Ensure Functioning Ecosystems

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Ecosystem Functions, Services, and Baseline Conditions

Baseline

The San Juan Bay Estuary (SJBE) is home to a variety of species including more than 160 birds, 300 plants, 87 fish, and 20 amphibians and reptiles. At least 16 of these species are considered endangered, threatened, endemic to Puerto Rico, and/or rare (U.S. Environmental Protection Agency [USEPA], 2025). Estuary ecosystems are a complex mix of fresh and marine water, requiring a delicate balance to achieve a fully functioning ecosystem. The unique mix of these two environments provide for a wide range of conditions for organisms to seek opportunities to outcompete others as tides ebb and flow, rains come and go, and storms create rapid changes to this complex environment. In a well-balanced ecosystem, these opportunities create a healthy and sustainable diversity of species; however, when extreme events and pollutants imbalance the ecosystem, infectious bacteria, harmful algal blooms, and invasive and nuisance species may be opportunistic in dominating the environment. The human adaptation of uplands, harvesting of ecosystem mineral and living resources, and pollutant discharges have drastically changed the ecosystem function, ecological services, and natural balance in the SJBE.

Infrastructure needs are outlined in the Maintain and Improve Aging and Failing Gray and Green Infrastructure that Negatively Impacts Water and Bottom Sediment Quality Action Plan, which also identifies actions that will be required to restore balance of the SJBE. While sewer systems, stormwater systems, and port and harbor infrastructure are visible and more easily recognized by most people, ecosystem function, biodiversity, and eutrophication are less tangible. Furthermore, the complexity and effect of ecological services are difficult to quantify. Ecological services are the benefits that humans derive from ecosystems as well as the benefits that organisms within the ecosystem can provide to improve ecosystem quality. These include direct benefits, such as food and commodities, but also greenspace and improvements to water and air quality. In SJBE, these ecological services include fisheries, leisure activities, carbon sequestration, and sediments and benthic organisms' ability to retain nutrients to improve water quality. As the SJBE declines, so do the ecological services.

The San Juan Bay Estuary Program Ecological Assessment – Biological Community and Habitat Characterization Report (Puerto Rico Department of Natural and Environmental Resources [DNER], 1997) provided a complete assessment of the biological community in 1995, with habitats divided into ten types. A historical perspective of the estuary was evaluated to establish a "benchmark time period" as a reference to the ecological baseline. While changes to the ecology of the estuary date back to the 1700s, significant changes to the system were not made until the mid-1800s and early 1900s. Based on available data and the major population increase in the 1940s, a benchmark of 1936 was used as the ecological baseline.

An inventory of urban forests in the SJBE was completed in 2001 and 2011 and reported in the San Juan Bay Urban Forest Inventory (U.S. Department of Agriculture [USDA], 2014). This is a comprehensive inventory of the plant species found in the SJBE watershed, population and coverage of those species, and change in time from 2001 to 2011. This inventory also documented the land use over the same time period. This study identified an increase in commercial/industrial/transportation and wetland/water/ agriculture land uses over the ten-year period, and a decrease in institution/park, mangrove forest, moist forest, and vacant land uses, suggesting developed lands have taken over natural and green land use in the period from 2001 to 2011. Given this change in land use, one would anticipate a similar change in the coverage and population of the natural vegetation; however, this did not seem to be the case. There was a significant increase in tree and shrub cover in each land use category and nearly double the stored carbon, suggesting a general shift

towards greener land use, and/or more mature plant species over the ten-year period. The study identified that the number and species richness of the species also increased in every land use category except institution/parks. This increase in plant coverage provides a significant benefit for ecological services, due to sequestration of carbon, green space, recreational opportunities, and ecological refuge (USDA, 2014).

As residential areas are developed and mature, the tree and shrub cover on them changes, here from 2001 (left) to 2011 (right). (photos by Jeffery Glogiewicz, Consultores Ambiental and the Fundación Puertorriqueña de Conservación)

Seagrass and benthic studies have been conducted for specific areas and projects over the past 20 years. These studies include Condado Lagoon (Tetra Tech, 2011), but no comprehensive inventory has been compiled or compared through time. These data may inform management and trends for other species, such as the Antillean manatee. The Antillean manatee was formerly a subspecies of the West Indian manatee and is now a separate species, In January 2025, the U.S. Fish and Wildlife Service (USFWS) proposed to remove the West Indian manatee from the threatened species list and add the Florida manatee (the other West Indian manatee subspecies) to the list as threatened and the Antillean manatee as endangered. The water quality and habitat destruction as well as increased severe storm activity and marine traffic have created increased pressure on this species population (USFWS, 2024).

