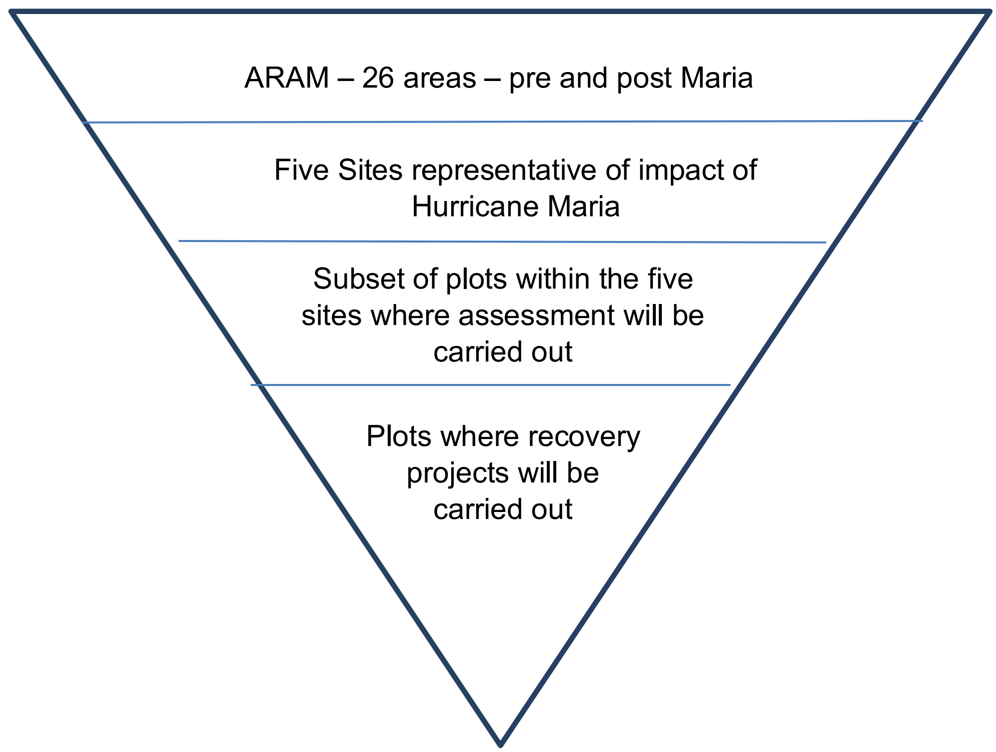
Natural and Cultural Resources Recovery Document

Environmental Resources: Coastal Wetlands



COURSE OF ACTION PROPOSED FOR COASTAL WETLAND RECOVERY

Executive summary:

The purpose of this course of action is to perform effective and measurable actions to restore the resiliency and functional capacity of Puerto Rico's coastal wetlands (hydrology and vegetation structure) to act as a natural barrier vital to reduce or minimize the eminent threats to lives and livelihoods, public infrastructure security and human health. Establishing resilience of social-ecological and technological systems, a system's property which provides the ability to adapt and function in a changing environment and overcoming disturbances and surprises while maintaining their state, structure, and functioning provides can be: 1) the ability of a system to resist a disturbance; 2) the rate of recovery of a system after a disturbance, or 3) the transformation of the system such that it bounces forward towards an adaptable state.

Nature-based infrastructure, such as coastal wetlands, which span from woody vegetation, such as mangroves, to woody/herbaceous vegetation in Puerto Rico and the Virgin Islands, reduce or minimize eminent threats to lives and livelihoods, public infrastructure security and human health through the resiliency of their functional capacity to provide ecosystem services: 1) reduction of flood impacts; 2) filtration of contamination such as sewage and heavy metals; 3) reduction of ocean swell impacts to public and private infrastructure due to cyclonic events in and off-shore disturbances; and 4) reduction of coastal erosion, among others. If the frequency and intensity of hurricanes increase, the value of coastal wetlands for protection from these storms will also increase. Coastal wetlands in the US provide $23.2 billion in storm protection services as they act as "horizontal levees" that are maintained by nature and are more cost effective than constructed ones. Constanza et al. (2008) estimated that a loss of one hectare is equivalent to an average of $30,000 per hectare increase in storm damage to coastal communities and infrastructure. The annual value of wetlands was estimated to be an average $8,240 per hectare, with variation depending on location and built infrastructure. Therefore, restoration and conservation of coastal wetlands is a cost-effective strategy allowing for a reduction in storm damages and in recovery costs.

Potential Benefits

1) Reduction of flood impacts to public and private infrastructure: reduction in maintenance and recovery costs.
2) Filtration of contamination such as sewage and heavy metals: increased water quality
3) Reduction of ocean swell impacts to public and private infrastructure due to cyclonic events in and off-shore disturbances: reduction in maintenance and recovery costs.
4) Reduction of coastal erosion: reduction of impact to inland public and private infrastructure, increased tourism, increased recreational activities for the population,
5) Sediment trapping avoiding loss or impact to coral reefs: reduction of storm events to the shores, improvement of habitat and breeding grounds for species of economic importance

6) Provision of wildlife habitat area for feeding and reproduction: maintenance of biodiversity
7) Improvement of quality of life, health and economies in the surrounding areas
8) Increased tourism; improvement the economies of the communities.
9) Capacity building in the implementation of the COAs and management of restored areas: stakeholder involvement will insure a successful implementation of management and policy and laws reinforcement.

Potential Spillover Impacts to Other Sectors

1) Water – flood control pumps can negatively impact the wetlands hydrology when they are not properly managed; need to coordinate storm water, flood control, and wetlands policies since they interconnect; ground water recharge; water sector manages sewage discharge to wetlands; filtration of contamination such as sewage and heavy metals: increased water quality.
2) Power – protect power generation or distribution sites at several coastal locations.
3) Economy – serves recreation by protecting beaches and reefs, and aesthetic value for tourism; protects infrastructure from flood damages; protects agricultural lands (buffer).
4) Municipalities – they need to participate in planning and land use policies/regulations and implementation, as they are important actors in the decision-making and implementation process and the local integrated services; reduction of flooding conditions in coastal areas, reduction of recovery and maintenance costs of public roads and infrastructure, improvement of health and water quality and local Integrated services
5) Education: provides the venue for education the government, public and private sector and communities and schools in the ecosystem services that wetlands provide that benefit quality of life and the economy without negative trade-offs that affect the surrounding communities.
6) Entrepreneurship business: providing recreational areas where microenterprises can be developed within the eco-tourism concept.
7) Transportation: by preventing flood impacts and erosion, maintenance costs are reduced.
8) Ocean economy: improvement of habitat and breeding grounds for species of economic importance
9) Natural resources: provision of wildlife habitat area for feeding and reproduction: maintenance of biodiversity; maintenance of nesting areas for critically endangered species.
10) Housing: reduction of flooding and improvement of water quality thus maintaining quality of life and maintaining house prices.

The final outcome of combined land use change/hydrological modifications and climatological events such as Hurricane Maria yield massive changes in vegetation structure, affected both by hydrological changes and erosion and sedimentation. Course of actions for each site vary depending upon extent and cause of damage. Extensive mortality caused by chronic hydrology changes requires extensive repairs to geomorphology in order to restore sustainable conditions, as well as parallel restoration of woody vegetation through planting. Sites in which relatively minor wind damage was the primary problem require only constant monitoring to ensure natural recovery progresses satisfactorily. Specific recommendations are based on the Assessment of Urban Coastal Wetlands Vulnerability to Hurricanes in Puerto Rico, carried out by the University of Puerto Rico, with contributions from: Jon Fripp, PE, Natural Resource Conservation Service and Barry Southerland, PhD, USDA Natural resource Conservation Service.

A total of $13,150,00 is required for coastal monitoring and rehabilitation of the five sites. If the Pterocarpus sites are considered, and additional costs should be based on the assessments of each site, presented below in order of priority. The potential amount

Estimated costs for coastal wetland monitoring and rehabilitation at the five sites across Puerto Rico. Costs assume $30/m^2 for rehabilitation of vegetation.

Site	Passive Monitoring	Hydrology Rehabilitation	Vegetation Rehabilitation	Total
Ciénaga las Cucharillas, Cataño	$20,000	$1,000,000	$2,250,000 /10 hectares	$3,270,000
Jobos, Isabela	$20,000	$350,000	$4,500,000 /20 hectares	$4,870,000
Punta Tuna, Maunabo	$20,000	$350,000	$4,500,000 /20 hectares	$4,87,000
Punta Santiago	$20,000	$0	$50,000	$7000.00
Piñones/Torrecillas	$20,000	$0	$50,000	$7000.00
	$100,000	$1,750,000	$12,250,000	**$13,150,000**

of jobs o to be generated during the rehabilitation actions of the wetlands in the short term is one hundred (100). However, the potential impact to the economy in jobs created in the surrounding areas can be considered to be in at least five thousand and the potential spillover to other sectors can be considered to be in billions of dollars. This a result not only from direct profits, but also 1) potential revenue that will benefit municipalities, entrepreneurship business, fisheries, education, among others, and 2) reduction of high **costs** associated to response and recovery costs from disasters such as hurricanes by maintaining the resilience of the coastal wetlands, thus increasing water quality and health, prevention of flood and swell damages to public and private infrastructure, protection of power generation or distribution sites at several coastal locations, thus to acting. as a natural barrier vital to reduce or minimize the eminent threats to lives and livelihoods, public infrastructure security and human health

