surveys within the cay have identified a total of 22 stony corals, a total of 79 fish species and many other algae and invertebrate species. Due to its richness and diversity, Cayo Coral is operated as a coral benthic nursery and restoration site supported by the NOAA Restoration Center, DNER, and HJR Reefscaping.

The nursery mainly manages elkhorn coral (*Acropora palmata*) and staghorn coral (*Acropora cervicornis*) which are used for outplanting at restoration sites. Several areas in Cayo Coral have also been restored using species from this nursery site. In addition, Sea Ventures, the DNER, and HJR Reefscaping are leading efforts in Cayo Coral to treat affected coral colonies for stony coral tissue loss disease.

Figure 38. Aerial shot of Cayo Coral taken by Dr. William Hernández.

The designation of a no take zone for this cay should be considered to preserve spawning areas of many aquatic species and the overall health of the coral reef.

Establishment of the Blue Economy

The United Nations defined the Blue Economy as an economy that "comprises a range of economic sectors and related policies that together determine whether the use of ocean resources is sustainable. An important challenge of the blue economy is to understand and better manage the many aspects of oceanic sustainability, ranging from sustainable fisheries to ecosystem health to preventing pollution." The blue economy is founded on emerging capabilities for acquiring data and developing knowledge that harnesses ocean resources for economic growth while protecting ocean health and ensuring social equity (Hotaling and Spinrad, 2021). A study by the Ocean Economy in 2020 predicted that the ocean's contribution would double in size from 2010 levels to USD $3T by 2030 (OECD, 2017).

Puerto Rico's coasts are home to close to 2.4 million people, and locations like the GSF ME and Cayo Aurora draw tourists from around the world and support jobs that can generate significant earnings annually. However, current, and new challenges such as sea level rise, fish stock declines, *Sargassum* inundations, and land-based sources of pollution impacts to coastal ecosystems can have a detrimental effect on the blue economy potential. The DNER began updating its coastal management strategy for 2023-2025 as part of the island's participation in the federal Coastal Zone Enhancement Program. This program promotes improvements to state and territory coastal management programs and focuses on nine enhancement areas: wetlands, coastal hazards, public access, marine debris, cumulative and secondary impacts, special area management plans, ocean and Great Lakes resources, energy and government facility siting, and aquaculture.

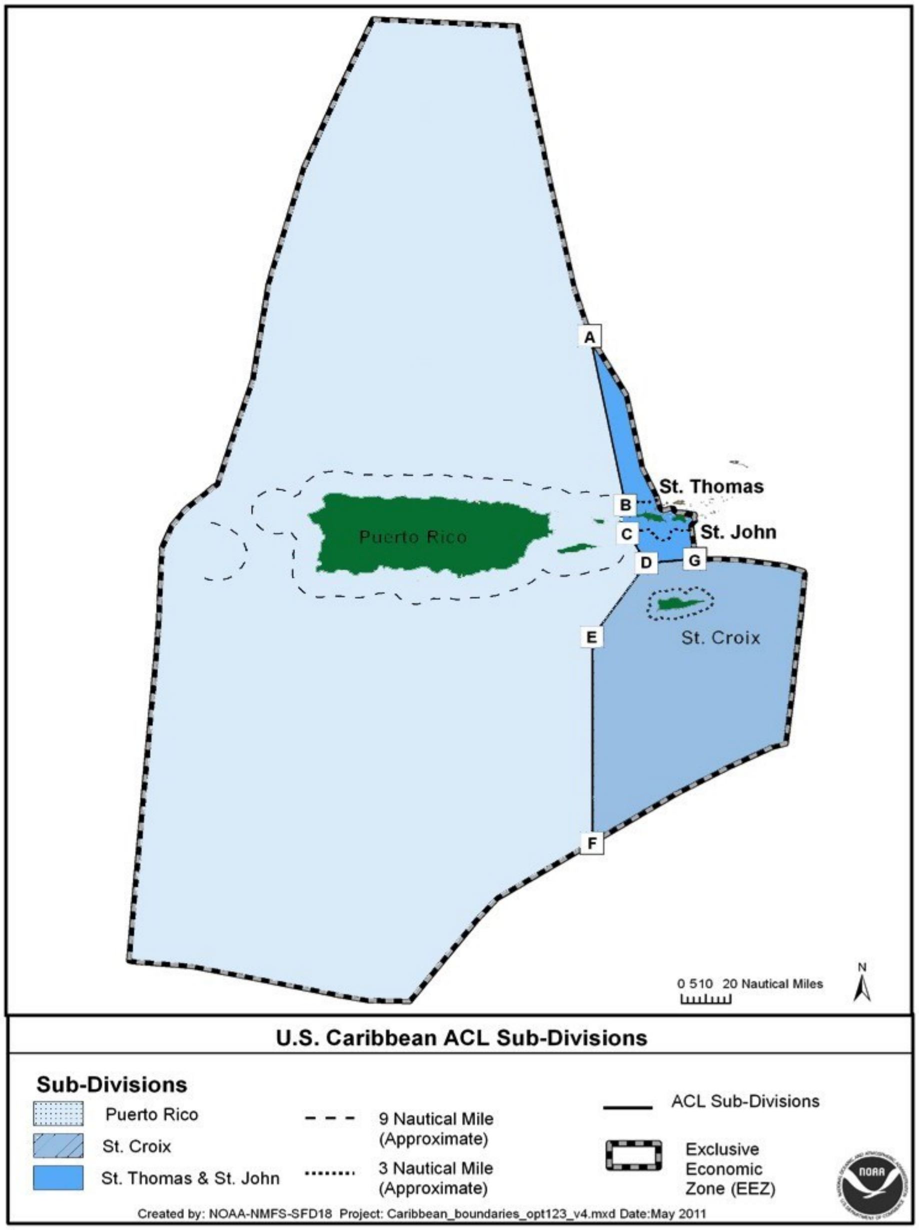
Structured management action plans can provide the information baseline of available resources, current uses of the coast, threats, and how to provide best management practices that align with a sustainable economic approach on the use of the resources. In addition, blue economy strategies like co-management of the marine reserve and protected areas can provide a socio-economic and sustainable benefit in the use of natural resources.

Fisheries Management

In Puerto Rico, fisheries management is regulated by various levels of authority. The CFMC, NOAA, and the U.S. Department of Commerce are responsible for developing management strategies for federal fisheries which reach 9-200 nm from the coast (Figure 39). Waters from the shore of Puerto Rico up to 9 nm are governed by the Commonwealth of Puerto Rico and managed by the DNER.

Fisheries and fishing communities are collectively managed by all these agencies who collaborate with fishermen and other stakeholders to create management plans and secure the conservation of these important ecosystems. A member from the DNER has a designated seat at the CFMC to facilitate the DNER's participation in the decision-making process for federal fishery management. This DNER participation helps promote federal and state regulations to remain as compatible as possible. However, discrepancies still arise (e.g., seasonal closures) that can confuse the public and that complicate the enforcement of regulations. Considering these discrepancies, the CFMC is currently trying to shift from a U.S. Caribbean-wide Fishery Management Plan

(FMP) to an island-based FMP for Puerto Rico. This change would provide a plan tailored to Puerto Rico's unique characteristics and would take into consideration the ecological, economic, and cultural profile of the island (Crabtree, 2019).



Marine fisheries in MPAs are generally managed to conserve, protect, and/or increase fish populations and prevent overfishing. The establishment of this new FMP would help identify potential management actions tailored for MPAs in Puerto Rico, including the GSF ME. There are different levels of fisheries management practices that include fishing gear restrictions, seasonal closures, and the creation of no-take zones within MPAs, among others. The level of fisheries management selected for GSF ME should consider the biological, ecological, and socio-economic data characteristic of the area to determine what type of management would work best to reach fisheries goals. The involvement and approval of the community is recommended to ensure the success of new management actions as a survey by PDC found that 86% of surveyed respondents of the GSF do not support the establishment of a no take zone (PDC Data, 2022).

Best Management Practices

Nature-based practices have been successfully implemented in Puerto Rico for the improvement of natural processes such as stormwater management, as well as management of land-based pollution and water quality improvement. The following best management practices (BMPs) are described with the intention of highlighting the potential these have in conserving the integrity of the ME. The following section describes options for BMP implementation within the following categories: stormwater treatment practices, nutrient reduction practices, soil stabilization practices, and pollution prevention practices.

The *Guánica Bay Watershed Management Plan: A Pilot Project for Watershed Planning in Puerto Rico* was developed to outline actions and create an overall management strategy to address and LBSP within the Guánica Bay Watershed. This plan is currently under revision, but provides preliminary data of possible BMPs that can help LBSP from entering Guánica Bay and subsequently affecting the ME. A list of potential projects within the watershed is included in Appendix C.

Stormwater Treatment Practices

Green infrastructure projects are constructed to intercept stormwater runoff and utilize plants (often native vegetation), soils and natural processes to filter and reduce runoff pollution. These practices can re-create wetlands and their natural processes to help reduce pollution sources. These practices would provide protection to the ME by reducing the amount of sediment that otherwise would be deposited on marine ecosystems such as coral reefs.

Rain Gardens

Rain gardens are vegetated depressions layered with engineered soil media that filter pollutants, increase the time water stays on the site, and provides stormwater storage (Figure 40). Rain garden systems usually have an underdrain to ensure the cell drains in a reasonable period of time. Although they are applicable in most settings, rain gardens are best used in small sites, urban areas, suburban areas, and parking lots.

Figure 40. Example of a rain garden prepared by PDC personnel at Jaboncillo Beach, Guánica. The red arrow indicates the influx of water following a rain event. Water passes through the vegetation where it reduces its speed while nutrients and sediments are retained.

Bioretention

As seen in Figure 41 (Vijayaraghavan *et al*., 2021), a stormwater bioretention or planter box system is often enclosed in a concrete container that contains porous soil media and vegetation to capture, detain, and filter stormwater runoff. Stormwater planter boxes are lined, contain an underdrain, have various small to medium plantings, and are installed below or at grade level to a street, parking lot or sidewalk. Runoff is directed to the stormwater planter, where water is filtered by vegetation before percolating into the ground or discharging through an underdrain. Stormwater is also used to irrigate trees or other vegetation in the planter box. In addition to stormwater control, stormwater planter boxes offer on-site stormwater runoff treatment and aesthetic value.