Noise pollution is another potential concern for manatees and other species in the SJBE. Harm to dolphins and whales from sonar and loud noises are well documented, but the effects on other organisms in the SJBE are not well understood. A recent study in Jobos Bay National Estuarine Research Reserve found that mangroves may be an effective natural barrier to anthropogenic noise (Castro-Rivera, 2024). As urban noise pollution is an increasing problem, mangroves may provide a valuable nature-based mitigation solution.

Urban light pollution is another growing issue that affects nesting sea turtles and limits the natural visibility of the night sky. Both direct light in the nesting areas and sky glow and glare can affect sea turtles. Reducing new light sources, ensuring lights are off when not needed, reducing the amount of lit area, and retrofitting existing light sources with full cutoff and mounted as low to the ground as possible may reduce the issues for sea turtles. These measures will also reduce energy needs and improve visibility of the natural night sky. When light sources are in direct line to sea turtle nesting areas, “turtle friendly” lighting should be used.

SJBE benthic systems are affected by water and sediment quality from anthropogenic activities in the high-density San Juan metropolitan area. Sediment quality is driven by dynamic circulation from dredging and filling, erosion and sedimentation from uplands, and bottom sediment resuspension (Estuario, 2000).

Historically, the bathymetry in portions of lagoons have been altered to allow for improved navigation. These alterations have had a significant effect on the ecological systems to the interconnected lagoons and channels that comprise much of the waterbody system. This has led to changes in water turnover from tidal influx due to increased depth from dredging. The increased depth and volume of the lagoons has reduced the capacity to accommodate increased runoff. Additionally, hydrological alterations in the watershed such as impervious surfaces, stream channelization, and watershed topography has increased stormwater discharge into the SJBE receiving waterbodies. This increase in urban runoff has dominated the tidal influence on the water exchange and led to organic material accumulation, salinity increases, and oxygen depletion (Lugo and Bauzá-Ortega, 2024). Subsequently, the increase in urban runoff carries with it higher concentrations of pollutants of concern that directly affect benthic systems. The figure below depicts water flows for dry weather conditions in the SJBE.