Site Name	Methodology	Sectors Impacted	Jobs generated during course of action
Cucharillas Natural Reserve/ Malaria Channel, Cataño	1) Restore hydrology: a. Funding /Repair/ Management improvements are needed at pump station/ tide gates for reestablishing marine - terrestrial connectivity and prevention of flooding episodes. 2) Monitor hydrology: a. Install monitoring wells equipped with recorders for water level and salinity b. Rehabilitate mangrove vegetation c. Plant mangrove saplings 3) Monitor plant succession and mangrove recovery a. Assess vegetation structure through on the ground measurements of tree and seedling densities b. Assess landscape scale vegetation coverage through unmanned aerial vehicles at each site	a. Local Integrated services b. Health care c. Education d. Human capital e. Entrepreneurship business f. Visitor economy g. Transportation h. Public and private Infrastructure i. Housing j. Power k. Public buildings l. Economics m. Municipalities n. Community Planning and Capacity Building o. Social services p. Water q. Natural resources r. Ocean economy	Passive monitoring: 1 Hydrology rehabilitation: 20 first year/ 4 per year afterwards Vegetation rehabilitation: 16/ year Supervisor – 1 Planting: 15 Yearly assessment of vegetation recovery via ground measurements: 4 Yearly assessment of vegetation recovery at landscape level: unmanned aerial vehicles measurements: 3 Total: First year: 44 Next years: 40
Jobos, Isabela	1) Restore hydrology: a. Remove deposition under bike train bridges and improve outlet with a constructed channel	a. Local Integrated services b. Education c. Human capital d. Entrepreneurship business e. Visitor economy	Passive monitoring: 1 Hydrology rehabilitation: 20 first year/ 4 per year afterwards

	b. Establish an MOU with USACE regulatory and other stakeholders to allow future maintenance of the channel outlet to be conducted as needed c. Install fill islands/peninsulas for depth diversity to increase resilience d. Replace fill portion of bike path with elevated trail 2) Monitor hydrology: a. Install monitoring wells equipped with recorders for water level and salinity 3) Rehabilitate mangrove vegetation a. Plant mangrove saplings 4) Monitor plant succession and mangrove recovery a. Assess vegetation structure through on the ground measurements of tree and seedling densities b. Assess landscape scale vegetation coverage through unmanned aerial vehicles at each site	f. Transportation g. Public and private Infrastructure h. Economics i. Municipalities j. Community Planning and Capacity Building k. Water l. Natural resources m. Ocean economy	Vegetation rehabilitation: 16/ year Supervisor – 1 Planting: 15 Yearly assessment of vegetation recovery via ground measurements: 4 Yearly assessment of vegetation recovery at landscape level: unmanned aerial vehicles measurements: 3 Total: First year: 44 Next years: 40

Punta Tuna, Maunabo	1) Restore hydrology: a. Improve outlet from wetland system to ocean (maintenance will be needed) b. Establish an MOU with USACE regulatory and other stakeholders to allow future maintenance of the channel outlet to be conducted as needed 2) Monitor hydrology: a. Install monitoring wells equipped with recorders for water level and salinity 3) Rehabilitate mangrove vegetation a. Plant mangrove saplings 4) Monitor plant succession and mangrove recovery a. Assess vegetation structure through on the ground measurements of tree and seedling densities b. Assess landscape scale vegetation coverage through unmanned aerial vehicles at each site	a. Local Integrated services b. Education c. Human capital d. Entrepreneurship business e. Visitor economy f. Transportation g. Public and private Infrastructure h. Economics i. Municipalities j. Community Planning and Capacity Building k. Water l. Natural resources m. Ocean economy	Passive monitoring: 1 Hydrology rehabilitation: 20 first year/ 4 per year afterwards Vegetation rehabilitation: 16/ year Supervisor – 1 Planting: 15 Yearly assessment of vegetation recovery via ground measurements: 4 Yearly assessment of vegetation recovery at landscape level: unmanned aerial vehicles measurements: 3 Total: First year: 44 Next years: 40
Torrecillas/ Pinones, Carolina	1) Monitor hydrology: a. Install monitoring wells equipped with recorders for water level and salinity 2) Rehabilitate mangrove vegetation a. Plant mangrove saplings 3) Monitor plant succession and mangrove recovery	a. Local Integrated services b. Education c. Human capital d. Entrepreneurship business e. Visitor economy f. Transportation	Passive monitoring: 1 Yearly assessment of vegetation recovery via ground measurements: 4 Yearly assessment of vegetation recovery at

	a. Assess vegetation structure through on the ground measurements of tree and seedling densities a. Assess landscape scale vegetation coverage through unmanned aerial vehicles at each site	g. Public and private Infrastructure h. Economics i. Municipalities j. Community Planning and Capacity Building k. Natural resources l. Ocean economy	landscape level: unmanned aerial vehicles measurements: 3 Total:8
Punta Santiago, Humacao	1) Monitor hydrology: a. Install monitoring wells equipped with recorders for water level and salinity 2) Rehabilitate mangrove vegetation a. Plant mangrove saplings 3) Monitor plant succession and mangrove recovery a. Assess vegetation structure through on the ground measurements of tree and seedling densities b. Assess landscape scale vegetation coverage through unmanned aerial vehicles at each site	a. Local Integrated services b. Education c. Human capital d. Entrepreneurship business e. Visitor economy f. Transportation g. Public and private Infrastructure h. Economics i. Municipalities j. Community Planning and Capacity Building k. Natural resources l. Ocean economy	Passive monitoring: 1 Yearly assessment of vegetation recovery via ground measurements: 4 Yearly assessment of vegetation recovery at landscape level: unmanned aerial vehicles measurements: 3 Total:8

Issue/Problem Being Solved:

The purpose of this course of action is to provide measurable and effective recommendations towards the restoration of the resiliency and functional capacity of Puerto Rico's coastal wetlands (hydrology and vegetation structure) to act as a natural barrier vital to reduce or minimize the eminent threats to lives and livelihoods, public infrastructure security and human health.

Establishing resilience of social-ecological and technological systems, a system's property which provides the ability to adapt and function in a changing environment and overcoming disturbances and surprises while maintaining their state, structure, and functioning provides can be: 1) the ability of a system to resist a disturbance; 2) the rate of recovery of a system after a disturbance, or 3) the transformation of the system such that it bounces forward towards an adaptable state.

Anthropogenic cumulative impacts: ditches, swales, drainage channels, pump stations and improper or lack of management that potentiates hydrological modifications over coastal wetlands, have caused inadequate and management dependent conditions in some areas. Restoring wetlands hydrology functions, e.g. aquifer recharge, filtration, sediment and erosion control, protection of coasts from wave energy will strengthened the resiliency of the human/natural system thus minimizing storm effects resulting in improvement of cost/effectiveness of rehabilitation of natural-human-economic systems after natural disasters.

Nature-based infrastructure, such as coastal wetlands, which span from woody vegetation, such as mangroves, to woody/herbaceous vegetation in Puerto Rico and the Virgin Islands, reduce or minimize eminent threats to lives and livelihoods, public infrastructure security and human health through the resiliency of their functional capacity to provide ecosystem services: 1) reduction of flood impacts; 2) filtration of contamination such as sewage and heavy metals; 3) reduction of ocean swell impacts to public and private infrastructure due to cyclonic events in and off-shore disturbances; and 4) reduction of coastal erosion, among others.

Coastal wetlands depend and are affected by both terrestrial/marine and marine/terrestrial connectivity in which both human activity and natural processes, such as hurricanes and storm events, play an important role. Thus, the determinants of coastal wetlands structure and function are at the same time risk factors for their capacity to maintain their ecosystem services:

a. Hydrology:
    - determined by past and present activities such as urban and rural development and agriculture.
    - terrestrial/marine connectivity – determined by the inflow of fresh water via rivers as a product of rainfall and runoff in the mountains and in situ rainfall and subsequent runoff events.
    - marine/terrestrial connectivity – saltwater intrusion due to ocean swells and subsurface salt wedge.
b. Erosion and sedimentation:
    - terrestrial/marine connectivity – sediment accretion due to inflow of fresh water via rivers as a product of rainfall and runoff and subsequent erosion in the mountains, and in situ rainfall and subsequent runoff events.
    - marine/terrestrial connectivity – high energy events sand accretion due ocean swells and runoff.
    -

The final outcome of combined land use change/hydrological modifications and climatological events such as Hurricane Maria yield massive changes in vegetation structure, affected both by hydrological changes and erosion and sedimentation: 1) deforestation and defoliation; 2) changes in biodiversity, both invasive and native species; and 3) changes in the proportion of functional forms, e.g, woody (mangroves, non-halophytic trees), herbaceous (grasses and sedges), vines and lianas.

Hurricanes Irma and María passed over the island of Puerto Rico in September of 2017, resulting in what is widely considered the worst natural disaster in the island's history. The number of human deaths from the storms has been widely debated and is thought to be between 64 and 1052. Most of the deaths following the storm resulted from medical complications because of crippled power and health system infrastructure due to one of the largest blackouts in history. This infrastructure was primarily impacted by category five storm force winds, flying debris, as well as extensive and prolonged flooding from precipitation, storm surge, and failed hydraulic infrastructure. Current estimates of damages range between USD 30 and USD 60 billion and will require years of extensive repairs. Damages to natural resources are less well understood but preliminary estimates suggest the loss of around 23-31 million trees across the island. Previous weather or tsunami disasters have shown coastal wetlands to provide significant protection to human life, property, and infrastructure such as the capacity to absorb/attenuate the impact of storms while protecting coastal communities' infrastructure including agriculture and habitats to the order of USD 33,000 per hectare.

Anthropogenic cumulative impacts: ditches, swales, drainage channels, pump stations and improper or lack of management that potentiates hydrological modifications over coastal wetlands, have caused inadequate and management dependent conditions in some areas. Restoring wetlands hydrology functions, e.g. aquifer recharge, filtration, sediment and erosion control, protection of coasts from wave energy will strengthened the resiliency of the human/natural system thus minimizing storm effects resulting in improvement of cost/effectiveness of rehabilitation of natural-human-economic systems after natural disasters.

Coastal wetlands depend on and are affected by both terrestrial/marine and marine/terrestrial connectivity in which both human activity and natural processes, such as hurricanes and storm events, play an important role. Forested coastal wetlands have been singled out as providing extremely highly valuable protective services against natural disasters. Thus, by combining maintaining this service via rehabilitation and the enforcement of established federal and state regulations, these ecosystems would contribute to the goal of increasing the resilience of Puerto Rico's coast against similar natural disasters. As is the case in the other sites, hydrology must be the focus of any intended rehabilitation program. Therefore, the proposed course of action will provide measurable and effective recommendations towards the restoration of the resiliency and functional capacity of Puerto Rico's coastal wetlands (hydrology and vegetation structure) to act as a natural barrier vital to reduce or minimize the eminent threats to lives and livelihoods, public infrastructure security and human health.

Primary damage to all sites was in the form of defoliation, uprooting of trees, and or breaking of tree branches and trunks. While destructive to individual trees, these forms of damage do not typically result in forest wide mortality. This was evident in the moderate mortality rates observed at three of the five sites, where less than fifty percent of mangrove coverage was classified as dead. In these cases, it is expected the surviving trees will be capable of reaching near full canopy coverage in the next 12-18 months. Further, with some viable germinating seeds and seedlings present at these sites, understory coverage has already begun to regrow and will continue to fill in remaining canopy gaps. We expect these sites to reach pre-hurricane forest metrics of stem density and diameter over the next five years. Complete secondary succession of large patches may take longer, around 15 years, but only if the appropriate hydrology is maintained and if there is a sustainable supply of germinated seeds from adjacent stands. The two sites at Punta Tuna and Isabela, however, do not meet these criteria and will require active management towards an accelerated recovery.