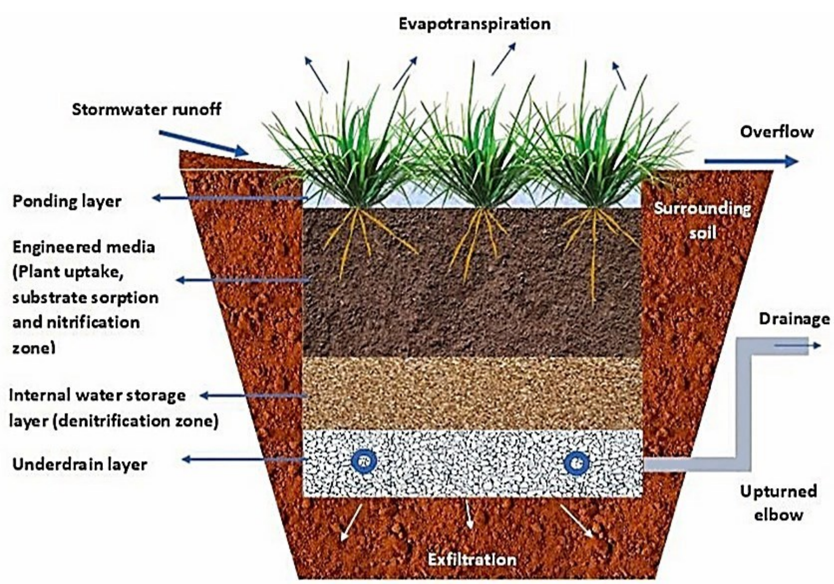


Figure 41. From "Bioretention systems for stormwater management: Recent advances and future prospects" by Vijayaraghavan *et al.*, 2021, Journal of Environmental Management, 292, p. 2. Schematic representation of a bioretention container. These systems are useful in urban areas with limited space and have multiple layers of soil media.

Stormwater planter boxes are optimal for urban or streetscape environments. When combined with nutrient reduction techniques, planter boxes help to reduce the negative impacts of sewage overflow into the storm drain system. Techniques can include the incorporation of various layers of different granulometry stone types, biochar, or woodchips.

Bioswales

Bioswales are similar to bioretention cells in design and function but are linear elements that can also be used for conveyance and storage in addition to their biofiltration function. They can be used anywhere and are best used on small sites, in urbanized and suburban commercial areas, residential areas, and parking lots.

Vegetated Swale

A vegetated swale is a wide, shallow channel with vegetation covering the sides and bottom. Swales are designed to convey and treat stormwater, promote infiltration, remove pollutants, and reduce runoff velocity (Figure 42). Vegetated swales mimic natural systems better than traditional drainage ditches. Vegetated swales can be used on sites that naturally cultivate a dense vegetative cover and have an appropriate area, slope, and infiltration potential. Swales are most effective when used in a treatment train with other green infrastructure techniques. They are widely used to convey and treat stormwater runoff from parking lots, roadways, and residential and commercial developments and are compatible with most land uses.

Figure 42. Example of a vegetated swale prepared by PDC personnel at Fulladosa, Culebra. In this design rocks were used along with the vegetation to create a channel.

Vegetated Filter Strip

A vegetated filter strip is a band of vegetation, usually a mix of grasses and native plants that acts as a buffer between an impervious surface and a waterway (Figure 43). They are designed to slow runoff from adjacent impervious surfaces, filter pollutants, and provide infiltration (depending upon the permeability of underlying soils). They can also provide aesthetic benefits, stormwater storage, and wildlife habitat. In addition to stormwater management, vegetated filter strips can add recreational value with opportunities to incorporate trails into their

Figure 43. Example of a vegetated filter strip prepared by PDC personnel at the facilities of PDC in Yauco, PR. This strip helps to redirect and filter rainwater before arriving at the nearby river.

design. Filter strips are best suited on sites that naturally support dense vegetation. Filter strips are best used in treating runoff from roads, roofs, small parking lots, and other small surfaces.

Nutrient Reduction Practices

Nutrient Reduction Practices (NRP) are a type of stormwater treatment practice that is used with the purpose of reducing nutrient concentrations on areas that are known to be sources of contamination with high nutrient content. NRP are designed to provide treatment for constant flows and are also commonly used to provide treatment from agricultural activities.

Treatment Wetlands

As seen in Figure 44 (Wang *et al.*, 2017), treatment wetlands are shallow depressions that receive flow inputs for water quality treatment. Long residence time allows nutrient pollutants removal processes to operate. The wetland environment provides an ideal environment for gravitational settling, biological uptake, and microbial activity. Treatment wetlands have become widely accepted as urban stormwater treatment practices and are increasingly being integrated into urban design practices. These types of systems provide a simple treatment solution for stormwater treatment while at the same time providing habitat for wildlife and aesthetic value to recreational areas such as parks.

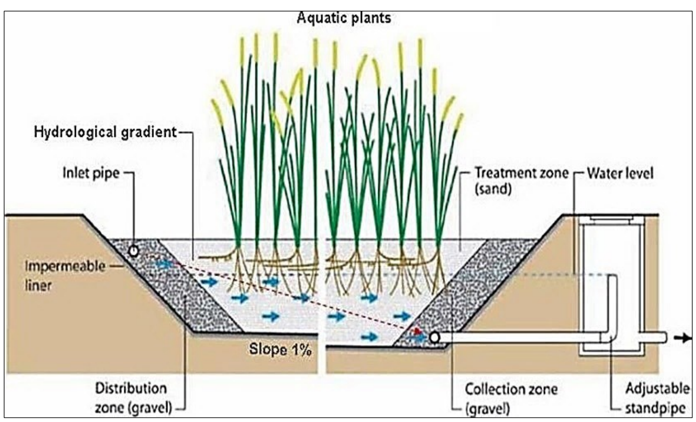


Figure 44. From "Constructed wetlands for wastewater treatment in cold climate — A review" by Wang *et al.* 2017, Journal of Environmental Sciences, 57, 293-311. Schematic representation of treatment wetlands. These are passive systems that help remove pollutants while providing habitat to wildlife and aesthetic value to the landscape.

Floating Treatment Wetlands

Floating Treatment Wetland is another type of treatment wetland. These are a variant of constructed wetland technology which consist of emergent wetland plants growing hydroponically on structures floating on the surface of a pond-like basin. They represent a means of potentially improving the treatment performance of conventional pond systems by integrating the beneficial aspects of emergent vegetation without being constrained by the requirement for shallow water depth. Floating treatment wetlands are a perfect solution for existing ponds that are too deep for wetland development.

Woodchip Bioreactor

Woodchip bioreactors were designed originally to treat wastewater from agricultural operations but can be adapted for use in addressing human wastewater. As seen in Figure 45 (López-Ponnada *et al.*, 2017), the main component of a woodchip bioreactor is a buried trench filled with woodchips. Using an in-line water control structure, water is diverted from a cesspool or septic system to the woodchip trench. The trench provides the proper environment (carbon from woodchips, nitrate-nitrogen from wastewater drainage, and low dissolved oxygen) to promote denitrification, a process that converts nitrate to the harmless nitrogen gas that makes up 70% of the air we breathe and is the same process that naturally occurs in wetlands and mangrove areas. Woodchip bioreactors are passive systems, located at the edges of farm fields or urban areas where they require little or no maintenance over their 15–20-year lifespan. The cost per pound of nitrogen removed is very low because of the extended life of the projects and the high efficiency of the system.

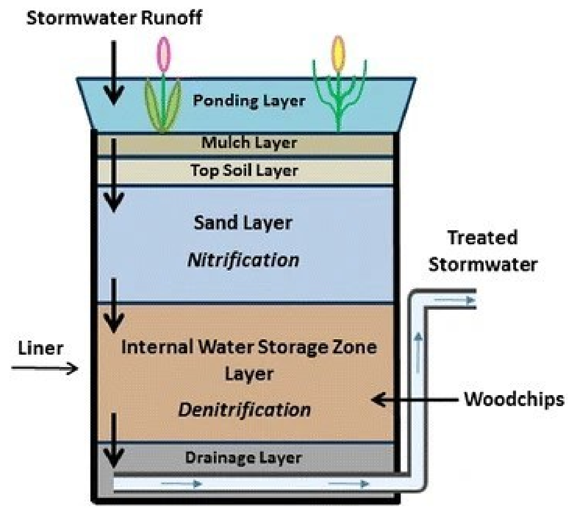


Figure 45. From "Application of denitrifying wood chip bioreactors for management of residential non-point sources of nitrogen" by López-Ponnada *et al.*, 2017. Journal of Biological Engineering. 11(1), 1-14. Schematic representation of a woodchip bioreactor. This system provides the proper environment to promote the denitrification of wastewater.

As summarized below, they are easy to implement and maintain, and are efficient, inexpensive, and effective.

- These practices are passive; the construction of the practice creates the conditions that biologically converts nitrate to nitrogen gas.

- They are typically constructed as an edge-of-field practice that takes very little land out of service and they are covered with a foot of soil and turf grass or native vegetation.
- They require little maintenance. Sediment must be cleaned out of the diversion box once or twice a year.
- They are highly efficient. Data from Iowa State and Maryland project have shown that over 90% of nitrate entering the system is converted to harmless nitrogen gas (Rosen and Christenson, 2017).
- When coupled with the addition of biochar they can also effectively reduce ammonia and phosphorus (Bock *et al.*, 2015; Ridge to Reefs, *pers. comm.*)

Soil Stabilization Practices

Stabilization of bare soils involves the rapid re-stabilization of vegetation and a general transition to more native and stable forms of vegetation. One effective way to re-establish vegetation in an area is to utilize hydroseeding followed by watering to rapidly transition to a more stable vegetated system where runoff is reduced. Dirt roads are stabilized using methods to remove water from the road and reduce erosion. All exposed soil and dirt roads transport sediment at a rate of 5x to 100x the natural transport rate from a forest or a field. Maximizing the number of treated roads and bare soil areas in the uplands of the watershed is a critical element as it reduces the impact of future dirt roads and new construction.

Hydroseeding

Figure 46. Example of hydroseeding application by PDC personnel at the facilities of Sartorius in Yauco, PR.

Hydroseeding refers to a process of planting grass using a mulch mixture that is fast, efficient, and an economic alternative to restore areas of high slopes with difficult access (Figure 46). This process has proven to be more effective than traditional sowing and with lower costs than conventional transplantation. A mulch mixture composed of fibers, seeds, fertilizer, and water is added to the tank of the hydroseeding machine. Once the appropriate mulch mixture is achieved, the mixture is pumped from the tank and applied on the soil. Once the materials encounter the soil, they easily adhere and create favorable conditions for seed germination. This method is mostly used to restore areas devoid of vegetation and affected by erosion processes and sedimentation, in order to protect bodies of water and marine ecosystems from the adverse effects of sediment laden runoff.

There are many available mulch options, including the most inexpensive (composed of 100% recycled paper or a mixture of 50% recycled paper and 50% wood fiber), intermediate costs (composed of 100% wood fiber), and the highest cost, bounded fiber matrix (composed of 100% wood fiber with added polymers and other additives that maximize its attachment to the soil). Typically, the mixture chosen depends on the degree of the slope, the available budget, and the quality of the desired product. Regular irrigation of restored areas during the first four to six weeks after Hydroseeding is necessary to obtain optimum results. Application should occur during dry periods, where heavy rain is not anticipated during 48 to 72 hours following application to allow product fixation to the soil.