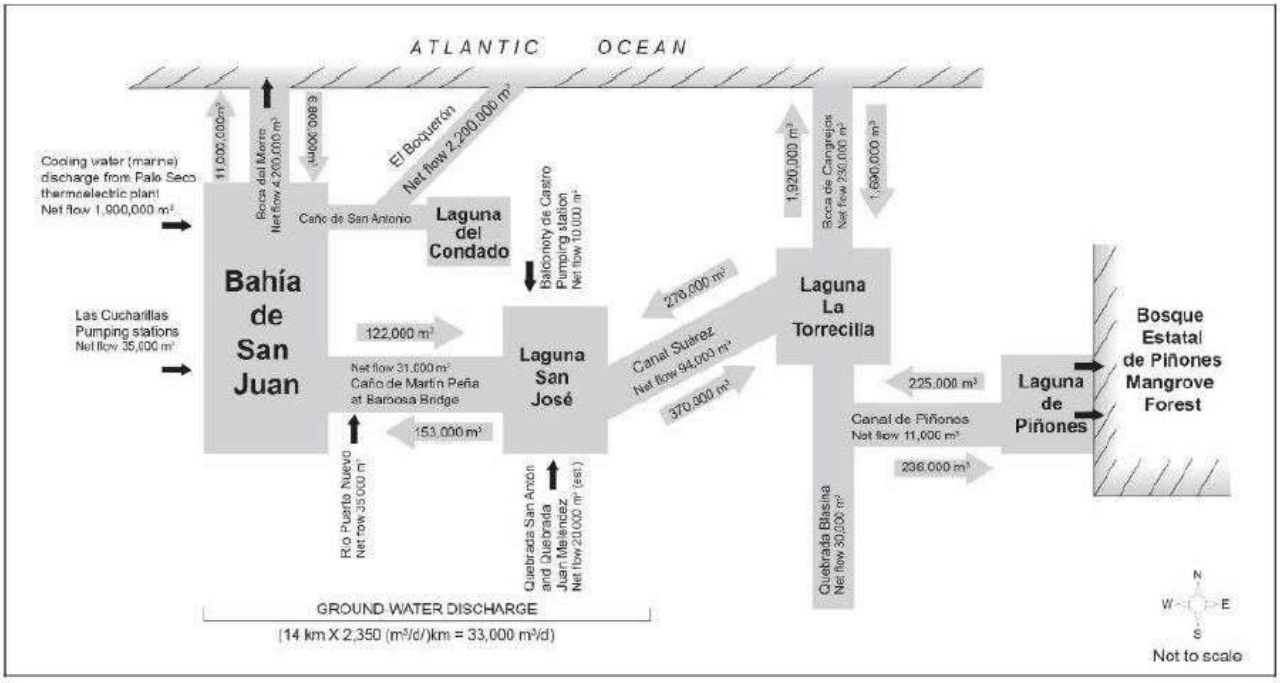

Figure 25. Average daily water flows for dry weather conditions in the San Juan Bay Estuary (Webb and Gómez Gómez 1998). This is a more comprehensive version of Figure 17. Reversing tidal flows dominate unidirectional flow. Flow from *río Grande de Loíza* into the mangroves is not shown.

Not all benthic systems are affected equally by environmental changes. Ramirez et al. (2012) theorized that the high proportion of diadromous fish, which have the ability to migrate between the ocean and freshwater, are able to continuously colonize urban streams and maintain populations in heavily affected environments if their associated marine environment is not severely degraded (Ramirez, 2012).

Anthropogenic activities, such as wastewater treatment system discharges, are estimated to have a combined yield that is four times higher than other urban and rural-agricultural watersheds in Puerto Rico (Ortiz, 2006). Benthic communities on the lagoon bottom were negatively affected by this increase in nutrient-rich urban runoff and wastewater treatment systems discharge, which overwhelmed the biotic capacity to process the nutrients leading to algal blooms that further distress benthic communities The SJBE was assessed in 2009 through a benthic index to better compare the relative health of the waterbodies in the system against one another and to track degradation or improvements. This assessment

was completed to document benthic community diversity, presence or absence of pollution-tolerant taxa, and presence or absence of pollution-sensitive taxa as shown in Table 1.

Table 1. Benthic Index Scores for Individual Waterbodies (from PS&J, 2009)

Waterbody	Mean	Standard Deviation	Maximum	Medium	Minimum	# of Observations
San Juan Bay	2.74	0.80	4.13	2.86	1.45	15
Condado Lagoon	2.62	1.09	4.01	3.04	1.00	7
San José Lagoon	1.14	1.03	2.24	1.63	0.00	12
Torrecilla Lagoon	3.07	0.42	3.41	3.21	2.35	5
Piñones Lagoon	1.01	0.88	2.14	0.95	0.00	4
San Antonio Canal	3.09	-	3.09	3.09	3.09	1
Martín Peña Canal	1.00	-	1.00	1.00	1.00	1
Suárez Canal	0.00	0.00	0.00	0.00	0.00	2
Other Channel Sites	1.48	0.20	1.63	1.56	1.26	3

Based on this index, the values suggest the following waterbody classifications for benthic communities:

- Healthiest: Torrecilla Lagoon and Condado Lagoon
- Healthy: San Juan Bay
- Moderately healthy to stressed: San José Lagoon
- Stressed: Canal locations and Piñones Lagoon

It should be noted that this type of assessment may not be appropriate for Piñones Lagoon as the surrounding area has a low population density and does not have the same anthropogenic activities as the other waterbodies. Furthermore, these benthic index scores were compared to the water quality index, which was based on dissolved oxygen, turbidity, fecal coliform bacteria, and pH (see Table 2). The water quality index indicates that the Piñones Lagoon exhibited a healthy water quality environment. Therefore, the benthic index may not be the appropriate comparison tool for this waterbody.