Unlike the primarily wind damage at the other sites, the mangroves of Punta Tuna and Isabela were likely affected by drastic changes in hydrology. At Punta Tuna, the closing of the wetland channel by sand deposition during the storm, followed by the flooding from precipitation and storm surge, resulted in extremely high-water levels and no drainage channel. As a result, the wetland was flooded with abnormally high water (1 meter) for an abnormally long time (4 months). Plant roots were thus drowned with no oxygen source and consequently died. This hypothesis is strengthened by the survival of trees and plants along higher grounds at the wetland perimeter. Similar observations were made at Isabela, where the drainage of the wetland was further hindered by a paved bike path. Although some effort was made to allow for drainage under the paved path, it was not sufficient to completely drain the wetland following hurricane María. Therefore, although trees were likely impacted by wind damage, it was prolonged high flood waters that ultimately killed most of the forest. This flooding also killed any existing seeds and seedlings. Thus, unlike the other sites where viable propagules (germinated seeds) and seedlings were observed, there are very few to no recruits capable of regenerating the forest at Isabela and Punta Tuna. For these reasons, active management involving extensive planting will be necessary at these sites to hasten recovery to pre-hurricane optimal conditions.

Course of actions for each site vary depending upon extent and cause of damage. Extensive mortality caused by chronic hydrology changes requires extensive repairs to geomorphology in order to restore sustainable conditions, as well as parallel restoration of woody vegetation through planting. Sites in which relatively minor wind damage was the primary problem require only constant monitoring to ensure natural recovery progresses satisfactorily. Specific recommendations given in Table 5 are based on the Assessment of Urban Coastal Wetlands Vulnerability to Hurricanes in Puerto Rico, carried out by the University of Puerto Rico, with contributions from: Jon Fripp, PE, Natural Resource Conservation Service and Barry Southerland, PhD, USDA Natural resource Conservation Service.

Locations:

Five sites across the island were chosen for their relative potential to reduce or minimize eminent threats to lives and livelihoods, public infrastructure, security, human health and tourism (Figure 1). The selection was determined based on results the Antilles Rapid Assessment Methodology carried out after the hurricanes. Additional input from local experts in the Puerto Rico Department of Natural Resources, the United States Army Corps of Engineers, and The University of Puerto Rico was also considered. Of the five sites, two were in the metropolitan area of Carolina-San Juan-Cataño in the northern coast, two sites were in the eastern and south eastern coast of the island, and one in the northwestern side of the island. The two sites in the San Juan metropolitan area are representative of urban coastal wetlands surrounded by high population density, and transportation and industrial infrastructure. On the eastern end, Piñones State Forest is primarily woody vegetation habitat dominated by mangroves. This site is within 3.5 km of the island’s busiest international airport and is also an important component of both internal and external tourism. On the western side, Ciénaga Las Cucharillas is composed of both woody and herbaceous vegetation and is within 4 km of the shipping and port related industries of the san Juan Bay. The Ciénaga is an important component of local hydrology and the maintenance of low flooding conditions in the surrounding areas composed of high population density neighborhoods, and transportation and industrial infrastructure. One hundred kilometers to the west, the mangroves of Isabela are near where Hurricane María left the island

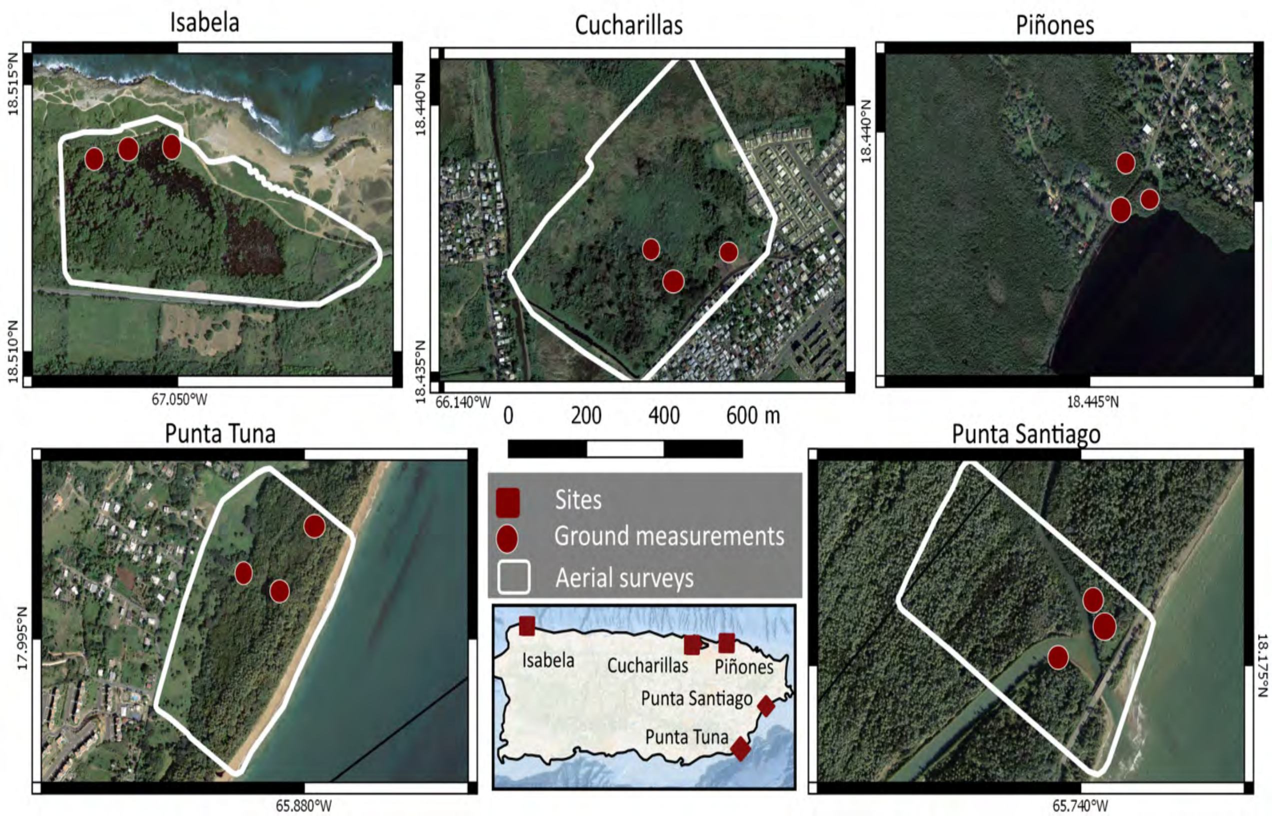


Figure 1. The five sites chosen based on expert input and the economic and infrastructural importance of the sites. Isabela represents hurricane María's exit from the island. Cucharillas and Piñones represent the island's largest urban and industrial center. Punta Santiago and Punta Tuna represent where the hurricane made landfall and the nearby city of Humacao. Distance bar applies to all insets except the island wide center map. Imagery is pre-hurricane from 2010. White polygons represent aerial survey boundaries. Piñones was not assessed by air due to restrictions from the nearby Luis Muñoz Marín international airport.

and are of high economic importance to internal and external tourism. On the southern coast, Punta Santiago lies between the ocean and the town of Humacao, near where hurricane María made landfall. This site is composed primarily of both upland forests as well as saltwater forested wetlands. Finally, Punta Tuna lies roughly twenty-five kilometers southwest of Punta Santiago and is composed of both woody and herbaceous marine and freshwater wetlands, as well as upland forests.

Based on the ARAM results four other sites were identified for additional assessment and courses of action, ut are not oncluded in this COA: Pterocarpus forests in Dorado Beach, Punta Viento in Patillas and Palmas del Mar in Humacao. Pterocarpus ecosystems are a critical habitat because of the limited cover of this type of wetland across the island. All three are highly relevant for their tourism and educational functions. Pterocarpus forest were drastically impacted by the hurricane promoting ground exposure to new species that could compete to colonize the area. Pterocarpus forests ecosystems are DNER designated critical habitat, since there is limited cover of this type of wetland across the island.

Additional Information:

Damage to vegetation varied greatly across the sites and depending upon habitat type (Figures 2,5,7,9, Tables 1-4). Below is a list of overall findings followed by site specific results at each location:

a) Overall mortality across all sites and habitats was 27%, but overall mangrove mortality was double at 53%. This corresponds to a total mangrove loss of 15 hectares across the five study sites.
b) The mangroves at Isabela suffered the most damage, with 95% of the post-hurricane forest classified as dead, leaving only a small strip surrounding the wetland shoreline.
c) The mangroves at Punta Tuna also suffered widespread mortality, with 68% of mangrove habitat classified as dead. This is likely an underestimate, as some of the mangrove classified habitat is upland vegetation, which fared better. Ground based observations estimate the mortality at Punta Tuna is closer to 95%. Below are specific results from each site.
d) There are shifts in vegetation types in the Ciénaga Las Cucharillas due to the excess and continuous freshwater flooding as a result of management of flood gates and water pumps at the mouth of the Malaria Channel, where the flood gates have remained closed during the last six years. Failure of the water pumps occurred during and after the hurricane and currently only one is active for half an hour three-times daily.
e) The other two sites experience relatively minimal mortality and are expected to recover naturally.

Jobos - Isabela

Aerial surveys at Isabela show the most extensive mortality of all sites (Figure3, Table 1). Across all habitats, 67% of coverage is either dead or converted to bare ground, corresponding to a loss of 13 hectares of live vegetation habitat. Mangrove habitat suffered the highest mortality rate, with 95% dead.

On site assessments at Isabela confirmed almost complete mortality, with the only surviving individuals present along higher grounds along the shore of the wetland (Figure 2). When measuring water depth just inside the wetland, it was discovered that numerous black mangrove pneumatophores (aerial roots) were submerged. These roots are extremely important for mangrove survival, serving as a conduit for air to reach often flooded root zones and thus allowing for normal plant metabolism. These roots will grow to a height just above normal flood depth, allowing for gas exchange with the air even when flooded. The fact that these roots were flooded and that the only surviving trees were found along higher shorelines, provides strong evidence that extremely high and prolonged flooding as a result of the hurricanes effectively drowned the trees and resulted in their death. Water depth recordings at the site (Figure 3), further confirm this in that they show no tidal connectivity and very slow drainage or evaporation. The hydrological and geomorphological assessment (Appendix D) suggests the bike path constructed along the wetland perimeter may be impeding normal tidal connectivity and this may have worsened as a result of the deposition of sand during the storm. Water chemistry measurements were normal for mangrove wetlands and are not thought to be the cause for mortality.