Dirt Road Stabilization

Dirt roads are stabilized using methods to remove water from the road and reduce erosion. These include concrete or dirt cross-swales, check dams and sediment traps. Frequency of maintenance and the percentage of fine particles available for transport are key factors in sediment loss. Maintenance is defined as maintenance using heavy equipment backhoes and bulldozers, which results in considerable disturbance and exposure of fine soil particles. Transport factor is the ability of the sediment to be transported to the nearshore marine environment and to a lesser degree to be transported to coastal lagoons important for processing/trapping sediment and other contaminants before reaching the marine environment. A high transport factor has greater potential of leading to the marine environment, particularly with transport to coral reef communities.

Dirt roads can be stabilized using several BMPs depending on the slopes and available space. Based on our experience implementing BMPs, we can recommend that one practice on its own is not enough to observe an improvement. Instead, it is important to implement a series or combination of BMPs that are best suited for the location, while taking into consideration other factors such as slope gradients, soil type and composition. Examples include:

A. Sediment trapping techniques: work best when constructed with functional redundancy. Integrated sediment trapping is the most effective approach to manage sediment migration when compared with individual and combined measures alone. Sediment traps are constructed to help filter storm water that is causing erosion problems and discharging sediments (Figure 47).

Figure 47. Example of a sediment trap technique implemented by PDC personnel at the facilities of Sartorius in Yauco, PR.

B. Dirt road stabilization techniques: use fill material to stabilize the steep segments of roads. The fill material layer used for road stabilization contains small rocks and granulate materials that makes a good soil mixture for compaction. The use of this paving material is one of the most effective practices that can be implemented on dirt road stabilization as it is a cost-effective way of preventing road deterioration by rainfall and subsequent runoff and erosion problems. These techniques should be followed by a compacting roller the same day to prevent soil loss and damage to the work if a rain event occurs (Figure 48).

Figure 48. Example of dirt road stabilization techniques in Punta Soldado, Culebra, PR.

C. Vetiver grass: the use of this grass is a very simple, practical, inexpensive, low maintenance and effective means of soil and water conservation, sediment control, land stabilizations and rehabilitation. When planted in a linear pattern or in half-moons, vetiver plants will form a vegetative mass which is highly effective in slowing and spreading run off water, reducing soil erosion, conserving soil moisture, and trapping sediment on site. The extremely deep and massively thick root system of Vetiver binds the soil and at the same time makes it difficult for it to be displaced under high velocity water flows. It is a very deep and fast-growing plant that can also tolerate extreme drought conditions as well as moderate soil salinity concentrations with a highly effectiveness on steep slope stabilization. The most commonly available Vetiver plant material comes in small plots, but the best and more rapid results are achieved when plots are transplanted to a 1-gallon pot and grown for no less than 3 months. With this technique, planted

Figure 49. Vetiver grass in PDC's nursery in Yauco, PR.

Vetiver grass, responds more rapidly, and adapts to the site's climate conditions more efficiently and with less maintenance (Figure 49).

D. Regrading: this is the process of diverting road incline to desired topography to divert runoff to implemented BMPs. Incline of the road can be done to the inner, outside or both sides of the road depending on the treatment that will be constructed to deal with the runoff and the existing slope grade. This practice is highly recommended as it will be difficult to near impossible to implement other BMPs without regrading. All regarded roads should be compacted with a compacting roller the same day it has been regraded to prevent soil loss and damage to the work if a rain event occurs (Figure 50).

Figure 50. Example of regrading by PDC on a dirt road in Culebra, Puerto Rico.

E. Check dams: form barriers that prevent erosion and reduces sedimentation by slowing the velocity of water and filtering runoff (Figure 51). Check dams are best implemented in combination with a continuous swale along the inner side of the road. Check dams intersect flow at intervals of approximately 25 to 30 ft. depending on the slope. As stormwater runoff flows through the structure, the check dam catches sediment from the channel itself or from the contributing drainage area. They can be built from a combination of 8–12-inch stones and Vetiver grass. They are most effective when used with other stormwater, erosion, and sediment-control measures. Check dams also help redirect the flow

Figure 51. Example of check dams constructed by PDC on a dirt road network in Hacienda Candelaria located on the coffee region of Yauco Puerto Rico.

of sediments towards other practices implemented. Check dams are another cost-effective technique applicable for dirt road stabilization. If combined with the installation of erosion control blankets, vetiver grass and Hydroseeding (if the budget is available) check dams can work better and need less maintenance.

Pollution Prevention Practices

Pollution prevention includes measures that help reduce pollution from existing and future sources of pollution by taking a proactive preventative approach and working directly with key entities and individuals that may be responsible for pollution. This includes increased detection and elimination of illicit discharges, increased erosion and sediment control training workshops and door-to-door surveys of areas where water pollution is persistent to determine whether homes are properly connected to sewer or whether they have failing septic systems. These steps are critical to effectively safeguard the natural resources of the ME.

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Appendix A

Summary of the benthic composition by major category and species for study sites in percent (%)*.

I. South of Guánica Bay sites

MAJOR CATEGORY (of transect)	Gu 1-2	Gu 3-4	Gu 5-6	Gu 7-8	Gu 9-10
OCTOCORAL (OCTO)	0.0	0.0	1.1	3.1	18.8
CYANOBACTERIA (CYAN)	0.1	0.0	0.0	0.0	0.0
CORAL (C)	3.7	0.6	5.5	8.2	6.4
GORGONIANS (G)	0.1	0.7	0.1	0.3	2.0
SPONGES (S)	5.4	2.4	6.3	7.4	6.5
MACROALGAE (MA)	52.5	45.7	38.8	40.1	3.6
OTHER LIVE (OL)	0.0	0.2	0.0	0.1	0.0
DEAD CORAL WITH ALGAE (DCA)	0.1	0.1	0.3	0.6	0.9
CORALLINE ALGAE (CA)	0.2	0.1	0.8	1.1	0.1
SAND, PAVEMENT, RUBBLE (SPR)	37.9	50.3	47.1	39.1	61.7
CORAL (C)					
Acropora cervicornis (AC)	0.0	0.3	0.0	0.0	0.0
Pseudodiploria clivosa (DC)	2.3	0.0	0.6	0.1	1.0
Pseudodiploria strigosa (DS)	0.4	0.0	0.0	0.7	1.1
Millepora alcicornis (MILA)	0.0	0.1	0.1	1.2	0.8
Orbicella faveolata (MFAV)	0.0	0.1	0.0	0.0	0.0
Porites astreoides (PA)	0.3	0.0	1.5	4.6	1.0
Porites divaricata (PD)	0.0	0.0	0.0	0.3	0.0
Porites furcata (PF)	0.0	0.0	0.3	0.0	0.0
Siderastrea siderea (SS)	0.8	0.2	3.0	1.4	2.3
OCTOCORAL (OCTO)					
Gorgonian (GORG)	0.1	0.7	0.1	0.3	2.0
Other Sp.	0.0	0.0	1.1	3.1	18.8
SPONGES (S)					
Chondrilla nucula (CHNU)	0.0	0.0	0.0	0.1	0.0
Cliona (CLIO)	0.9	0.0	1.8	1.5	2.9
Other Sp.	4.5	2.4	4.5	5.8	3.6
MACROALGAE (MA)					
Dictyota (DICT)	2.8	36.3	6.6	26.3	1.0
Halimeda (HALI)	0.1	2.5	1.0	1.9	0.6
Other Sp.	1.7	6.0	0.8	5.7	0.1
Padina (PAD)	0.0	0.0	0.3	5.9	2.0
Sargassum (SARG)	47.9	0.8	30.2	0.1	0.1
Udotea sp (UDO)	0.0	0.1	0.0	0.1	0.0
SAND, PAVEMENT, RUBBLE (SPR)					
Bottom covered with algae (BA)	1.7	0.0	1.3	2.0	4.1
Pavement (P)	33.9	4.9	41.8	36.5	57.0
Rubble (R)	1.8	0.3	0.8	0.6	0.6
Sand (S)	0.5	45.2	3.2	0.0	0.0

A. Original data is available upon request.

II. <u>Cayo Aurora</u>

A. Transects

MAJOR CATEGORY (of transect)	Au 1-2	Au 3-4	Au 5--6	Au 7-8	Au 9-10
OCTOCORAL (OCTO)	7.3	27.9	35.6	18.4	2.7
SEAGRASSES (GRASS)	0.0	0.0	0.0	0.0	0.0
CORAL (C)	7.2	8.1	18.2	9.5	1.1
GORGONIANS (G)	8.4	3.4	1.1	2.0	1.4
SPONGES (S)	9.2	4.8	5.4	2.3	5.9
ZOANTHIDS (Z)	0.5	2.0	2.2	4.5	0.1
MACROALGAE (MA)	20.9	0.2	0.2	0.4	9.6
OTHER LIVE (OL)	0.1	0.0	0.0	0.1	0.0
DEAD CORAL WITH ALGAE (DCA)	0.0	3.0	2.0	0.1	0.1
CORALLINE ALGAE (CA)	0.0	3.0	0.2	1.8	0.0
SAND, PAVEMENT, RUBBLE (SPR)	46.5	47.8	35.3	60.8	79.1
<u>CORAL (C)</u>					
Acropora cervicornis (AC)	0.7	1.5	5.3	0.0	0.0
Agaricia grahamae (AG)	0.0	0.0	0.0	0.1	0.0
Pseudodiploria clivosa (DC)	1.1	1.0	2.5	0.3	1.1
Pseudodiploria strigosa (DS)	1.5	1.2	4.7	0.6	0.0
Madracis decactis (MD)	0.0	0.0	0.0	0.8	0.0
Millepora alcicornis (MILA)	0.8	2.2	0.1	0.1	0.0
Montastraea cavernosa (MC)	0.0	1.2	1.7	3.8	0.0
Orbicella faveolata (MFAV)	0.0	0.0	0.0	1.7	0.0
Porites astreoides (PA)	0.7	0.8	1.2	1.7	0.0
Porites furcata (PF)	0.0	0.0	0.1	0.0	0.0
Porites porites (PP)	0.5	0.0	0.0	0.0	0.0
Siderastrea radians (SR)	0.4	0.1	0.0	0.0	0.0
Siderastrea siderea (SS)	1.5	0.2	1.8	0.2	0.0
Stephanocoenia michelinii (SM)	0.0	0.0	1.1	0.3	0.0
OCTOCORAL (OCTO)					
Erythropodium (ERY)	0.0	0.6	1.4	1.3	0.1
Gorgonian (GORG)	8.4	3.4	1.1	2.0	1.4
Other Sp.	7.3	27.3	34.3	17.1	2.7
SPONGES (S)					
Cliona (CLIO)	5.1	0.0	0.0	0.0	0.0
Other Sp.	4.1	4.8	5.4	2.3	5.9
MACROALGAE (MA)					
Caulerpa sp (CAU)	1.1	0.0	0.0	0.0	0.0
Dictyota (DICT)	17.4	0.0	0.0	0.0	9.5
Halimeda (HALI)	1.4	0.2	0.1	0.4	0.0
Other Sp.	1.0	0.0	0.1	0.0	0.1
SAND, PAVEMENT, RUBBLE (SPR)					
Bottom covered with algae (BA)	22.2	8.4	4.5	21.4	2.8
Pavement (P)	10.3	22.4	27.2	17.6	29.9
Rubble (R)	1.2	14.8	0.8	0.0	1.5
Sand (S)	12.8	2.2	2.9	21.8	44.9