Table 2. Comparison of Scores Produced using Water Quality Index (from PBS&J, 2009)

Waterbody	Water Quality Index Classification	Benthic Index Classification
San Juan Bay	B	B
Condado Lagoon	Not applicable	B
San José Lagoon	C	C
Torrecilla Lagoon	C	B
Piñones Lagoon	B	D/F
Suárez Canal	D	D/F
Martín Peña Canal	F	D/F

Approximately 50% of the benthic environments were mapped (Lugo and Bauzá-Ortega, 2024) to locate submerged aquatic vegetation (*Halophila decipiens* and red algae) and beds of bivalves (*Mytilopsis domingensis*). Benthic communities grew on dredged and non-dredged bottoms and artificial anthropogenic substrates. As expected, submerged aquatic vegetation was more abundant in non-dredged areas than dredged areas. The October 2022 list of aquatic organisms within the SJBE contains a diverse list of native and nonnative benthic communities including non-native fish, aquatic insects, shrimps and crabs, aquatic arthropods, worms and leeches, sponges, snails and bivalves, and reptilians.

Objectives

- Thoroughly understand novel ecosystems and their ecosystem services.

- Eliminate light pollution in the estuarine system, particularly along coastlines.
- Determine how noise pollution may affect estuarine organisms.

Actions

***NEW-1* Complete a biodiversity (flora and fauna) inventory of ecological systems and update periodically.**

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Obtain and manage an inventory of conservation lands and wetlands to preserve biological diversity, functional integrity, and productivity.	Identify and protect wetland areas.	Document and map identified conservation lands and wetlands.	Lead: Estuario Implementing partners: U.S. Army Corps of Engineers (USACE), National Marine Fisheries Service (NMFS), USFWS, DNER, municipalities, Conservation Trust of Puerto Rico, private conservation groups	Pending	0-2 years	TBD	DNER, municipalities, USEPA
2. Continue to update and improve the Estuario species inventory.	Updates to the tables and report *List of the Flora and Fauna of the San Juan Bay Estuary System (December 1996)*	Species inventory updated.	Lead: Estuario Implementing partners: USACE, NMFS, USFWS, DNER, municipalities, Conservation Trust of Puerto Rico, private conservation groups	Ongoing	0-2 years	TBD	DNER, USEPA
3. Integrate biodiversity considerations into planning and land use decisions.	Provide metrics for biodiversity in planning documents and evaluate effects on biodiversity in land use decisions.	Metrics created and effects on biodiversity evaluated.	Lead: Estuario Implementing partners: DNER, municipalities, Conservation Trust of Puerto Rico, private conservation groups	Pending	0-2 years	TBD	DNER, municipalities

Regulatory and Policy Requirements

Integration of biodiversity into planning and land use decisions will require advocacy to ensure biodiversity is a consideration for all planning documents and land use decisions in and around the SJBE.

HW-15 Recover the population and health of the Antillean manatee within the SJBE and establish manatee protection areas.

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Perform boat surveys and use a network of public informers to document sightings and establish the total number of manatees within the SJBE system.	Completed data collection on the number of manatees that use the SJBE system.	Survey with locations and counts of manatee sightings.	Lead: DNER Implementing partner: USFWS	Pending	0-2 years	TBD	DNER
2. Establish a radio telemetry study of manatee movements within the SJBE system.	Improved information on manatee movement.	Map of manatee movement patterns.	Lead: DNER Implementing partners: USFWS, U.S. Geological Survey (USGS)	Pending	0-2 years	TBD	DNER
3. Establish manatee protection areas.	Manatee refuges and/or manatee sanctuaries are established and regulated to enforce boat use and speeds.	Manatee protection areas created and enforced.	Lead: USFWS Implementing partners: DNER, U.S. Coast Guard	Pending	0-2 years	TBD	USFWS
4. Continue Species Status Assessment Report for the Antillean Manatee.	Status Assessment Report for the Antillean Manatee to be completed annually.	Species Status Assessment Report for the Antillean Manatee completed.	Lead: USFWS Implementing partners: DNER, U.S. Coast Guard	Ongoing	0-2 years	TBD	USFWS

Regulatory and Policy Requirements

There are state regulated speed zones but increased enforcement is required. There are currently no manatee protection areas in Puerto Rico; however, USFWS has the authority to establish these areas for manatee refuge or sanctuaries. A manatee refuge is as an area where some waterborne activities and other restrictions are put in place to prevent the taking of a manatee. A manatee sanctuary is an area in which all waterborne activities are prohibited. Like the state regulated speed zones, once established these areas will require enforcement (USFWS, 2024).