Figure 3 While most of the mangroves at Isabela are dead (left), there are some live trees and seedlings along the higher grounds on wetland shore

Course of Action:

Given that abnormally high and prolonged flooding as a primary cause of wetland mortality, and in accordance with the NRCS hydrology assessment, we recommend:

1) Reestablish wetland connectivity with the ocean for 2019. This includes the construction of a tidal channel as well as improvements and maintenance to existing infrastructure (bike path and flow channels under the bike path.
2) Perform consistent hydrologic monitoring to ensure the establishment of sustainable hydrology in parallel with vegetation rehabilitation.

3) Restore the vegetation by planting mangrove saplings of *Rhizophora mangle*, *Laguncularia racemosa* and *Avicennia germinans* in 2018-2019, so that a full forest can develop within the next ten years. Without planting, natural regeneration to a full forest will occur from existing reproductive trees, although this is likely to take twenty to thirty years. However, with or without planting, any regeneration will be impeded and vulnerable if the geomorphological and hydrological conditions are not improved.
4) Re-assessment of vegetation structure and cover every year by on the ground measurements of seedling and tree density and canopy cover and at the landscape level utilizing un-manned aerial vehicles.

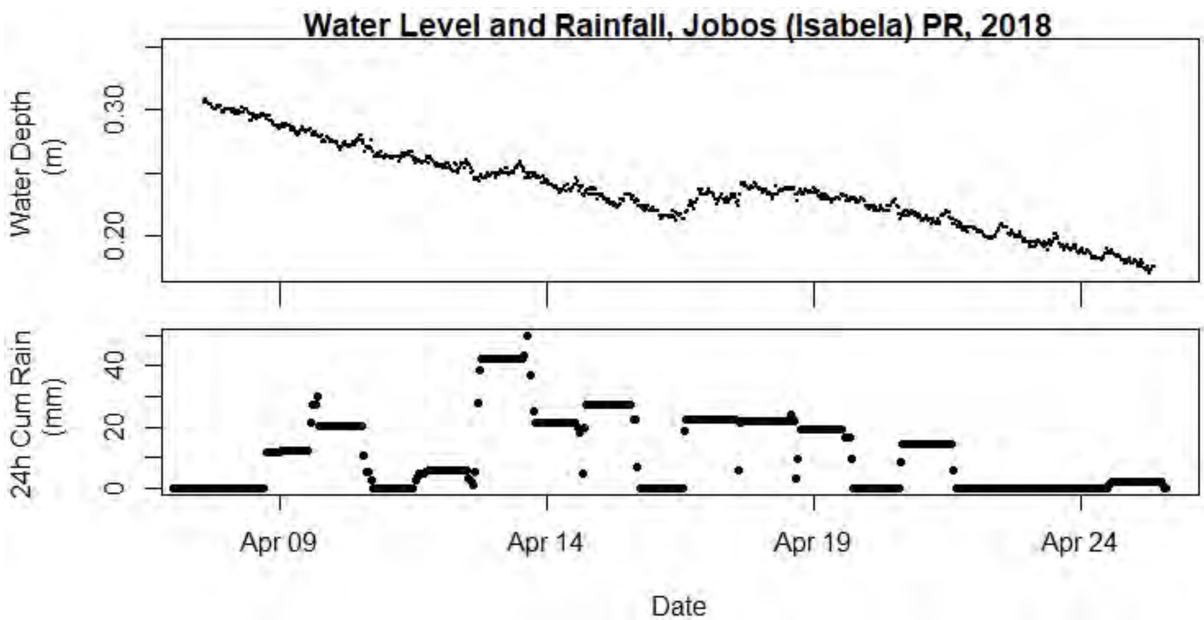


Figure 4 Water levels recorded at Isabela mangroves, Puerto Rico over a two-and-a-half-week period show a reduction of ten centimeters, with some response to local rainfall, and no tidal signature. This suggests the wetland is almost completely dependent on rainfall and thus vulnerable to extreme events like hurricanes. Better drainage would have allowed flood waters to recede quicker and would provide improved tidal connectivity.

Isabela, Puerto Rico

2010 **2018**

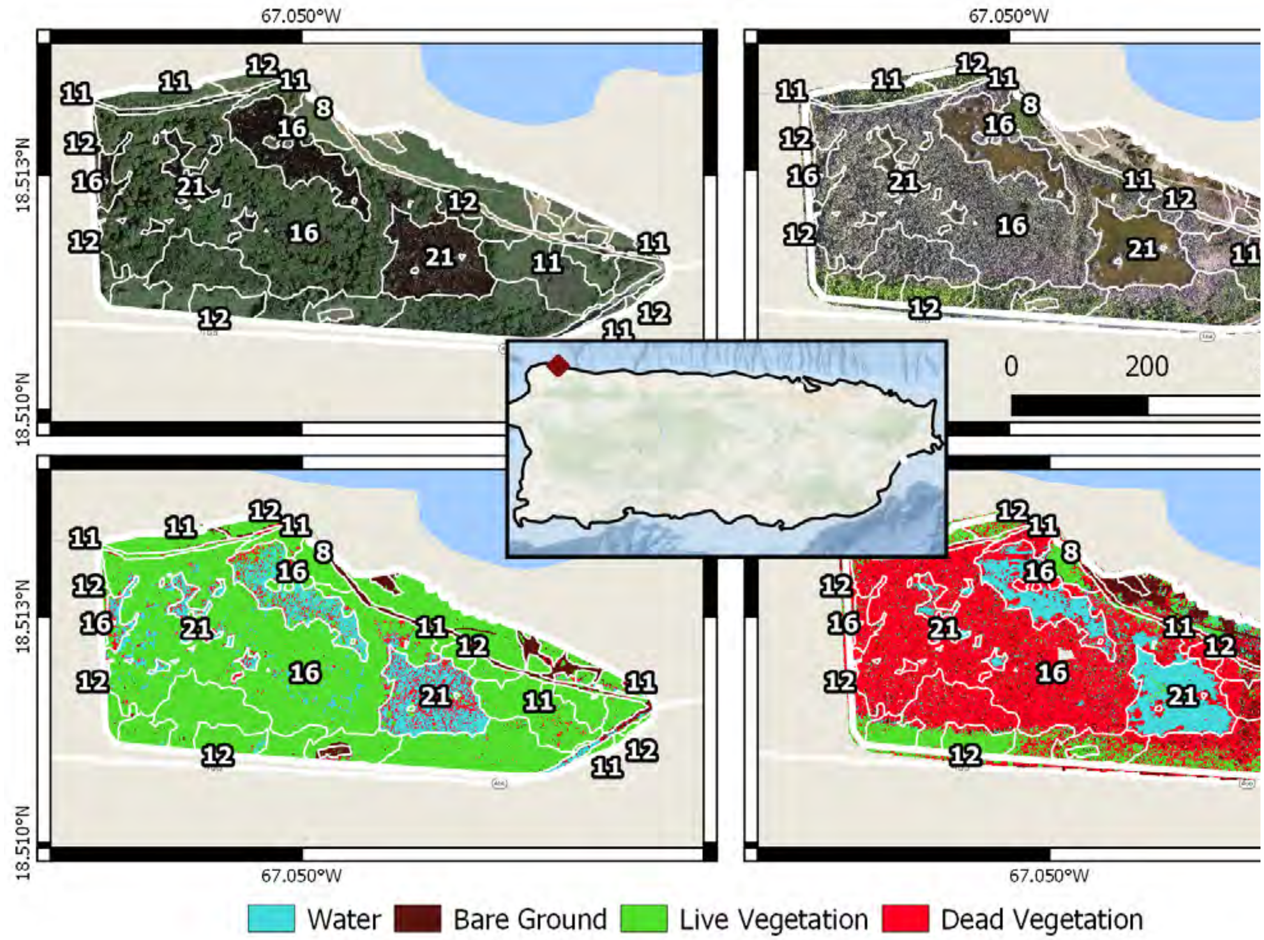


Figure 2 Aerial imagery of the mangroves at Isabela, Puerto Rico from 2010 to 2018, representing pre and post hurricane, respectively. Numbers represent major habitat classes as represented in the below table. Isabela suffered the highest mangrove mortality rate of all sites. Surviving mangroves were concentrated on higher elevations shorelines, suggesting mortality was due to higher than normal water levels for longer than normal duration. Habitat class 21 is open water. Recovery of mangroves at Isabela would benefit from active management.

			2010				**2018**			
	Habitat Type	Area (ha)	Water	Bare Ground	Alive Veg.	Dead Veg.	Water	Bare Ground	Alive Veg.	Dea Veg
8	Grassland/Herbaceous	2.4	1%	6%	93%	0%	3%	42%	27%	28%
11	Upland Forest	4.7	1%	1%	97%	1%	0%	6%	33%	61%
12	Scrub/Shrub	2.9	1%	2%	94%	2%	0%	6%	56%	37%
16	Estuarine Forested Wetland	7.5	6%	0%	91%	3%	3%	0%	2%	95%

Table 1 The mangroves at Isabela suffered the highest mortality rate of all included sites, with aerial imagery suggesting 95% mortality, equivalent to nearly 7.5 hectares of forest. Other vegetation also suffered to a lesser extent.

Punta Tuna

Punta Tuna suffered similar mortality to that of Isabela (Figure 5, Table 2). Aerial surveys suggest an overall mortality of 29%, but mangrove mortality was more than double at 68%, and on-the-ground surveys suggest a much higher mortality closer to 95%. The reason for the discrepancy is the misclassification of upland forest as mangrove habitat in the habitat classification dataset. Overall, eight hectares of mangrove died within the study area.

On site assessment at Punta Tuna showed similar patterns of mortality as that of Isabela, with only a small ring of surviving forested wetland along the higher ground perimeter. We again suspect the same process of events as that of Isabela leading up to the mass mortality. Local managers confirmed the normal drainage creek at Punta Tuna was blocked by sand deposition during hurricane María. With the accumulation of extreme precipitation and no means of drainage, the trees were drowned following prolonged flooding. Flood lines on trees suggest the water level was sustained at around 70 cm of depth for up to four months, which is too high to allow for oxygen exchange with roots (Figure 6). Water level recordings at the site confirmed no tidal connectivity and a strong dependence on rainfall. This makes the wetland especially vulnerable to extreme flooding and mortality following heavy rainfall events. Water chemistry parameters showed no abnormalities.