B. Original data is available upon request.

C. Random Waypoints

MAJOR CATEGORY (of transect)	R Au1	R Au2	R Au3	R Au4	R Au5
OCTOCORAL (OCTO)	0.0	0.0	0.0	0.0	0.0
SEAGRASSES (GRASS)	48.3	20.3	81.8	0.0	86.3
CORAL (C)	0.0	0.0	0.0	0.0	0.0
GORGONIANS (G)	0.0	0.0	0.0	0.0	0.0
SPONGES (S)	0.0	0.0	0.0	0.0	0.0
ZOANTHIDS (Z)	0.0	0.0	0.0	0.0	0.0
MACROALGAE (MA)	12.8	0.0	1.3	14.5	0.0
OTHER LIVE (OL)	0.0	0.0	0.0	0.0	0.0
DEAD CORAL WITH ALGAE (DCA)	0.0	0.0	0.0	0.0	0.0
CORALLINE ALGAE (CA)	0.0	0.0	0.0	0.0	0.0
SAND, PAVEMENT, RUBBLE (SPR)	39.0	79.7	17.0	85.5	13.8
CORAL (C)					
Acropora cervicornis (AC)	0.0	0.0	0.0	0.0	0.0
Agaricia grahamae (AG)	0.0	0.0	0.0	0.0	0.0
Pseudodiploria clivosa (DC)	0.0	0.0	0.0	0.0	0.0
Pseudodiploria strigosa (DS)	0.0	0.0	0.0	0.0	0.0
Madracis decactis (MD)	0.0	0.0	0.0	0.0	0.0
Millepora alcicornis (MILA)	0.0	0.0	0.0	0.0	0.0
Montastraea cavernosa (MC)	0.0	0.0	0.0	0.0	0.0
Orbicella faveolata (MFAV)	0.0	0.0	0.0	0.0	0.0
Porites astreoides (PA)	0.0	0.0	0.0	0.0	0.0
Porites furcata (PF)	0.0	0.0	0.0	0.0	0.0
Porites (PP)	0.0	0.0	0.0	0.0	0.0
Siderastrea radians (SR)	0.0	0.0	0.0	0.0	0.0
Siderastrea siderea (SS)	0.0	0.0	0.0	0.0	0.0
Stephanocoenia michelinii (SM)	0.0	0.0	0.0	0.0	0.0
OCTOCORAL (OCTO)					
Erythropodium (ERY)	0.0	0.0	0.0	0.0	0.0
Gorgonian (GORG)	0.0	0.0	0.0	0.0	0.0
Other Sp.	0.0	0.0	0.0	0.0	0.0
SPONGES (S)					
Cliona (CLIO)	0.0	0.0	0.0	0.0	0.0
Other Sp.	0.0	0.0	0.0	0.0	0.0
MACROALGAE (MA)					
Caulerpa sp (CAU)	0.0	0.0	0.0	0.0	0.0
Dictyota (DICT)	0.0	0.0	0.0	0.0	0.0
Halimeda (HALI)	0.0	0.0	0.0	3.8	0.0
Other Sp.	12.8	0.0	1.3	10.8	0.0
SAND, PAVEMENT, RUBBLE (SPR)					
Bottom covered with algae (BA)	2.0	0.0	0.3	0.0	0.0
Pavement (P)	0.0	0.0	0.0	0.0	0.0
Rubble (R)	0.0	0.0	0.0	0.0	0.0
Sand (S)	37.0	79.7	16.8	85.5	13.8

D. Original data is available upon request.

III. Ballena Beach

A. Transects

MAJOR CATEGORY (of transect)	Ba 3-4	Ba 5-6	Ba 7-8	Ba 9-10
OCTOCORAL (OCTO)	0.4	20.7	0.0	7.6
CORAL (C)	5.2	8.2	0.0	0.4
GORGONIANS (G)	2.2	1.2	0.0	1.7
SPONGES (S)	2.7	1.8	0.0	4.7
ZOANTHIDS (Z)	0.0	7.0	0.0	0.0
MACROALGAE (MA)	55.7	0.0	26.6	1.1
OTHER LIVE (OL)	1.4	0.0	0.0	0.4
DEAD CORAL WITH ALGAE (DCA)	0.1	0.2	0.0	0.0
CORALLINE ALGAE (CA)	0.1	0.0	0.0	0.1
SAND, PAVEMENT, RUBBLE (SPR)	32.3	60.9	73.4	84.0
CORAL (C)				
Pseudodiploria clivosa (DC)	3.6	0.5	0.0	0.0
Pseudodiploria strigosa (DS)	1.1	2.3	0.0	0.0
Millepora alcicornis (MILA)	0.2	0.3	0.0	0.0
Montastraea cavernosa (MC)	0.0	0.1	0.0	0.3
Orbicella faveolata (MFAV)	0.0	3.3	0.0	0.0
Porites astreoides (PA)	0.2	0.5	0.0	0.0
Porites porites (PP)	0.1	0.0	0.0	0.0
Siderastrea siderea (SS)	0.0	1.2	0.0	0.1
OCTOCORAL (OCTO)				
Gorgonian (GORG)	2.2	1.2	0.0	1.7
Other Sp.	0.4	20.7	0.0	7.6
SPONGES (S)				
Other Sp.	2.7	1.8	0.0	4.7
MACROALGAE (MA)				
Dictyota (DICT)	55.2	0.0	0.0	1.0
Halimeda (HALI)	0.3	0.0	0.0	0.0
Other Sp.	0.2	0.0	26.6	0.1
SAND, PAVEMENT, RUBBLE (SPR)				
Bottom covered with algae (BA)	2.7	1.8	0.0	39.8
Pavement (P)	24.0	43.4	0.0	43.5
Rubble (R)	0.4	9.2	0.0	0.3
Sand (S)	5.3	6.5	73.4	0.5

B. Original data is available upon request.

C. Random Waypoints

MAJOR CATEGORY (of transect)	R Ba 1	R Ba 2	R Ba 3	R Ba 4
OCTOCORAL (OCTO)	1.0	0.0	0.0	1.9
CORAL (C)	2.8	0.0	0.0	3.6
GORGONIANS (G)	1.0	0.0	0.0	8.0
SPONGES (S)	0.3	0.0	0.0	0.3
ZOANTHIDS (Z)	0.3	0.0	0.0	0.8
MACROALGAE (MA)	7.5	0.0	0.0	0.0
OTHER LIVE (OL)	0.0	0.0	0.0	0.0
DEAD CORAL WITH ALGAE (DCA)	0.5	0.0	0.0	7.3
CORALLINE ALGAE (CA)	0.3	0.0	0.0	0.0
SAND, PAVEMENT, RUBBLE (SPR)	86.5	100.0	100.0	78.3
CORAL (C)				
Pseudodiploria clivosa (DC)	0.3	0.0	0.0	0.0
Pseudodiploria strigosa (DS)	0.0	0.0	0.0	2.0
Millepora alcicornis (MILA)	0.0	0.0	0.0	0.0
Montastraea cavernosa (MC)	0.0	0.0	0.0	0.0
Orbicella faveolata (MFAV)	0.0	0.0	0.0	0.0
Porites astreoides (PA)	0.0	0.0	0.0	0.5
Porites porites (PP)	0.0	0.0	0.0	0.0
Siderastrea siderea (SS)	2.5	0.0	0.0	1.1
OCTOCORAL (OCTO)				
Gorgonian (GORG)	1.0	0.0	0.0	8.0
Other Sp.	1.0	0.0	0.0	1.9
SPONGES (S)				
Other Sp.	0.3	0.0	0.0	0.3
MACROALGAE (MA)				
Dictyota (DICT)	0.0	0.0	0.0	0.0
Halimeda (HALI)	0.0	0.0	0.0	0.0
Other Sp.	7.5	0.0	0.0	0.0
SAND, PAVEMENT, RUBBLE (SPR)				
Bottom covered with algae (BA)	36.0	0.0	0.0	34.6
Pavement (P)	0.0	0.0	0.0	0.0
Rubble (R)	0.0	0.0	0.0	0.0
Sand (S)	50.5	100.0	100.0	43.6

D. Original data is available upon request.

Appendix B

Location of transect and random waypoints used for benthic characterization with drop camera. * = data for the transect originally identified as Ba1-2 were not collected due to its shallowness (<1m depth) and risk to the research vessel.

ID	Location	LAT	LON	Date Sampled
Au 1	Cayo Aurora	17.94145	-66.88451667	1/23/2020
Au 2	Cayo Aurora	17.94145	-66.8848	1/23/2020
Au 3	Cayo Aurora	17.93651667	-66.86848333	1/23/2020
Au 4	Cayo Aurora	17.93653333	-66.86823333	1/23/2020
Au 5	Cayo Aurora	17.9377	-66.8633	1/23/2020
Au 6	Cayo Aurora	17.93778333	-66.86306667	1/23/2020
Au 7	Cayo Aurora	17.94121667	-66.85773333	1/23/2020
Au 8	Cayo Aurora	17.94125	-66.85746667	1/23/2020
Au 9	Cayo Aurora	17.94398333	-66.85601667	1/23/2020
Au 10	Cayo Aurora	17.94396667	-66.85573333	1/23/2020
R Au 1	Cayo Aurora	17.9404	-66.89195	1/23/2020
R Au 2	Cayo Aurora	17.94413333	-66.89258333	1/23/2020
R Au 3	Cayo Aurora	17.94935	-66.8844	1/23/2020
R Au 4	Cayo Aurora	17.94863333	-66.87148333	1/23/2020
R Au 5	Cayo Aurora	17.94593333	-66.87176667	1/23/2020
Ba 1*	Ballena	17.95375	-66.85195	Not sampled
Ba 2*	Ballena	17.95366667	-66.85171667	Not sampled
Ba 3	Ballena	17.95208333	-66.85056667	1/24/2020
Ba 4	Ballena	17.95233333	-66.85108333	1/24/2020
Ba 5	Ballena	17.94246667	-66.84223333	1/24/2020
Ba 6	Ballena	17.94246667	-66.84196667	1/24/2020
Ba 7	Ballena	17.94633333	-66.83991667	1/24/2020
Ba 8	Ballena	17.94633333	-66.8396	1/24/2020
Ba 9	Ballena	17.94698333	-66.8278	1/24/2020
Ba 10	Ballena	17.947	-66.82746667	1/24/2020
R Ba 1	Ballena	17.95468333	-66.8535	1/24/2020
R Ba 2	Ballena	17.95488333	-66.85673333	1/24/2020
R Ba 3	Ballena	17.95046667	-66.86048333	1/24/2020
R Ba 4	Ballena	17.95373333	-66.8532	1/24/2020
Gu 1	Guánica	17.93001667	-66.89606667	1/23/2020
Gu 2	Guánica	17.93003333	-66.89578333	1/23/2020
Gu 3	Guánica	17.92895	-66.88795	1/23/2020
Gu 4	Guánica	17.92891667	-66.88766667	1/23/2020
Gu 5	Guánica	17.92653333	-66.89578333	1/23/2020
Gu 6	Guánica	17.92653333	-66.8955	1/23/2020
Gu 7	Guánica	17.924	-66.88923333	1/23/2020
Gu 8	Guánica	17.92398333	-66.88895	1/23/2020
Gu 9	Guánica	17.9207	-66.88568333	1/23/2020
Gu 10	Guánica	17.92065	-66.88536667	1/23/2020

Appendix C

Summary of potential best management practices within the GBW.