***NEW-2* Reduce anthropogenic noise and light sources in the SJBE watershed to protect estuarine organisms.**

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Study how noise and light affect estuarine organisms in the SJBE system.	Obtain a more complete understanding of how noise and light affect estuarine organisms.	Effects of noise and light on estuarine organisms in the SJBE understood.	Lead: Estuario Implementing Partners: USACE, NMFS, USFWS, DNER	Pending	0-2 years	TBD	National Oceanic and Atmospheric Administration (NOAA)
2. Prepare an exterior light management plan for the SJBE.	Prepare an exterior light management plan for the SJBE and have municipalities enforce the actions through local ordinance.	Light management plan for the SJBE prepared and municipal ordinances in place.	Lead: Estuario Implementing Partners: Municipalities, NMFS, NOAA, USFWS, DNER	Pending	0-2 years	TBD	NOAA, DNER

Regulatory and Policy Requirements

Noise ordinances in the municipal areas need to be enforced to reduce anthropogenic noise around the SJBE. Percussive and other loud noises should also be considered in permit approval for construction in and around the SJBE. Municipalities should adopt turtle friendly lighting practices, and consider ordinances to eliminate direct lighting to the coastal sea turtle nesting areas, and reduce the sky glow.

***NEW-3* Support research to better understand benthic community dynamics within the SJBE watershed and continue to calculate the Benthic Index.**

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Establish partnerships with local universities and research institutions to study benthic communities.	Set up meetings and forums for partners to meet and collaborate.	Partnerships established.	Lead: Estuario Implementing partners: University of Puerto Rico, Ponce Health Sciences University. Caribbean Coral Reef Institute, NMFS, Caribbean Fisheries Management Council, USFWS, NOAA	Pending	0-2 years	TBD	NOAA

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
2. Organize workshops and training sessions to develop standardized methodology for research efforts and data collection.	Continue expansion of forums and meetings with partners to develop methodology and provide trainings.	Standardized methodologies developed.	Lead: NOAA Implementing partners: NMFS, USFWS	Pending	3-5 years	TBD	NOAA
3. Identify stakeholders and funding sources for priority research.	Continue expansion of forums and meetings with partners to identify sources of funding.	Sources of funding identified.	Lead: Estuario Implementing Partners: University of Puerto Rico, Ponce Health Sciences University. Caribbean Coral Reef Institute, NMFS, Caribbean Fisheries Management Council, USFWS, NOAA	Pending	3-5 years	TBD	NOAA, USACE
4. Use research findings to calculate benthic index.	Prepare a benthic index report.	Benthic index report prepared.	Lead: Estuario Implementing partners: NOAA, NMFS, and USFWS.	Pending	5+ years	TBD	NOAA, USACE
5. Use research findings to inform management practices and policy decisions.	Continue expansion of forums and meetings with partners to present research findings and train partners.	Management practices and policy decisions presented to partners.	Lead: Estuario Implementing Partners: DNER, USACE, NOAA, NMFS, USFWS	Pending	5+ years	TBD	NOAA, USACE

Regulatory and Policy Requirements

Funding is required to continue research and drive data to fully understand the benthic community and the ecological services they provide for supporting ecology and water quality.

***NEW-4* Gather data on critical habitats and species for protection in the expanded study area.**

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Develop and implement a study on critical habitats and species in the expanded study area including locations and conditions.	Gather information about habitats and species in the expanded study area.	Completed study with data to develop plans.	Lead: Estuario Implementing partners: DNER, municipalities, academia, scientific community	Pending	0-2 years	TBD	USEPA
2. Develop maps showing the results of the habitat and species study in the expanded study area.	Improve information on location and condition of critical habitats and species.	Maps showing habitats and species.	Lead: Estuario Implementing partners: DNER municipalities, academia, scientific community	Pending	3-5 years	TBD	USEPA
3. Use the study results to identify projects and management strategies for critical habitats and species in the expanded study area.	Improve condition of critical habitat and species in the expanded study area.	Project and management strategies list to improve habitat and species.	Lead: Estuario Implementing partners: DNER municipalities, academia, scientific community	Pending	5+ years	TBD	DNER, USEPA, municipalities

Regulatory and Policy Requirements

None for the study. The results will help inform regulatory and policy needs in the future.