Course of Action:

Hydrology was the primary cause of mortality at Punta Tuna and should thus be the focus of any rehabilitation program. Maintaining a consistent and sustainable connection with the ocean will allow for proper drainage in the case of extreme flooding as well as provide the tidal connectivity necessary for long term mangrove health.

1) The NRCS assessment (Appendix D) recommends ensuring proper communication with USACE and the establishment of a memorandum of understanding (MOU) allowing for channel maintenance to be carried out as needed and deemed necessary by local managers. Only by first ensuring stable and proper hydrology, can vegetative rehabilitation be successful.
2) Perform consistent hydrologic monitoring to ensure the establishment of sustainable hydrology in parallel with vegetative rehabilitation.
3) Implementation of an active management plan that includes planting of mangrove saplings to restore 100% mangrove cover and structure.
4) Re-assessment of vegetation structure and cover every year by on the ground measurements of seedling and tree density and canopy cover and at the landscape level utilizing un-manned aerial vehicles.

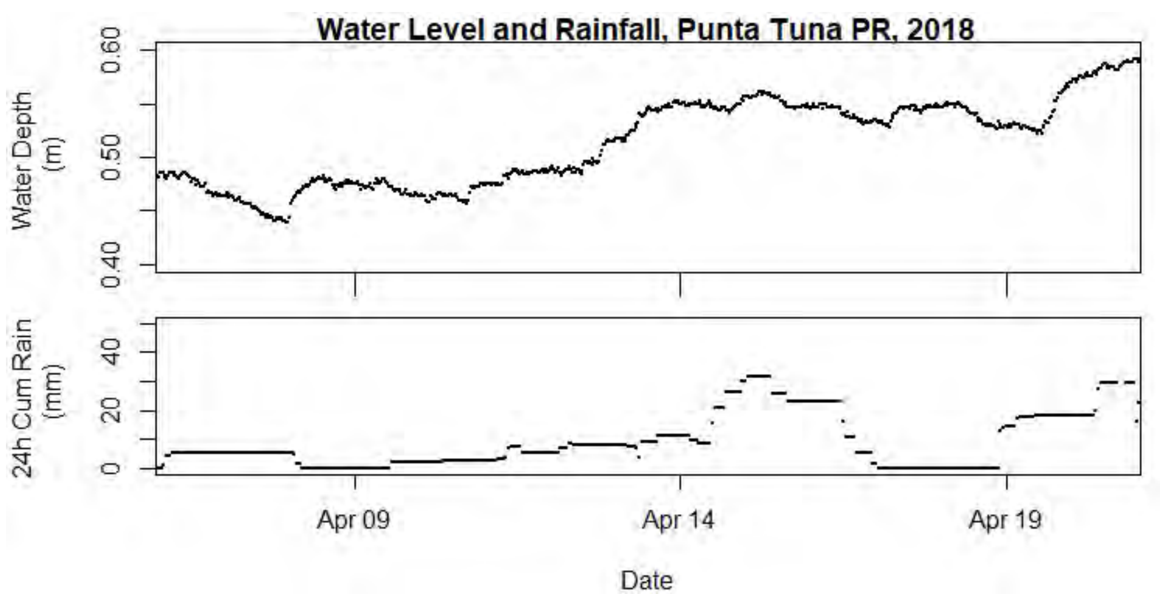


Figure 6 Flood lines on trees at Punta Tuna suggest a sustained water level of 70 cm above the forest floor and locals suggest the wetland was flooded for up to four months (top). These flood waters did not allow for proper oxygen levels in mangrove roots, and effectively drowned them. Water levels recorded at the site show minimal tidal signals and no drainage, with a strong connection to rainfall (bottom). This leaves the wetland vulnerable to flooding from extreme events like hurricanes.

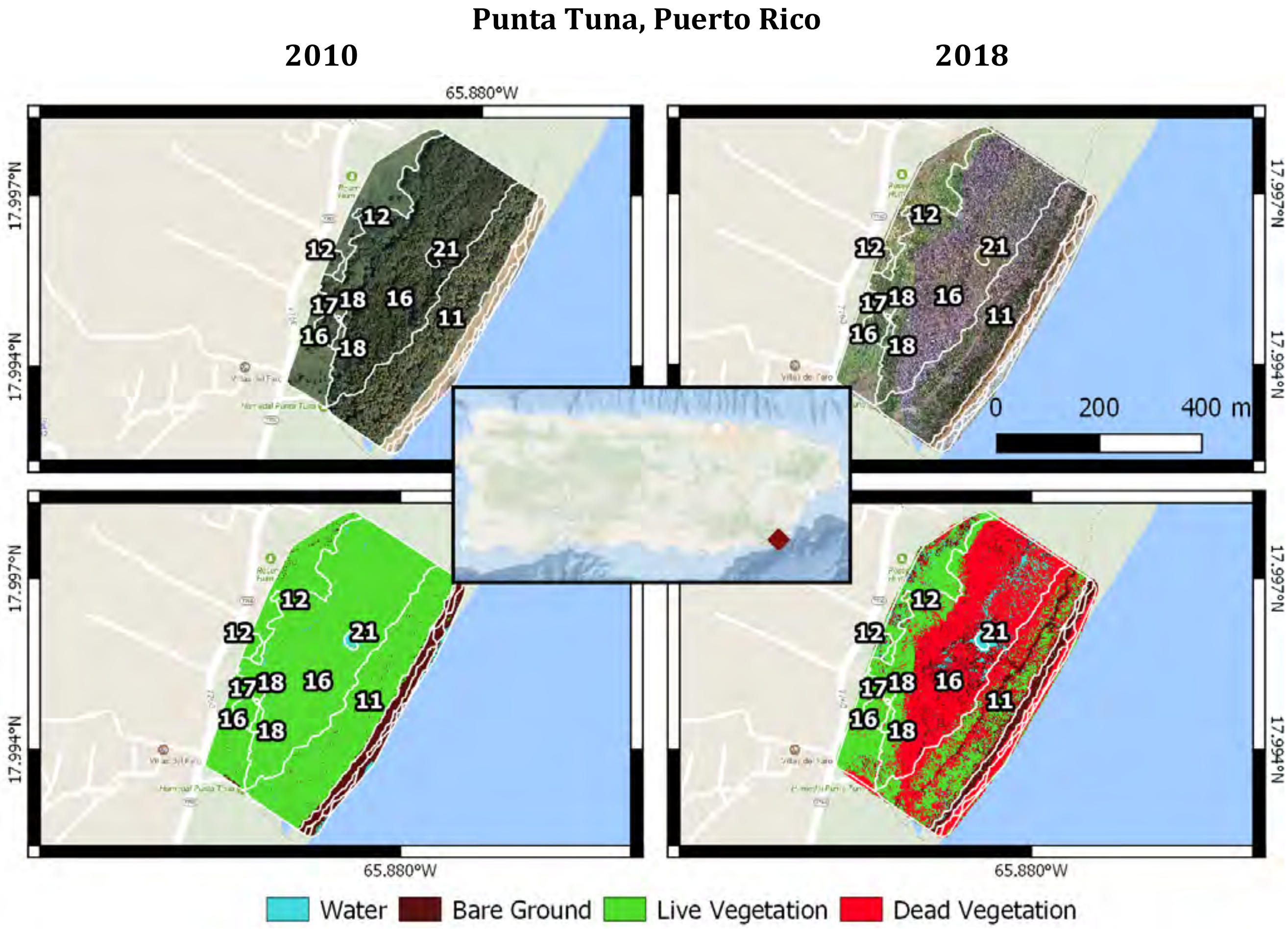


Figure 5 Aerial imagery of the mangroves at Punta Tuna, Puerto Rico from 2010 to 2018, representing pre and post hurricane, respectively. Numbers represent major habitat classes as represented in the below table. Punta Tuna suffered among the highest mangrove mortality rates of all sites. Punta Tuna is not expected to recover naturally within the next decade and would benefit significantly from active management.

			2010				2018			
	Habitat Type	Area (ha)	Water	Bare Ground	Alive Veg.	Dead Veg.	Water	Bare Ground	Alive Veg.	Dead Veg.
11	Upland Forest	4.9	0%	2%	99%	0%	0%	15%	40%	44%
12	Scrub/Shrub	0.1	0%	0%	100%	0%	2%	7%	88%	3%
16	Estuarine Forested Wetland	8.8	1%	0%	99%	0%	4%	4%	23%	68%
18	Estuarine Emergent Wetland	0.1	0%	0%	100%	0%	0%	0%	100%	0%

Table 2 The mangroves at Punta Tuna suffered high mortality, with aerial imagery suggesting 68% mortality, equivalent to nearly 6 hectares of forest. Other vegetation also suffered to a lesser extent.

Ciénaga Las Cucharillas

Initial damage and flooding in Ciénaga las Cucharillas was extensive (Figure 7). Ciénaga las Cucharillas contains the highest diversity of wetland habitats relative to the other sites, all of which suffered some mortality as well as significant shifts towards other habitats (Figure 8, Table 3).