RECOMMENDED STORMWATER TREATMENT PRACTICES

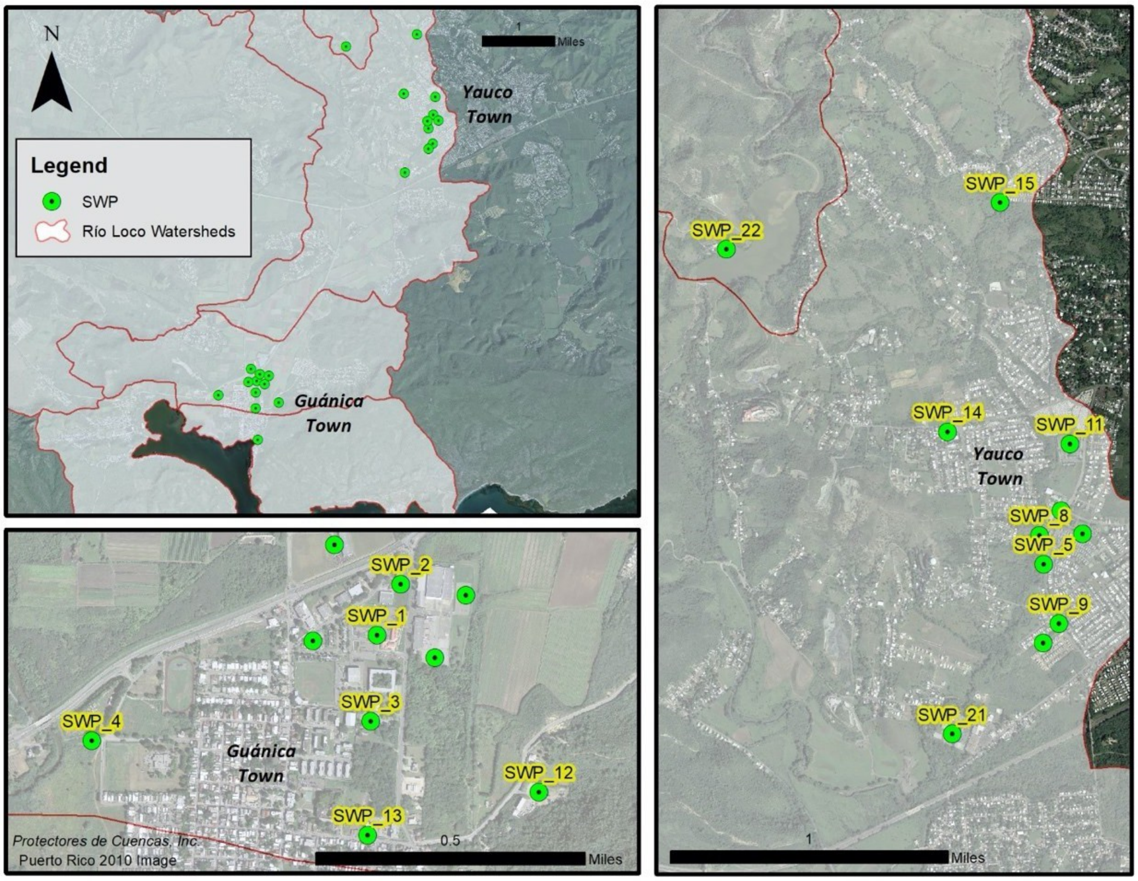

Figure 52. Map highlighting 22 potential locations where Stormwater Treatment Practices could be implemented within the GBW.

Table 3. List and description of proposed projects for stormwater treatment in the GBW.

ID	Observations	Estimated % Impervious Cover	Estimated Drainage Area (acres)	GPS coordinates	Type	Ownership	Existing Land Use	Sewer Infrastructure Service?
SWP_1	Multiple areas for BMP implementation with onsite modifications.	90%	5	17.976806° -66.904928°	Parking area	Public	Urban Commercial	Yes
SWP_2	Multiple areas for BMP implementation. Adjacent green area for potential additional treatment.	100%	1	17.978183° -66.904266°	Parking area	Private	Urban Commercial	Yes
SWP_3	Multiple areas for BMP implementation. Adjacent green area for potential additional treatment.	100%	6	17.974480° -66.905108°	Parking area	Public	Urban Institutional	Yes
SWP_4	Limited areas for BMP implementation. Adjacent green area for potential additional treatment.	100%	2	17.973930° -66.912983°	Public Works area	Public	Urban Industrial	Yes
SWP_5	Multiple areas for BMP implementation. Multiple landowners.	100%	20	18.027784° -66.868932°	Roadside	Public	High Density Urban	Yes
SWP_6	Multiple areas for BMP implementation	75%	6	18.030575° -66.867988°	Parking	Public	High Density Urban Institutional	Yes
SWP_7	Multiple areas for BMP implementation.	75%	6	18.029363 - 66.866801	Parking	Public	Urban Residential	Yes

ID	Observations	Estimated % Impervious Cover	Estimated Drainage Area (acres)	GPS coordinates	Type	Ownership	Existing Land Use	Sewer Infrastructure Service?
SWP_8	Suitable area for BMP implementation.	75%	2	18.029290° -66.869146°	Parking	Public	High Density Urban, Institutional	Yes
SWP_9	Limited area for BMP implementation.	100%	2	18.024671° -66.868088°	Road	Public	High Density Urban	Yes
SWP_10	Suitable area for BMP implementation.	100%	20	18.023650° -66.868943°	Drainage	Public	High Density Urban, Residential	Yes
SWP_11	Multiple areas for BMP implementation.	75%	7	18.034086 - 66.867494	Parking	Public	High Density Urban, Residential	Yes
SWP_12	Suitable area for BMP implementation.	40%	3	17.972568° -66.900347°	Public Works Area	Public	Medium Density Urban	Yes
SWP_13	Suitable area for BMP implementation.	75%	3	17.971392° -66.905182°	Green areas, Parking	Public	Low density Urban Institutional	Yes
SWP_14	Multiple areas for BMP implementation.	100%	2	18.034712° -66.874201°	Parking	Private	High Density Urban Industrial	Yes
SWP_15	Multiple areas for BMP implementation. Adjacent Public Land has the potential additional treatment.	100%	20	18.046739° -66.871368°	Resident	Public	Medium Density Urban, Residential	Yes
SWP_16	Suitable area for BMP implementation.	100%	6	17.977887 - 66.902434	Parking	Public	High Density Urban, Industrial	Yes
SWP_17	Multiple areas for BMP implementation.	100%	4	17.976202° -66.903299°	Parking	Public	High Density Urban, Industrial	Yes

ID	Observations	Estimated % Impervious Cover	Estimated Drainage Area (acres)	GPS coordinates	Type	Ownership	Existing Land Use	Sewer Infrastructure Service?
SWP_18	Multiple areas for BMP implementation.	75%	4	17.976652° -66.906747°	Parking, Green areas	Public	High Density Urban, Residential	Yes
SWP_19	Limited areas for BMP implementation.	100%	2	17.979250° -66.906142°	Community Outfall	Public	High Density Urban, Industrial	Yes
SWP_20	Limited areas for BMP implementation.	100%	3	17.965004° -66.904703°	Parking	Public	High Density Urban, Residential	Yes
SWP_21	Multiple areas for BMP implementation.	100%	3	18.018864° -66.873909°	Parking	Private	Medium Density Urban, Commercial	No
SWP_22	Multiple areas for BMP implementation. Adjacent Public Land has the potential additional treatment.	40%	6	18.044255° -66.886342°	Public Park	Public	Low Density Urban, Residential	No

Table 4. List of recommended actions for stormwater treatment in the GBW.

ID	BMP types	Cost scale	Est. cost range ($K)	Est. % engineering design	Topo survey	H&H study	Permits/Authorization	Possible funding partners	Possible matching partner
SWP_1	Bioretention, Raingarden, Bioswale	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal	EPA, NOAA, DNER, EQB, NFWF, Municipality	PDC, Municipality
SWP_2	Bioretention, Raingarden, Bioswale	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Landowner	EPA, NOAA, DNER, NFWF, Municipality	PDC, Municipality, Burger King
SWP_3	Bioretention, Raingarden, Bioswale	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Public Buildings Authority	EPA, NOAA, DNER, NFWF	PDC, Municipality
SWP_4	Bioretention, Raingarden, Bioswale	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal	EPA, NOAA, DNER, NFWF, Municipality	PDC, Municipality
SWP_5	Bioretention, Raingarden	Small	46→65	30%	Simple	No	General Construction Permit, Municipal	EPA, NOAA, DNER, NFWF, Municipality	PDC, Municipality
SWP_6	Bioretention, Raingarden, Bioswale	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal, Public Buildings Authority	EPA, NOAA, DNER, NFWF, Municipality	PDC, Municipality, Public Buildings Authority
SWP_7	Bioretention, Raingarden, Bioswale	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal, Public Buildings Authority	EPA, NOAA, DNER, Municipality	PDC, Municipality, Public Buildings Authority
SWP_8	Bioretention, Bioswale, Raingarden	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal, Public Buildings Authority	NRCS, EPA, NOAA, USFS, DNER	PDC, Municipality, Public Buildings Authority
SWP_9	Bioretention, Bioswale	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal	EPA, NOAA, DNER, Municipality	PDC, Municipality
SWP_10	Bioretention, Bioswale	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal	NRCS, EPA, NOAA, DNER, NFWF, Municipality	PDC, Municipality