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Integrated and Resilience-Based Ecosystem Management

Baseline

The SJBE is a highly dynamic and complex ecosystem that integrates diverse coastal and urban habitats, such as mangroves, seagrasses, coral reefs, riparian corridors, beaches, beach thickets, sand dunes, and upland moist forests. Each of these habitats plays a distinct yet interconnected role in maintaining the ecological integrity and resilience of the estuary. However, the SJBE is increasingly challenged by the cumulative effects of urbanization, industrial development, pollution, habitat loss, and altered hydrology, all threats that undermine ecosystem functions, degrade water quality, and jeopardize the social and economic well-being of dependent communities (Lugo and Bauzá-Ortega, 2024).

These challenges underscore the urgent need for an integrated and resilience-based ecosystem management approach that comprehensively addresses the interdependencies among habitats, improves ecological quality, and ensures that ecosystems are managed according to their conservation designations. The complexity of SJBE's ecosystems demands a management framework that transcends isolated actions or single-issue responses and instead fosters cross-sector collaboration, science-based restoration, and adaptive strategies that can respond to ongoing environmental change.

SJBE's habitats function as interconnected ecological networks. Mangrove forests, for example, not only stabilize shorelines and sequester carbon but also provide essential nursery grounds for fish and shellfish species, including the blue land crab (*Cardisoma guanhumi*), which has experienced population declines due to overfishing and habitat degradation (Govender, 2019; Bauzá-Ortega, 2015). Seagrass beds function as underwater corridors linking mangroves with coral reefs and support over 150 aquatic species, including endangered fauna such as the Antillean manatee and green sea turtle (Bauzá Ortega, 2015; LG2 Environmental Solutions and CSA Ocean Sciences, 2021). Coral reefs and artificial habitats enhance biodiversity and fish abundance, providing critical ecosystem services and recreational opportunities (Wenger et al., 2017; Harris, 2009).

Riparian corridors connect terrestrial and aquatic ecosystems, offering habitat diversity and supporting water quality, yet these corridors are vulnerable to canalization and urban encroachment, which fragment habitats and reduce ecological functions (Lugo et al., 2011; de Jesús Crespo and Ramírez, 2011). Coastal features such as beaches, beach thickets, and sand dunes provide buffers for storms and habitat for unique flora and fauna, but they face accelerated erosion and "coastal squeezing" due to sea level rise and human disturbance (Lugo and Bauzá-Ortega, 2024; Bruun, 1962; Fish et al., 2005).

The interdependence of these habitats means that degradation or loss in one area cascades through the system, reducing overall resilience. For example, mangrove deforestation or altered tidal flows can diminish fish nursery habitats, reduce sediment trapping, and impair water quality downstream. Likewise, loss of seagrass beds can increase sediment resuspension and turbidity, further stressing coral reefs and benthic communities. Recognizing and managing these links is fundamental to sustaining the estuary's ecological functions and the services they provide.

The SJBE system is subject to multiple, interacting stressors. Urbanization and industrial development introduce pollutants, nutrients, heavy metals, and trash that impair water quality and aquatic life (USEPA, 2009). Infrastructure development alters hydrology, disrupting tidal flows and sediment transport, which leads to sediment accumulation and habitat degradation.

These overlapping threats reduce the estuary's capacity to absorb disturbances and recover, which are fundamentally core aspects of resilience. Without strategic, integrated management, the cumulative effects erode biodiversity, compromise ecosystem services, and threaten the livelihoods of local fishing, tourism, and coastal communities.