Figure 7 Aerial view of Ciénaga Las Cucharillas and surrounding urban and industrial infrastructure immediately after hurricane Maria. Photo Date: 9/23/2017 8:42:33 AM http://imageryuploader.geoplatform.gov/imageeventspublic/map.html#

Even if there was initial extensive defoliation and breakage, the site experienced 6% mortality with the highest rates around 14% seen in palustrine (freshwater) emergent wetlands and estuarine (saline) forested wetlands. Viable White mangrove (*Laguncularia racemosa)* seedlings and saplings were observed at the site, suggesting natural regeneration. However, 16% and 8% of palustrine emergent and estuarine forested wetlands, respectively, were also converted to open ground. Additionally, some small sections of bare ground have been colonized by grasslands. These trends signify shifting vegetation habitats that might be in response to altered hydrology from the management of the flood gates and pumps after the hurricane. Altogether, this site lost

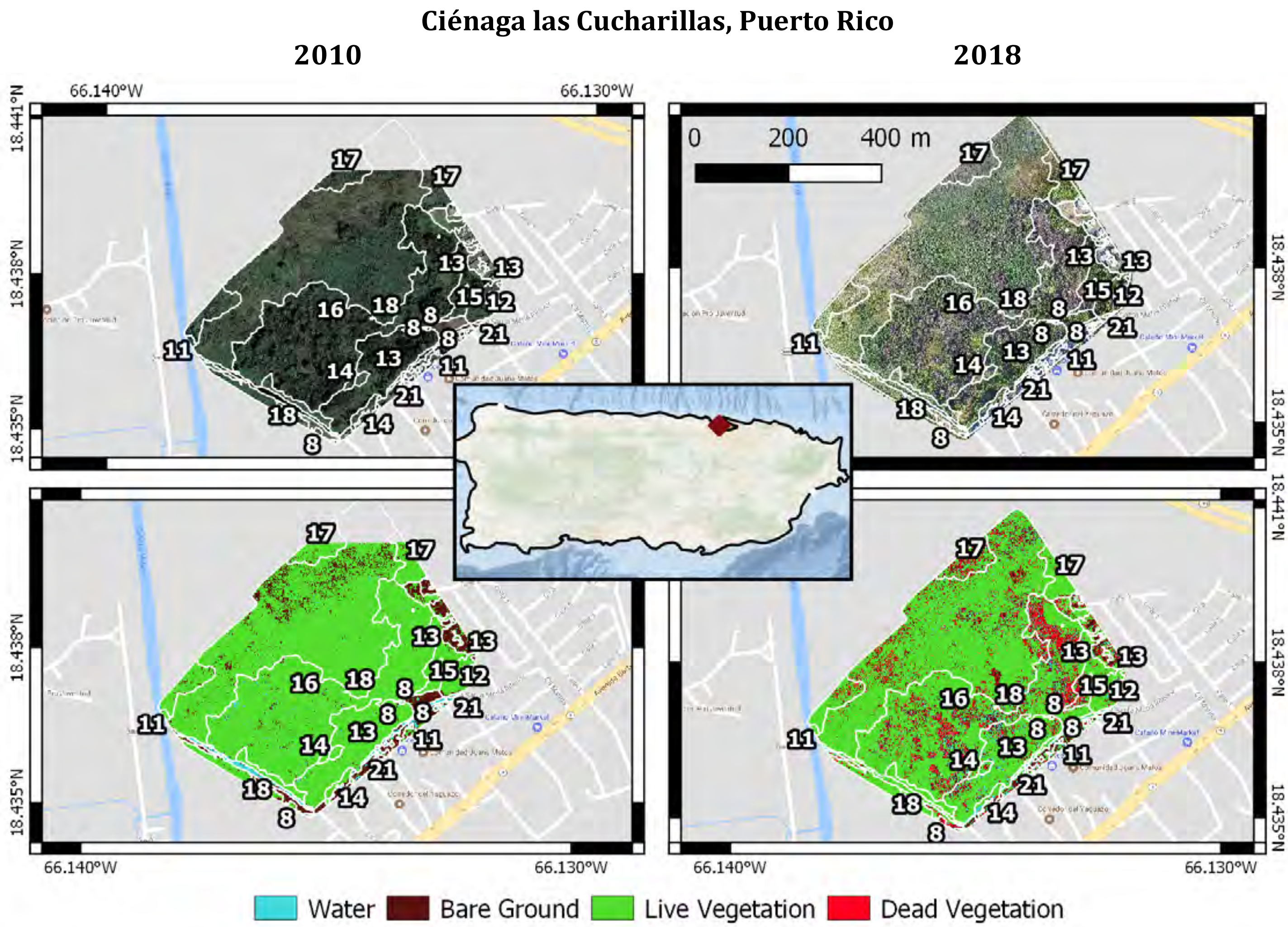


Figure 8 Aerial imagery of the mangroves at Cataño, Puerto Rico from 2010 to 2018, representing pre and post hurricane, respectively. Numbers represent major habitat classes as represented in the below table. Cataño suffered moderate mortality compared to other sites.

			2010				2018			
	Habitat Type	Area (ha)	Water	Bare Ground	Alive Veg.	Dead Veg.	Water	Bare Ground	Alive Veg.	Dead Veg.
8	Grassland/Herbaceous	0.3	0%	65%	35%	0%	0%	2%	91%	6%
11	Upland Forest	0.2	17%	36%	48%	0%	14%	36%	48%	2%
12	Scrub/Shrub	0.1	0%	6%	94%	0%	0%	5%	93%	1%
13	Palustrine Forested Wetland	2.9	1%	3%	96%	0%	4%	6%	85%	5%
15	Palustrine Emergent Wetland	0.4	10%	7%	83%	0%	8%	16%	63%	14%
16	Estuarine Forested Wetland	7.6	1%	1%	98%	0%	1%	8%	78%	13%
18	Estuarine Emergent Wetland	10.2	0%	5%	95%	0%	0%	4%	93%	3%

Table 3 The mangroves at Ciénaga Cucharillas suffered moderate mortality, with aerial imagery suggesting 13% mortality, equivalent to nearly 1 hectares of forest. Other vegetation also suffered to a similar or lesser extent.

wooded vegetation to freshwater grasses and sedges.

Although Ciénaga Las Cucharillas suffered relatively little mortality in comparison to other sites, its shifting vegetation is a sign of potential habitat conversion at the site. This is due to a change in hydrology, as has been observed in other coastal wetlands with gradual or rapid changes to hydrology. Our assessment based on water depth and salinity measurements for the last four years by the University of Puerto Rico where marine-terrestrial connectivity is maintained by subsurface inflow of the marine water from the coast, as well as that of the report of NRCS hydrology/geomorphology team, see the pump/gate station at the Malaria Channel as a critical component of site hydrology, and thus to rehabilitating site vegetation to provide optimal protective services (Figure 9). This primarily means allowing sufficient tidal exchange in the wetland to promote its natural estuarine (saltwater) and not palustrine (freshwater) conditions. In doing so, the hydrology will naturally favor a forested wetland system over the current herbaceous dominated system. Forested coastal wetlands have been singled out as providing extremely highly valuable protective services against natural disasters, thus maintaining via rehabilitation and enforcement of established federal and state regulations, these ecosystems would contribute to the goal of increasing the resilience of Puerto Rico's coast against similar natural disasters. As is the case in the other sites, hydrology must be the focus of any intended rehabilitation program. Parallel to establishing a favorable hydrological, vegetative rehabilitation with mangrove plantings need to be carried out for optimal success.

Figure 9a. Some of the mortality at Ciénaga Cucharillas (left) is likely a result of shifting hydrology due to the pump/gate station at the mouth of the Malaria canal (right). A freshwater hydrology regime is promoted by the operation of the tidal gate at the mouth of the Malaria Channel managed by the Department of Natural Resources and Environment (DRNA), where for the past six years the flood gates have not been opened, restraining the marine-terrestrial connectivity through the channel and favoring freshwater conditions in the area.

Figure 9b. Flooding conditions (0.5m above ground surface) of the Cucharillas Natural Reserve wetland, 20 meters from the nearby populated area, photographed on May12, 2018, as a consequence of Hurricane María's effects and present non-functioning pumps and permanent locked gate conditions at the station.

Course of Action:

Parallel to establishing a favorable hydrological, vegetative rehabilitation with mangrove plantings need to be carried out for optimal success.

1) Funding /Repair/ Management improvements at pump station/ tide gates to be carried out by 2019 for reestablishing marine -terrestrial connectivity and prevention of flooding episodes.
2) Planting of ten ha with Black mangrove and White mangrove saplings by 2020 to cover and structure.
3) Monitoring of water depth, salinity and flooding.
4) Re-assessment of vegetation structure and cover every year by on the ground measurements of seedling and tree density and canopy cover and at the landscape level utilizing un-manned aerial vehicles.

Punta Santiago

The mangroves at Punta Santiago suffered primarily wind damage, with little evidence for drastically altered hydrology. Overall mortality at Punta Santiago was 34%, with most of the loss occurring in upland forests, not wetlands (Figure 11, Table 4). Wetlands experienced a loss of 34%, corresponding to a loss of around 1.6 hectares. Viable seeds were observed at the sites, suggesting natural regeneration will occur, and no abnormalities in water chemistry were measured. Further, the NRCS hydrology/geomorphology report found no significant alterations to site hydrology. This suggests the primary damage to the vegetation at Punta Santiago was due to wind and that no active management is necessary for rehabilitation. We therefore recommend a passive monitoring program with no active management unless significant changes in recovery are detected.

Figure 10 The mangroves at Punta Santiago suffered a mortality rate of 34%, although natural regeneration, including seed germination and tree re-sprouting has already begun. Recommendations are to passively monitor and allow for natural regeneration.

Course of Action:

1) Passive monitoring program with no active management unless significant changes in recovery are detected.
2) Re-assessment of vegetation structure and cover every year by on the ground measurements of seedling and tree density and canopy cover and at the landscape level utilizing un-manned aerial vehicles.