ID	BMP types	Cost scale	Est. cost range ($K)	Est. % engineering design	Topo survey	H&H study	Permits/Authorization	Possible funding partners	Possible matching partner
SWP_11	Bioretention, Bioswale, Raingardens	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal, Public Buildings Authority	NRCS, EPA, NOAA, DNER, NFWF, Municipality	PDC, Municipality, Public Buildings Authority
SWP_12	Bioretention, Bioswale, Rain Garden	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal	EPA, NOAA, DNER, NFWF, Municipality	PDC, Municipality
SWP_13	Bioretention, Bioswale, Rain Garden	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal, Public Buildings Authority	EPA, NOAA, USFS, DNER, NFWF, Municipality	PDC, Municipality, Public Buildings Authority
SWP_14	Bioretention, Raingarden, Rain Garden	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal, Landowner	EPA, NOAA, USFS, DNER, NFWF,	PDC, Municipality, Landowner
SWP_15	Bioretention, Bioswale, Raingarden	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal, Adjacent Landowners	EPA, NOAA, USFS, DNER, NFWF, Municipality	PDC, Municipality, Landowners,
SWP_16	Bioretention, Bioswale	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal	EPA, NOAA, USFS, DNER, NFWF, Municipality	PDC, Municipality
SWP_17	Bioretention, Bioswale	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal	EPA, NOAA, USFS, DNER, NFWF, Municipality	PDC, Municipality
SWP_18	Bioretention, Bioswale, Raingarden	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal, Adjacent Landowners	EPA, NOAA, USFS, DNER, NFWF, Municipality	PDC, Municipality, Landowners,
SWP_19	Bioretention, Bioswale	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal	EPA, NOAA, USFS, DNER, NFWF, Municipality	PDC, Municipality
SWP_20	Bioretention, Bioswale	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal	EPA, NOAA, USFS, DNER, NFWF, Municipality	PDC, Municipality

ID	BMP types	Cost scale	Est. cost range ($K)	Est. % engineering design	Topo survey	H&H study	Permits/Authorization	Possible funding partners	Possible matching partner
SWP_21	Bioretention, Bioswale	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal, Landowner	EPA, NOAA, USFS, DNER, NFWF, Municipality	PDC, Municipality, Landowner
SWP_22	Bioretention, Bioswale, Rain Garden	Small	25→45	30%	Simple	No	NEPA, General Construction Permit, Municipal	EPA, NOAA, USFS, DNER, NFWF, Municipality	PDC, Municipality

Recommended Nutrient Reduction Projects

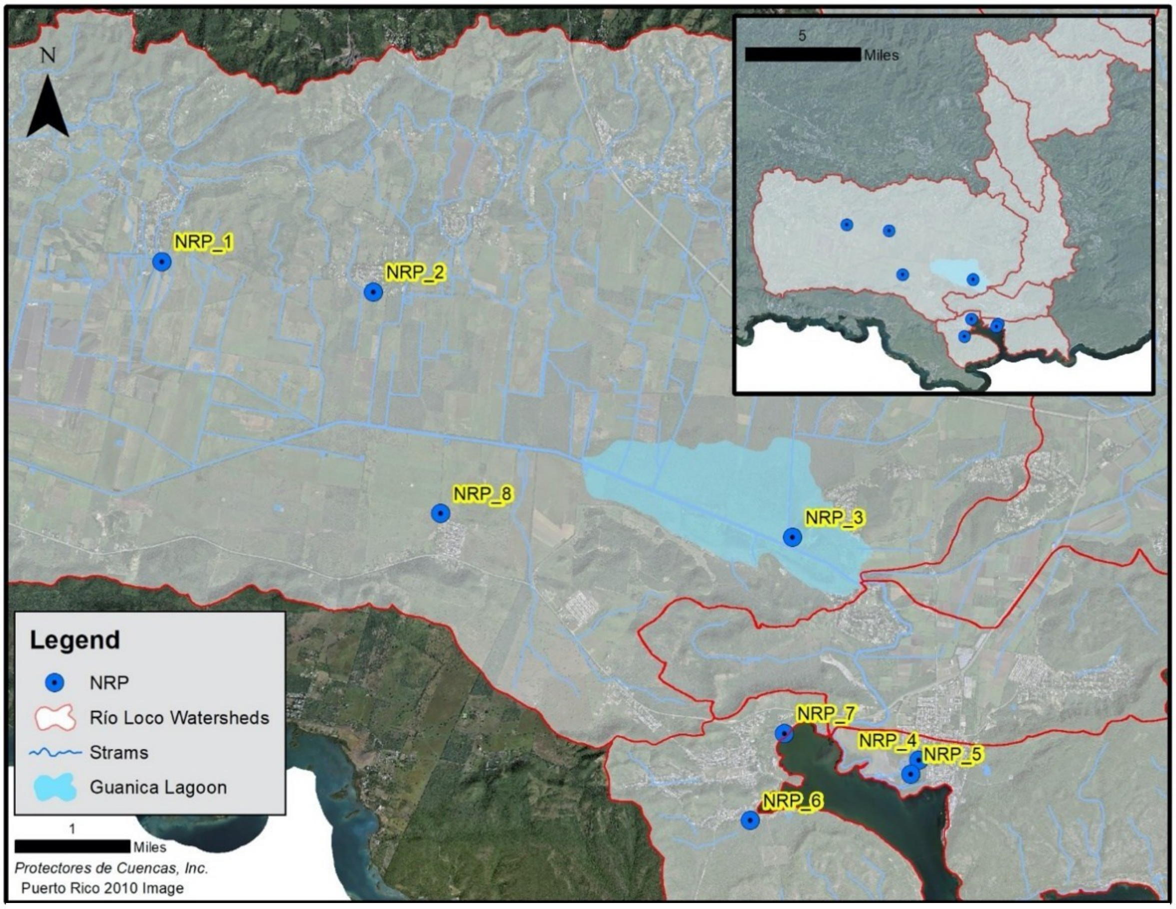

Table 5. List and description of proposed projects for nutrient reduction practices in the GBW.

ID	Observations	Estimated Treatment Practice area (acres)	Estimated Drainage Area (acres)	GPS coordinates	Type	Ownership	Existing Land Use	Sewer Infrastructure Service?
NRP_1	Enough available area with apparent topographic condition suitable for Treatment Wetlands implementation.	4	80	18.031164° -67.010402°	Community Outfall	Public	Urban, Agriculture	No
NRP_2	Enough available area with apparent topographic condition suitable for Treatment Wetlands implementation.	3	30	18.027366° -66.982361°	Community Outfall	Public	Urban, Agriculture	No
NRP_3	Guánica Lagoon Restoration Project	900	9,800	17.996365° -66.926573°	Wetland	Public	Urban, Agriculture	No
NRP_4	Guánica Sewage Treatment Plant Treatment Wetland Project. Project has started but has no funds for completion	7	N/A	17.968099° -66.909793°	Treatment Wetland	Public	Urban	Yes
NRP_5	Enough available area with apparent topographic condition suitable for Treatment Wetlands implementation.	10	100	17.966343° -66.910853°	Community Outfall	Public	Urban	Yes
NRP_6	Sufficient available area with apparent topographic condition suitable for Treatment Wetlands implementation. Residential area with direct sewage outfall to the Guánica Bay	3	20	17.960412° -66.932116°	Community Outfall	Public	Urban	No
NRP_7	Limited area for project implementation. Installation of sealed septic tanks for truck service. Hotel and Institutional area.	N/A	8	17.971449° -66.927629°	Community Outfall	Public	Urban	No
NRP_8	Enough available area with apparent topographic condition	2	60	17.999281° -66.973336°	Community Outfall	Public	Urban, Agriculture	No

ID	Observations	Estimated Treatment Practice area (acres)	Estimated Drainage Area (acres)	GPS coordinates	Type	Ownership	Existing Land Use	Sewer Infrastructure Service?
	suitable for Treatment Wetlands implementation.							

Table 6. List of proposed projects and recommended nutrient reduction practices in the GBW.

ID	BMP types	Cost scale	Estimated cost range ($K)	Estimated Engineering Design (%)	Topo. Survey	H&H Study	Permits/ Authorization	Possible Funding Partners	Possible Matching Partner
NRP_1	Treatment Wetlands	Small	106→125	100%	Detailed	Yes	NEPA, General Construction Permit, Municipal/ PRASA	EPA, NOAA, DNER, NFWF, EQB, Municipality	PDC, Municipality, PRASA
NRP_2	Treatment Wetlands	Small	106→125	100%	Detailed	Yes	NEPA, ACOE, General Construction Permit, Municipal/Land Authority	EPA, NOAA, DNER, NFWF, Municipality	PDC, Municipality, Land Authority
NRP_3	Lagoon Restoration	Large	546→	100%	Detailed	Yes	NEPA, ACOE, General Construction Permit, Municipal/Land Authority	EPA, NOAA, DNER, NFWF, USFWS, Municipality	PDC, Municipality, Land Authority, DNER
NRP_4	Treatment Wetlands	Medium	266→305	100% Completed	Detailed Completed	Yes Completed	NEPA, ACOE, General Construction Permit, Municipal/Land Authority (Completed)	EPA, NOAA, DNER, NFWF, Municipality	PDC, Municipality, PRASA

ID	BMP types	Cost scale	Estimated cost range ($K)	Estimated Engineering Design (%)	Topo. Survey	H&H Study	Permits/ Authorization	Possible Funding Partners	Possible Matching Partner
NRP_5	Treatment Wetlands	Medium	266→305	100%	Detailed	Yes	NEPA, ACOE, General Construction Permit, Municipal/PRASA	PRASA, Municipality, Landowners	PDC, DNER, Municipality
NRP_6	Treatment Wetland	Medium	266→305	100%	Detailed	Yes	NEPA, ACOE, General Construction Permit, Municipal/Land Authority, PRASA, EPA	PRASA, EPA, NOAA, DNER, NFWF, USFWS, Municipality	PDC, Municipality, Land Authority
NRP_7	Bioretention, Floating Treatment Wetland	Medium	126→165	30%	Simple	No	NEPA, General Construction Permit, Municipal/Land Authority	EPA, NOAA, DNER, NFWF, Municipality	PDC, Municipality, Land Authority
NRP_8	Septic Tank Recovery/ connection to sewer system	Large	546→	100%	Detailed	Yes	NEPA, General Construction Permit, Municipal/Land Authority	NRCS, EPA, NOAA, USFS	PDC, Municipality, PRASA

Recommended Soil Stabilization Practices

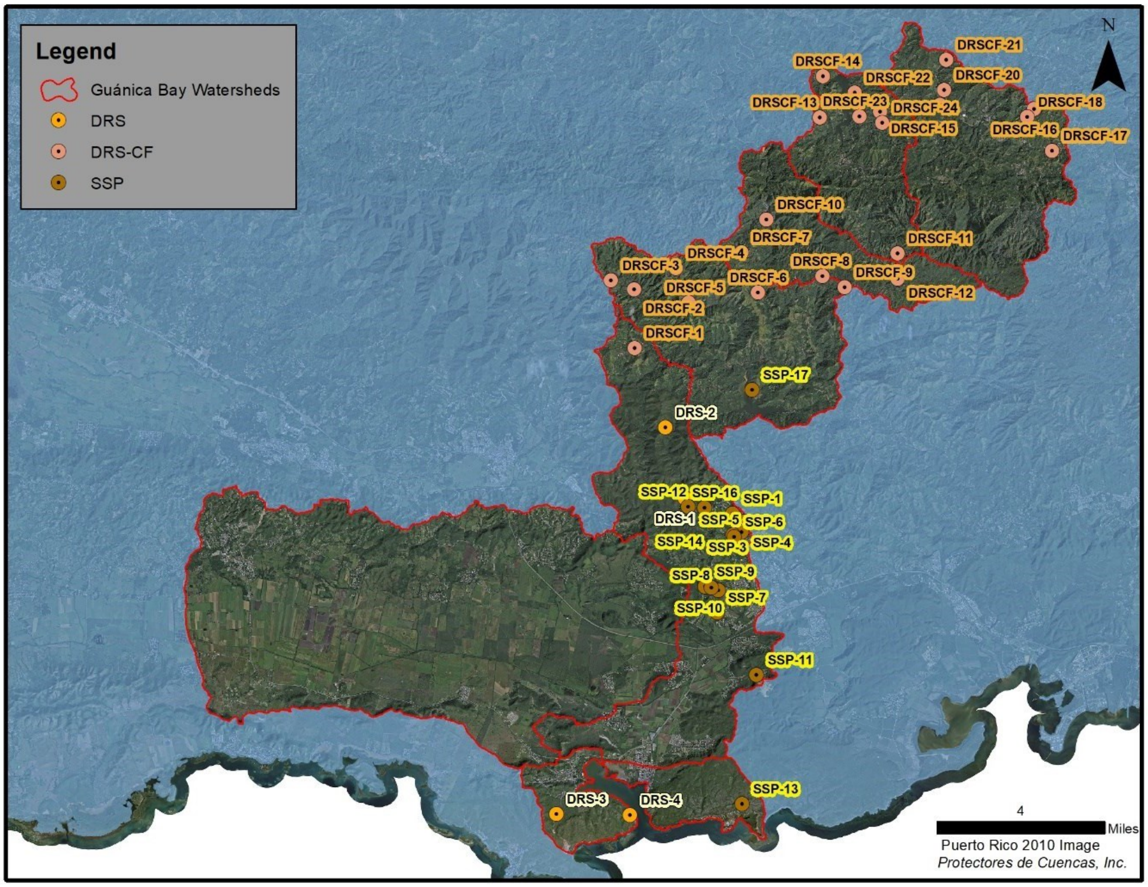

Figure 54. Map of the 49 locations of recommended soil stabilization projects in the GBW.

Table 7. List and description of proposed projects for soil stabilization practices in the GBW

ID	Observations	Estimated unstable soil area (acres)	Estimated distance from a stream or coastline (meters)	GPS coordinates	Type	Ownership	Existing land cover/ Land use	Slopes type
SSP-1	Cattle area close to stream. Includes dirt roads. Maximum exposed soil during dry season. Area is part of the southern agricultural corridor.	39	0	18° 3'29.29"N 66°52'28.86"W	Cattle farm, Dirt Road	Private	Pasture and Hay / SR-EP-A	Steep
SSP-2	Cattle area close to stream. Need for improved riparian vegetation. Includes dirt roads. Area is part of the southern agricultural corridor.	15	0	18° 3'19.28"N 66°52'13.55"W	Cattle farm, Dirt Road	Private	Pasture and Hay / SR-EP-A	Moderate to Steep
SSP-3	Cattle area close to stream. Need for improved riparian vegetation. Includes dirt roads. Area is part of the southern agricultural corridor.	34	0	18° 3'12.87"N 66°52'16.94"W	Cattle farm, Dirt Road	Private	Pasture and Hay / SR-EP-A	Moderate to Steep
SSP-4	Cattle area close to stream. Need for improved riparian vegetation. Includes dirt roads. Area is part of the southern agricultural corridor.	21	0	18° 3'6.30"N 66°52'16.93"W	Cattle farm, Dirt Road	Private	Pasture and Hay / SR-EP-A	Moderate to Steep
SSP-5	Cattle area close to stream. Need for improved riparian vegetation. Includes dirt roads. Area is part of the southern agricultural corridor.	35	0	18° 3'0.36"N 66°52'26.81"W	Cattle farm, Dirt Road	Private	Grassland / SR-EP-A	Moderate to Steep
SSP-6	Quarry operation and dirt road network.	25	35	18° 1'25.47"N 66°52'48.96"W	Mining and Dirt roads	Private	Bare / SRC	Moderate
SSP-7	Dirt road network with some segments providing access to a water tank owned by the Commonwealth of Puerto Rico	15	135	18° 1'47.16"N 66°52'37.83"W	Dirt roads	Private and Public	Shrub, Grassland, Bare / SRC, Vial	Moderate to Steep

ID	Observations	Estimated unstable soil area (acres)	Estimated distance from a stream or coastline (meters)	GPS coordinates	Type	Ownership	Existing land cover/ Land use	Slopes type
SSP-8	Quarry operation and dirt road network.	16	40	18° 1'53.30"N 66°52'47.21"W	Mining and Dirt roads	Private	Bare / SRC, Vial	Moderate to Steep
SSP-9	Quarry operation and dirt road network.	3.5	120	18° 1'57.83"N 66°53'4.41"W	Mining and dirt roads	Private	Bare / SRC	Moderate to Steep
SSP-10	Quarry operation and dirt road network.	1.4	450	18° 1'57.00"N 66°52'56.21"W	Mining and dirt roads	Private	Bare / SRC	Moderate to Steep
SSP-11	Landfill dirt road network	68	10	18° 0'7.60"N 66°51'57.21"W	Landfill and dirt roads	Public: Yauco Municipality	Bare / SRC	Moderate to Steep
SSP-12	Landslide area discharging sediment directly to stream for more than 30 years. Located in Susúa State Forest.	1.9	0	18° 3'38.07"N 66°53'27.18"W	Landslide	Public: Sabana grande Municipality	Bare, upland Forest / SREP-E	Steep
SSP-13	Bare soil threatened by forest fires in the Guanica State Forest.	3.2	280	17°57'26.78"N 66°52'15.92"W	Bare soil	Public: Guanica State Forest	Grassland, Shrub / SREP-EP	Flat to Moderate
SSP-14	Cut slope and bare soil area that might compromise the stability of a water tank used for public supply.	0.8	330	18° 1'40.33"N 66°52'31.86"W	Bare soil	Public	Bare, Upland Forest / SU	Moderate to Steep
SSP-15	Dirt roads in land adjacent to the Susúa State Forest.	3.6 / 4,828 meters long road network	30	18° 3'48.33"N 66°53'30.99"W	Dirt roads	Private	Upland Forest / SREP-EP	Moderate to Steep
SSP-16	Dirt road in the Susúa State Forest.	0.5 / 643 meters long road network	60	18° 5'17.27"N 66°53'57.19"W	Dirt road	Public: Sabana Grande Municipality	Upland Forest / SREP-E	Moderate to Steep
SSP-17	Dirt road in the periphery of the Guanica State Forest. Segment of a paved road that is unpaved.	1.4	400	17°57'13.19"N 66°56'18.36"W	Dirt road	Private	Impervious Surface / SREP-E	Flat to Moderate

ID	Observations	Estimated unstable soil area (acres)	Estimated distance from a stream or coastline (meters)	GPS coordinates	Type	Ownership	Existing land cover/ Land use	Slopes type
SSP-18	Dirt road in the periphery of the Guanica State Forest.	0.03	180	17°57'12.45"N 66°54'41.94"W	Dirt road	Private	Impervious Surface / SREP-E	Moderate to Steep
SSP-19	Dirt road network used by ATV vehicles located less than 30 meters off the Lucchetti Reservoir shoreline.	2.3 / 3,057 meters long road network	20	18°6'4.972"N 66°52'4.112"W	Dirt road	Private	Upland Forest / SREP-EH	Moderate to Steep
SSP-20	Dirt road network in a coffee farm located in the headwaters of the Lucchetti subwatershed.	1.3 / 1,693 meters long road network	48	18° 8'33.25"N 66°55'22.97"W	Agricultural dirt road network.	Private	Upland Forest / SREP-A	Steep
SSP-21	Dirt road network in a coffee farm located in the headwaters of the Lucchetti subwatershed.	1.5 / 1,996 meters long road network	10	18° 8'45.13"N 66°54'0.07"W	Agricultural dirt road network.	Private	Cultivated Crop / SREP-A	Steep
SSP-22	Dirt road network in a coffee farm located in the headwaters of the Lucchetti subwatershed.	1.5 / 2,000 meters long road network	10	18° 9'5.83"N 66°53'12.37"W	Agricultural dirt road network.	Private	Cultivated Crop / SREP-A	Steep
SSP-23	Dirt road network in a coffee farm located in the headwaters of the Lucchetti subwatershed.Close to Rio Chiquito.	0.7 / 900 meters long road network	5	18° 7'58.18"N 66°53'15.35"W	Agricultural dirt road network.	Private	Cultivated Crop / SREP-A	Steep
SSP-24	Dirt road network in a coffee farm located in the headwaters of the Lucchetti subwatershed.	2.3 / 3,000 meters long road network	20	18° 8'28.69"N 66°53'39.91"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-25	Dirt road network in a coffee farm located in the headwaters of the Lucchetti subwatershed.	1.9 / 2,570 meters long road network	60	18° 8'39.00"N 66°53'46.96"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-26	Dirt road network in a coffee farm located in the headwaters of the Lucchetti subwatershed.	4.4 / 5,800 meters long road network	50	18° 8'49.06"N 66°53'48.42"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-27	Dirt road network in agricultural land in Rio Prieto subwatershed	1.1 / 1,394 meters long road network	57	18° 8'58.39"N 66°52'22.36"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep