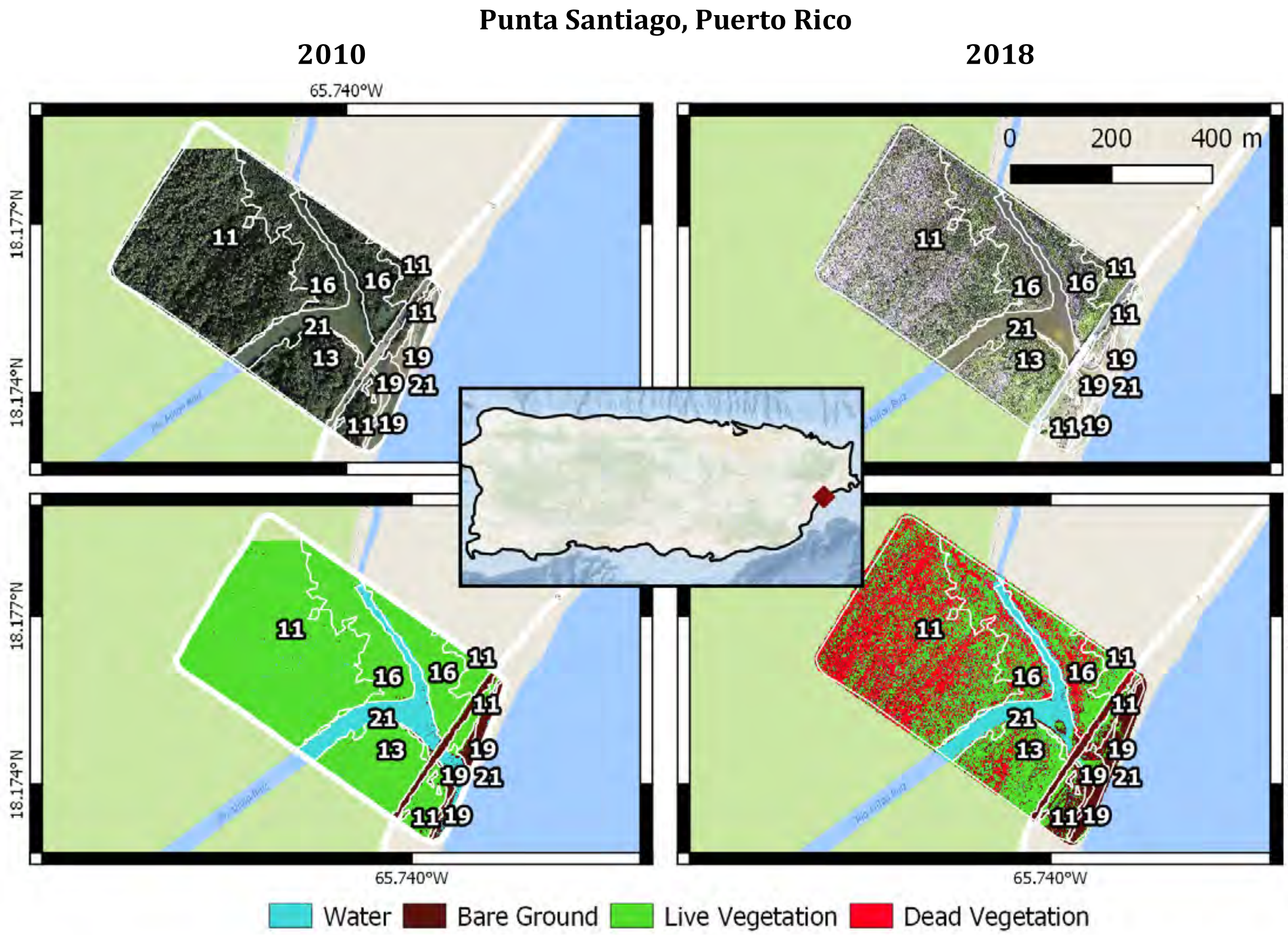


Figure 11 Aerial imagery of the mangroves at Punta Santiago, Puerto Rico from 2010 to 2018, representing pre and post hurricane, respectively. Numbers represent major habitat classes as represented in the below table. Punta Santiago suffered moderate mangrove mortality rates and is expected to recuperate naturally and would not likely benefit significantly from active management.

			2010				2018			
	Habitat Type	Area (ha)	Water	Bare Ground	Alive Veg.	Dead Veg.	Water	Bare Ground	Alive Veg.	Dead Veg.
11	Upland Forest	10.9	0%	1%	99%	0%	0%	8%	45%	47%
12	Scrub/Shrub	2.5	1%	0%	99%	0%	0%	7%	83%	10%
16	Estuarine Forested Wetland	4.5	3%	0%	97%	0%	7%	2%	57%	34%

Table 4 The mangroves at Punta Santiago suffered moderate mortality, with aerial imagery suggesting 34% mortality, equivalent to nearly 1.5 hectares of forest. Other vegetation also suffered to a greater extent, such as upland forests.

Piñones Forest

Although no aerial surveys were possible at Piñones due to restrictions from the nearby international airport, we were able to assess the site on the ground (Appendix B). This assessment found 30% mortality in the mangroves, with sufficient live mangrove seedlings and hydrological and water chemistry conditions that did not suggest any imminent threats to ecosystem vitality (Figure 12). We expect natural regeneration and canopy closure to occur over the next five years. Therefore, we recommend only passive monitoring to ensure natural rehabilitation occurs unimpeded and no active vegetation rehabilitation unless significant changes are detected.

Figure 12 The mangroves at Piñones suffered a mortality rate of 30%, although natural regeneration, including seed germination and tree re-sprouting has already begun. Recommendations are to passively monitor and allow for natural regeneration.

Course of Action:

1) Passive monitoring program with no active management unless significant changes in recovery are detected.
2) Re-assessment of vegetation structure and cover every year by on the ground measurements of seedling and tree density and canopy cover and at the landscape level utilizing un-manned aerial vehicles.

Short Description of CoA: Restoration of the resiliency and functional capacity of Puerto Rico's coastal wetlands (hydrology and vegetation structure) to act as a natural barrier vital to reduce or minimize the eminent threats to lives and livelihoods, public infrastructure security and human health.

What does the CoA do?

Carry effective and measurable actions to restore the resiliency and functional capacity of Puerto Rico's coastal wetlands (hydrology and vegetation structure) to act as a natural barrier vital to reduce or minimize the eminent threats to lives and livelihoods, public infrastructure security and human health.

Primary damage to all sites was in the form of defoliation, uprooting of trees, and or breaking of tree branches and trunks. While destructive to individual trees, these forms of damage do not typically result in forest wide mortality. This was evident in the moderate mortality rates observed at three of the five sites, where less than fifty percent of mangrove coverage was classified as dead. In these cases, it is expected the surviving trees will be capable of reaching near full canopy coverage in the next 12-18 months. Further, with some viable germinating seeds and seedlings present at these sites, understory coverage has already begun to regrow and will continue to fill in remaining canopy gaps. We expect these sites to reach pre-hurricane forest metrics of stem density and diameter over the next five years. Complete secondary succession of large patches may take longer, around 15 years, but only if the appropriate hydrology is maintained and if there is a sustainable supply of germinated seeds from adjacent stands. The two sites at Punta Tuna and Isabela, however, do not meet these criteria and will require active management towards an accelerated recovery.

Unlike the primarily wind damage at the other sites, the mangroves of Punta Tuna and Isabela were likely affected by drastic changes in hydrology. At Punta Tuna, the closing of the wetland channel by sand deposition during the storm, followed by the flooding from precipitation and storm surge, resulted in extremely high-water levels and no drainage channel. As a result, the wetland was flooded with abnormally high water (1 meter) for an abnormally long time (4 months). Plant roots were thus drowned with no oxygen source and consequently died. This hypothesis is strengthened by the survival of trees and plants along higher grounds at the wetland perimeter. Similar observations were made at Isabela, where the drainage of the wetland was further hindered by a paved bike path. Although some effort was made to allow for drainage under the paved path, it was not sufficient to completely drain the wetland following hurricane María. Therefore, although trees were likely impacted by wind damage, it was prolonged high flood waters that ultimately killed most of the forest. This flooding also killed any existing seeds and seedlings. Thus, unlike the other sites where viable propagules (germinated seeds) and seedlings were observed, there are very few to no recruits capable of regenerating the forest at Isabela and Punta Tuna. For these reasons, active management involving extensive planting will be necessary at these sites to hasten recovery to pre-hurricane optimal conditions.

Course of actions for each site vary depending upon extent and cause of damage. Extensive mortality caused by chronic hydrology changes requires extensive repairs to geomorphology in order to restore sustainable conditions, as well as parallel restoration of woody vegetation through planting. Sites in which relatively minor wind damage was the primary problem require only constant monitoring to ensure natural recovery progresses satisfactorily. Specific recommendations given in Table 5 are based on the Assessment of Urban Coastal Wetlands Vulnerability to Hurricanes in Puerto Rico, carried out by the University of Puerto Rico, with contributions from: Jon Fripp, PE, Natural Resource Conservation Service and Barry Southerland, PhD, USDA Natural resource Conservation Service.

Table 5 specific site recommendations. Variations in recommendations depend on extent and cause of mortality, with hydrologically altered sites requiring more extensive repairs.

Site Name	Methodology
Jobos, Isabela	5) Restore hydrology: a. Remove deposition under bike train bridges and improve outlet with a constructed channel b. Establish an MOU with USACE regulatory and other stakeholders to allow future maintenance of the channel outlet to be conducted as needed c. Install fill islands/peninsulas for depth diversity to increase resilience d. Replace fill portion of bike path with elevated trail 6) Monitor hydrology: a. Install monitoring wells equipped with recorders for water level and salinity 7) Rehabilitate mangrove vegetation a. Plant mangrove saplings 8) Monitor plant succession and mangrove recovery a. Assess vegetation structure through on the ground measurements of tree and seedling densities b. Assess landscape scale vegetation coverage through unmanned aerial vehicles at each site
Punta Tuna, Maunabo	5) Restore hydrology: a. Improve outlet from wetland system to ocean (maintenance will be needed) b. Establish an MOU with USACE regulatory and other stakeholders to allow future maintenance of the channel outlet to be conducted as needed 6) Monitor hydrology: a. Install monitoring wells equipped with recorders for water level and salinity 7) Rehabilitate mangrove vegetation a. Plant mangrove saplings 8) Monitor plant succession and mangrove recovery a. Assess vegetation structure through on the ground measurements of tree and seedling densities b. Assess landscape scale vegetation coverage through unmanned aerial vehicles at each site

Cucharillas Natural Reserve/ Malaria Channel, Cataño	• Restore hydrology: a. Funding /Repair/ Management improvements are needed at pump station/ tide gates for reestablishing marine -terrestrial connectivity and prevention of flooding episodes. • Monitor hydrology: a. Install monitoring wells equipped with recorders for water level and salinity • Rehabilitate mangrove vegetation a. Plant mangrove saplings • Monitor plant succession and mangrove recovery a. Assess vegetation structure through on the ground measurements of tree and seedling densities b. Assess landscape scale vegetation coverage through unmanned aerial vehicles at each site
Torrecillas/ Pinones, Carolina	4) Monitor hydrology: a. Install monitoring wells equipped with recorders for water level and salinity 5) Rehabilitate mangrove vegetation a. Plant mangrove saplings 6) Monitor plant succession and mangrove recovery a. Assess vegetation structure through on the ground measurements of tree and seedling densities b. Assess landscape scale vegetation coverage through unmanned aerial vehicles at each site
Punta Santiago, Humacao	4) Monitor hydrology: a. Install monitoring wells equipped with recorders for water level and salinity 5) Rehabilitate mangrove vegetation a. Plant mangrove saplings 6) Monitor plant succession and mangrove recovery a. Assess vegetation structure through on the ground measurements of tree and seedling densities b. Assess landscape scale vegetation coverage through unmanned aerial vehicles at each site

Who is implementing the CoA?

The following agencies and institutions will establish a concerted effort of the COA implementation for improving efficiency and reducing costs.

DNER – Government of Puerto Rico
NOAA
US Fish & Wildlife
Non-governmental Institutions
Community-based organizations
USDA
USACE
USEPA
University of Puerto Rico

How are they implementing the CoA?

Assessment-based restoration recommendations:

Site Name	Methodology
Jobos, Isabela	9) Restore hydrology: a. Remove deposition under bike train bridges and improve outlet with a constructed channel b. Establish an MOU with USACE regulatory and other stakeholders to allow future maintenance of the channel outlet to be conducted as needed c. Install fill islands/peninsulas for depth diversity to increase resilience d. Replace fill portion of bike path with elevated trail 10) Monitor hydrology: a. Install monitoring wells equipped with recorders for water level and salinity 11) Rehabilitate mangrove vegetation a. Plant mangrove saplings 12) Monitor plant succession and mangrove recovery a. Assess vegetation structure through on the ground measurements of tree and seedling densities b. Assess landscape scale vegetation coverage through unmanned aerial vehicles at each site

Punta Tuna, Maunabo	9) Restore hydrology: a. Improve outlet from wetland system to ocean (maintenance will be needed) b. Establish an MOU with USACE regulatory and other stakeholders to allow future maintenance of the channel outlet to be conducted as needed 10) Monitor hydrology: a. Install monitoring wells equipped with recorders for water level and salinity 11) Rehabilitate mangrove vegetation a. Plant mangrove saplings 12) Monitor plant succession and mangrove recovery a. Assess vegetation structure through on the ground measurements of tree and seedling densities b. Assess landscape scale vegetation coverage through unmanned aerial vehicles at each site
Cucharillas Natural Reserve/ Malaria Channel, Cataño	• Restore hydrology: a. Funding /Repair/ Management improvements are needed at pump station/ tide gates for reestablishing marine -terrestrial connectivity and prevention of flooding episodes. • Monitor hydrology: a. Install monitoring wells equipped with recorders for water level and salinity • Rehabilitate mangrove vegetation a. Plant mangrove saplings • Monitor plant succession and mangrove recovery a. Assess vegetation structure through on the ground measurements of tree and seedling densities b. Assess landscape scale vegetation coverage through unmanned aerial vehicles at each site
Torrecillas/ Pinones, Carolina	7) Monitor hydrology: a. Install monitoring wells equipped with recorders for water level and salinity 8) Rehabilitate mangrove vegetation a. Plant mangrove saplings 9) Monitor plant succession and mangrove recovery a. Assess vegetation structure through on the ground measurements of tree and seedling densities b. Assess landscape scale vegetation coverage through unmanned aerial vehicles at each site

Punta Santiago, Humacao	7) Monitor hydrology: a. Install monitoring wells equipped with recorders for water level and salinity 8) Rehabilitate mangrove vegetation a. Plant mangrove saplings 9) Monitor plant succession and mangrove recovery a. Assess vegetation structure through on the ground measurements of tree and seedling densities b. Assess landscape scale vegetation coverage through unmanned aerial vehicles at each site

Site-specific management plans
Public Policy development and enforcement

What is the likely time scale to see benefits?
Short-term – two-five (2-5) years
Long-term – ten-twenty (10-20) years habitat recovery and structural function of wetlands as interface between the land and aquatic ecosystems

Location (if any) of CoA.
In order of priority, if only one course of action can be initially implemented:
1) Ciénaga las Cucharillas Natural Reserve. Sector(s) Impacted:

a. Local Integrated services
b. Health care
c. Education
d. Human capital
e. Entrepreneurship business
f. Visitor economy
g. Transportation
h. Public and private Infrastructure
i. Housing
j. Power
k. Public buildings
l. Economics
m. Municipalities
n. Community Planning and Capacity Building
o. Social services
p. Water
q. Natural resources
r. Ocean economy

2) Punta Tuna and Playa Jobos,Isabela: Sector(s) Impacted:

a. Local Integrated services
b. Education
c. Human capital
d. Entrepreneurship business
e. Visitor economy
f. Transportation
g. Public and private Infrastructure
h. Economics
i. Municipalities
j. Community Planning and Capacity Building
k. Water
l. Natural resources
m. Ocean economy

3) Piñones Forest and Punta Santiago: Sector(s) Impacted:

a. Local Integrated services
b. Education
c. Human capital
d. Entrepreneurship business
e. Visitor economy
f. Transportation
g. Public and private Infrastructure
h. Economics
i. Municipalities
j. Community Planning and Capacity Building
k. Natural resources
l. Ocean economy

4) Pterocarpus forests: Sector(s) Impacted:

a. Education
b. Visitor economy
c. Economics
d. Municipalities
e. Community Planning and Capacity Building
f. Social services
g. Natural resources
h. Ocean economy

Potential Benefits

A brief description of how the CoA will impact the issue together with estimates of the benefits (qualitative or quantitative)

1) Reduction of flood impacts to public and private infrastructure: reduction in maintenance and recovery costs.
2) Filtration of contamination such as sewage and heavy metals: increased water quality
3) Reduction of ocean swell impacts to public and private infrastructure due to cyclonic events in and off-shore disturbances: reduction in maintenance and recovery costs.
4) Reduction of coastal erosion: reduction of impact to inland public and private infrastructure, increased tourism, increased recreational activities for the population,
5) Sediment trapping avoiding loss or impact to coral reefs: reduction of storm events to the shores, improvement of habitat and breeding grounds for species of economic importance
6) Provision of wildlife habitat area for feeding and reproduction: maintenance of biodiversity
7) Improvement of quality of life, health and economies in the surrounding areas
8) Increased tourism; improvement the economies of the communities.
9) Capacity building in the implementation of the COAs and management of restored areas: stakeholder involvement will insure a successful implementation of management and policy and laws reinforcement.

Additional Information:

Describe the expected outcomes of the COA. Provide analysis and/or research/literature of why this COA should be beneficial.

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Potential Spillover Impacts to Other Sectors

1. Water – flood control pumps can negatively impact the wetlands hydrology when they are not properly managed; need to coordinate storm water, flood control, and wetlands policies since they interconnect; ground water recharge; water sector manages sewage discharge to wetlands; filtration of contamination such as sewage and heavy metals: increased water quality.
2. Power – protect power generation or distribution sites at several coastal locations.
3. Economy – serves recreation by protecting beaches and reefs, and aesthetic value for tourism; protects infrastructure from flood damages; protects agricultural lands (buffer).
4. Municipalities – they need to participate in planning and land use policies/regulations and implementation, as they are important actors in the decision-making and implementation process and the local integrated services; reduction of flooding conditions in coastal areas, reduction of recovery and maintenance costs of public roads and infrastructure, improvement of health and water quality and local Integrated services
5. Education: provides the venue for education the government, public and private sector and communities and schools in the ecosystem services that wetlands provide that benefit quality of life and the economy without negative trade-offs that affect the surrounding communities.
6. Entrepreneurship business: providing recreational areas where microenterprises can be developed within the eco-tourism concept.
7. Transportation: by preventing flood impacts and erosion, maintenance costs are reduced.
8. Ocean economy: improvement of habitat and breeding grounds for species of economic importance
9. Natural resources: provision of wildlife habitat area for feeding and reproduction: maintenance of biodiversity; maintenance of nesting areas for critically endangered species.
10. Housing: reduction of flooding and improvement of water quality thus maintaining quality of life and maintaining house prices.

Additional Information:

Add additional analysis and/or research/literature of why this COA may have spillover impacts.

Potential Costs

A total of $13,150,00 is required for coastal monitoring and rehabilitation of the five sites. If the Pterocarpus sites are considered, and additional costs should be based on the assessments of each site.

Estimated costs for coastal wetland monitoring and rehabilitation at the five sites across Puerto Rico. Costs assume $30/m^2$ for rehabilitation of vegetation.

Site	Passive Monitoring	Hydrology Rehabilitation	Vegetation Rehabilitation	Total
Isabela	$20,000	$350,000	$4,500,000 /20 hectares	$4,870,000
Punta Tuna	$20,000	$350,000	$4,500,000 /20 hectares	$4,87,000
Ciénaga las Cucharillas	$20,000	$1,000,000	$2,250,000 /10 hectares	$3,270,000
Punta Santiago	$20,000	$0	$50,000	$7000.00
Piñones	$20,000	$0	$50,000	$7000.00
	$100,000	$1,750,000	$12,250,000	**$13,150,000**

Additional Information:

Add additional information about how costs may vary depending on different assumptions/limitations.

Costs may vary if another hurricane or natural event happens during the restoration period.

Potential Funding Mechanisms

Federal (specific agency and program is best), commonwealth, private sector, … sources that could be used to fund the CoA

- NOAA
- US Fish & Wildlife Service
- USDA
- USACE
- USEPA
- Private sector

Potential Pitfalls

Where the CoA could fail for reasons outside of the CoA. Dependencies that exist with other sectors or subsectors.

- Lack of a concerted effort of the COA implementation among agencies, institutions and organizations, reducing efficiency and increasing costs.

- Lack of strategic focus: overall strategy and goals must be integrated into a performance management process to meet the goals.

- Lack of leadership support in the implementing agencies, institutions and organizations: Without leadership support, performance management will not be successful no matter how well-designed the process can be.
- Lack of synchrony between availability of funds and implementation of the COAs due to bureaucratic constraints in each agency or institution that does not support a cost/effective product: Carry effective and measurable actions to restore the resiliency and functional capacity of Puerto Rico's coastal wetlands (hydrology and vegetation structure) to act as a natural barrier vital to reduce or minimize the eminent threats to lives and livelihoods, public infrastructure security and human health

- Lack of timely, meaningful feedback about the implementation process.

- Lack of integration among agencies, institutions, municipalities and stakeholders.

- Lack of stakeholder involvement in the planning and implementation phases

- Lack of proper training and communication

Likely Precursors

Brief description of the precursors required for the COA.

- Review previous wetlands policies / plans for potential actions
- Coordination and incentives for private owners of wetlands
- Coordination and incentives for community-based organizations and sectors with the potential or that are presently managing the wetlands.
- Insurance by respective agencies and institutions of providing the necessary permits and effective administrative support to carry out the COA in a cost/effective way without unnecessary delays and bureaucratic restrictions.

- Effective coordination among agencies that will be involved in debris removal, erosion control, restoration of hydrological conditions, maintenance of culverts, ditches, pumps, etc.

Additional Information:
Add additional information about interdependencies and precursors for the COA.