ID	Observations	Estimated unstable soil area (acres)	Estimated distance from a stream or coastline (meters)	GPS coordinates	Type	Ownership	Existing land cover/ Land use	Slopes type
SSP-28	Dirt road network in agricultural land in Rio Prieto subwatershed	0.8 / 1,018 meters long road network	39	18° 8’54.81”N 66°52’7.77”W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-29	Dirt road network in agricultural land in Rio Prieto subwatershed	0.8 / 1,095 meters long road network	47	18° 8'46.47"N 66°52'4.24"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-30	Dirt road network in a coffee farm located in the headwaters of the Lucchetti subwatershed.	1.6 / 2,145 meters long road network	37	18° 8'25.84"N 66°55'17.20"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-31	Dirt road network in a coffee farm located in the headwaters of the Lucchetti subwatershed.	1.9 / 2509 meters long road network	100	18° 8'31.33"N 66°55'9.45"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-32	Dirt road network in a coffee farm located in the headwaters of the Lucchetti subwatershed.	0.8 / 1,043 meters long road network	10	18° 8'26.08"N 66°53'45.59"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-33	Dirt road network in agricultural land in Rio Prieto subwatershed	0.6 / 749 meters long road network	82	18° 8'50.43"N 66°52'18.34"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-34	Dirt road network in agricultural land in Rio Prieto subwatershed	1.3 / 1733 meters long road network	110	18° 8'53.20"N 66°51'18.37"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-35	Dirt road network in agricultural land in Rio Prieto subwatershed	0.5 / 658 meters long road network	310	18° 8'40.38"N 66°50'50.62"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-36	Dirt road network in agricultural land in Rio Prieto subwatershed	0.8 / 1,052 meters long road network	230	18° 8'44.06"N 66°50'39.39"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-37	Dirt road network in agricultural land in Luchetti subwatershed	2.1 / 2,842 meters long road network	500	18° 8'19.69"N 66°50'42.53"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-38	Dirt road network in agricultural land in Luchetti subwatershed	2.1 / 2,837 meters long road network	330	18° 8'21.94"N 66°50'23.67"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep

ID	Observations	Estimated unstable soil area (acres)	Estimated distance from a stream or coastline (meters)	GPS coordinates	Type	Ownership	Existing land cover/ Land use	Slopes type
SSP-39	Dirt road network in agricultural land in Rio Prieto subwatershed	1.3 / 1,758 meters long road networks	680	18° 8'33.08"N 66°50'28.30"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-40	Dirt road network in agricultural land in Luchetti subwatershed	3.6 / 4,837 meters long road network	0	18° 8'15.97"N 66°50'0.49"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-41	Dirt road network in agricultural land in Luchetti subwatershed	2.8 / 3,703 meters long road network	35	18° 8'6.59"N 66°50'6.52"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-42	Dirt road network in agricultural land in Luchetti subwatershed	3.7 / 4,894 meters long road network	380	18° 7'57.54"N 66°50'23.71"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-43	Dirt road network in agricultural land adjacent to Guayo reservoir. Land is of high hydrologic importance due to proximity to the reservoir.	3.5 / 4,635 meters long road network	0	18°12'12.89"N 66°49'51.91"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-AH	Steep
SSP-44	Dirt road network in agricultural land adjacent to Guayo reservoir. Land is of high hydrologic importance due to proximity to the reservoir.	3.2 / 4,268 meters long road network	50	18°11'46.19"N 66°49'43.93"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-AH	Steep
SSP-45	Dirt road network in agricultural land adjacent to Guayo reservoir. Land is of high hydrologic importance due to proximity to the reservoir.	0.9 / 1,148 meters long road network	100	18°12'36.70"N 66°49'54.85"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-AH	Steep
SSP-46	Dirt road network in agricultural land adjacent to Guayo reservoir. Land is of high hydrologic importance due to proximity to the reservoir.	4.5 / 5,940 meters long road network	20	18°11'57.94"N 66°49'21.19"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-AH	Steep

ID	Observations	Estimated unstable soil area (acres)	Estimated distance from a stream or coastline (meters)	GPS coordinates	Type	Ownership	Existing land cover/ Land use	Slopes type
SSP-47	Dirt road network in agricultural land adjacent to Guayo reservoir. Land is of high hydrologic importance due to proximity to the reservoir.	6.4 / 8,580-meter-long road network	0	18°11'33.44"N 66°49'18.11"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-AH	Steep
SSP-48	Dirt road network in agricultural land in the Guayo subwatershed.	1.5 / 2,043 meters long road network	200	18° 9'43.63"N 66°50'5.83"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep
SSP-49	Dirt road network in agricultural land in the Guayo subwatershed.	0.8 / 1,055 meters long road network	560	18° 8'45.81"N 66°48'50.81"W	Agricultural dirt road network	Private	Cultivated Crop / SREP-A	Steep

Table 8. List of proposed projects and recommended soil stabilization practices in the GBW.

ID	BMP types	Cost scale	Estimated cost range ($K)	Estimated engineering design (%)	Topo. survey	H&H study	Permits/Authorization	Possible funding partners	Possible matching partner
SSP-1	Hydroseeding, Riparian forested buffer, Fencing, Dirt Road stabilization	Small	46→65	30%	Simple	No	NEPA, Municipal/Landowner	USDA, NRCS, NOAA, DNER, NFWF	PDC, Municipality, Landowner
SSP-2	Hydroseeding, Riparian forested buffer, Fencing, Dirt Road stabilization	Small	46→65	30%	Simple	No	NEPA, Municipal/ Landowner	USDA, NRCS, NOAA, DNER, NFWF	PDC, Municipality, Landowner
SSP-3	Hydroseeding, Riparian forested buffer, Fencing, Dirt Road stabilization	Small	46→65	30%	Simple	No	NEPA, Municipal/ Landowner	USDA, NRCS, NOAA, DNER, NFWF	PDC, Municipality, Landowner
SSP-4	Hydroseeding, Riparian forested buffer, Fencing, Dirt Road stabilization	Small	46→65	30%	Simple	No	NEPA, Municipal/ Landowner	USDA, NRCS, NOAA, DNER, NFWF	PDC, Municipality, Landowner
SSP-5	Hydroseeding, Riparian forested buffer, Fencing, Dirt Road stabilization	Small	46→65	30%	Simple	No	NEPA, Municipal/ Landowner	USDA, NRCS, NOAA, DNER, NFWF	PDC, Municipality, Landowner
SSP-6	Hydroseeding, Dirt Road stabilization	Small	46→65	30%	Simple	No	NEPA, Municipal/ Landowner	NOAA, DNER, NFWF, AIPA, PB	PDC, AIPA, DNER, PB, Municipality, Landowner
SSP-7	Hydroseeding, Dirt Road stabilization	Small	46→65	30%	Simple	No	NEPA, Municipal/ Landowner	NOAA, DNER, NFWF, AIPA, PB	PDC, AIPA, DNER, PB, Municipality, Landowner

ID	BMP types	Cost scale	Estimated cost range ($K)	Estimated engineering design (%)	Topo. survey	H&H study	Permits/Authorization	Possible funding partners	Possible matching partner
SSP-8	Hydroseeding, Dirt Road stabilization	Small	46→65	30%	Simple	No	NEPA, Municipal/ Landowner	NOAA, DNER, NFWF, AIPA, PB	PDC, AIPA, DNER, PB, Municipality, Landowner
SSP-9	Hydroseeding, Dirt Road stabilization	Small	46→65	30%	Simple	No	NEPA, Municipal/ Landowner	NOAA, DNER, NFWF, AIPA, PB	PDC, AIPA, DNER, PB, Municipality, Landowner
SSP-10	Hydroseeding, Dirt Road stabilization	Small	46→65	30%	Simple	No	NEPA, Municipal/ Landowner	NOAA, DNER, NFWF, AIPA, PB	PDC, AIPA, DNER, PB, Municipality, Landowner
SSP-11	Hydroseeding, Dirt Road stabilization, Sediment retention ponds	Medium	126→165	100%	Detailed	Yes	NEPA, Municipal, DNER	DNER, NFWF, EPA, ADS	PDC, DNER, EPA, Municipality, ADS
SSP-12	Hydroseeding, Riparian buffer reforestation.	Small	46→65	30%	Simple	No	NEPA, Sabana Grande Municipality, DNER	DNER, USFWS, Municipality	PDC, DNER, USGS,
SSP-13	Hydroseeding, Reforestation, Fire Breakers.	Small	46→65	30%	Simple	No	DNER, Guanica Municipality	DNER, USFS, USFWS, PLN	PDC, PLN, DNER, USFS, USFWS,
SSP-14	Hydroseeding, Cutslope stabilization	Medium	126→165	100%	Detailed	Yes	NEPA, PRASA, Yauco Municipality, DNER	PRASA, Yauco Municipality, DNER, EPA	PDC, PRASA, Yauco Municipality, EPA
SSP-15	Dirt road stabilization, sediment retention ponds.	Small	46→65	30%	Simple	No	NEPA, Sabana Grande Municipality, DNER	PDC, DNER, NOAA, NFWF, USFWS, Municipality	PDC, DNER, NOAA, NFWF, USFWS, Municipality
SSP-16	Dirt road stabilization, sediment retention ponds.	Small	46→65	30%	Simple	No	NEPA, Sabana Grande Municipality, DNER	PDC, DNER, NOAA, NFWF, USFWS, Municipality	PDC, DNER, NOAA, NFWF, USFWS, Municipality

ID	BMP types	Cost scale	Estimated cost range ($K)	Estimated engineering design (%)	Topo. survey	H&H study	Permits/Authorization	Possible funding partners	Possible matching partner
SSP-17	Dirt Road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality	DNER, NOAA, NFWF, USFWS, Municipality	PDC, DNER, NOAA, NFWF, USFWS, Municipality
SSP-18	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality	DNER, NOAA, NFWF, USFWS, Municipality	PDC, DNER, NOAA, NFWF, USFWS, Municipality, Landowner
SSP-19	Dirt road stabilization, sediment retention ponds	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, PREPA	DNER, PRASA, PREPA, NOAA, NFWF, Municipality,	PDC, DNER, PRASA, PREPA, NOAA, NFWF, Municipality, Landowner
SSP-20	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-21	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-22	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-23	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-24	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-25	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-26	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner

ID	BMP types	Cost scale	Estimated cost range ($K)	Estimated engineering design (%)	Topo. survey	H&H study	Permits/Authorization	Possible funding partners	Possible matching partner
SSP-27	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-28	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-29	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-30	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-31	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-32	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-33	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-34	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-35	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-36	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner

ID	BMP types	Cost scale	Estimated cost range ($K)	Estimated engineering design (%)	Topo. survey	H&H study	Permits/Authorization	Possible funding partners	Possible matching partner
SSP-37	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-38	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-39	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-40	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-41	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-42	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-43	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-44	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-45	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-46	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner

ID	BMP types	Cost scale	Estimated cost range ($K)	Estimated engineering design (%)	Topo. survey	H&H study	Permits/Authorization	Possible funding partners	Possible matching partner
SSP-47	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-48	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner
SSP-49	Dirt road stabilization	Small	46→65	30%	Simple	No	NEPA, DNER, Municipality, Landowner	NFWF, DNER, NOAA, NRCS	PDC, DNER, NOAA, Municipality, NRCS, DA, Landowner