Integrated ecosystem management embraces the complexity of the SJBE system by coordinating across habitat types, sectors, and stakeholders to enhance connectivity, ecological functions, and adaptive capacity. This approach includes science-based habitat restoration, such as the deployment of artificial reefs that provide shoreline protection while enhancing habitats and supporting aquaculture and recreation (Harris, 2009). It prioritizes the conservation and restoration of mangroves, seagrasses, and riparian corridors to maintain critical ecosystem services and biodiversity (Bauzá-Ortega, 2015; Lugo and Bauzá-Ortega, 2024).

Moreover, integrated management recognizes the importance of managing ecosystems according to their designated ecological roles and regulatory frameworks, including species-specific protections like those for the blue land crab (*Cardisoma guanhumi*) (Govender, 2019). Adaptive management strategies are vital to respond effectively to ongoing and future environmental changes, such as sea level rise-induced habitat migration and storm-driven sediment dynamics (Bruun, 1962; Estuario, 2016).

This process also recognizes critical species in the SJBE. There are 17 plant species considered critical, including Arana (*Schoepfia arenaria*) and Cobana Negra (*Stahlia monosperma*), which are listed as endangered and threatened, respectively by the USFWS and DNER. The Torrecilla – Vacía Talega – Piñones area serves as habitat for 11 critical plant species, of which four are endemic and eight are not found anywhere else in the system. Four other critical species are restricted exclusively to Las Cucharillas Marsh: two vines (Whitejacket [*Aniseia martinicensis*] and hog slip [*Ipomoea tiliacea*]) and two herbaceous species (John Charles [*Hyptis verticillata*] and Egger's nutrush [Scleria mitis]). Most of the remaining critical plant species are restricted to the less impacted areas of the estuary. These include a water fern (dwarf waterclover [*Marsilea polycarpa*]); an endemic shrub (Arana [*Schoepfia arenaria*]); endemic trees (uvero de monte [*Coccoloba sintenisii*], zapote de costa [*Manilkara pleeana*], and Maga wood [*Thespesia grandiflora]*); sea-purslane (*Sesuvium maritimum*); waterlily (*Nymphaea pulchella*); gray nickers (*Caesalpinia bonduc*); certain herbaceous species (twining screwstem [*Paronia paniculata*] and black sesame [*Hyptis spicigera*]); and intermediate arrowhead (*Sagittaria intermedia*) (Estuario, 2000).

A key objective of integrated management is to enhance ecosystem quality indicators that reflect ecological health and resilience. This includes improving water quality through pollution reduction, restoring habitat complexity to support diverse species assemblages, and increasing carbon sequestration via forest and wetland restoration (Brandeis et al., 2014). Monitoring these indicators provides feedback for adaptive decision-making and helps prioritize restoration efforts that yield the greatest ecological and social benefits.

SJBE's ecological richness and socio-economic importance hinge on the health of its interconnected ecosystems. Given the multitude of anthropogenic and climatic pressures, integrated and resilience-based ecosystem management is not only necessary but imperative. By understanding ecosystem interconnections, improving critical ecological indicators, and effectively managing protected areas, stakeholders can enhance the estuary's capacity to withstand and adapt to change, safeguarding its natural resources and the well-being of its communities for generations to come.

Objectives

- Determine the current condition and monitor ecosystem quality as the basis for integrated and resilience-based management.
- Determine the current condition and monitor the population status of threatened and endangered species.
- Determine the current condition and monitor the ecosystem function of natural protected areas.
- Thoroughly understand ecosystem interconnections.
- Improve ecosystem quality indicators.
- Properly manage natural protected areas according to their designation.

Actions

HW-01, HW-03, HW-05 Enhance mangrove forests along the shorelines of the SJBE system.

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Conduct a baseline assessment of existing mangrove populations to identify areas of degradation and prioritize conservation efforts.	Comprehensive mapping of mangrove populations.	Finalized baseline assessment.	Lead: DNER Implementing partners: Estuario, academia, local organizations	Pending	0-2 years	TBD	USEPA, DNER, municipalities
2. Develop guidelines for sustainable management practices and restoration techniques for mangrove ecosystems.	Identification of best practices for sustainable management and restoration.	Summary of successful, sustainable mangrove management practices and restoration.	Lead: DNER Implementing partners: Estuario, USFWS, USEPA	Pending	3-5 years	TBD	USEPA, DNER, municipalities
3. Establish a monitoring program to track the health and growth of mangrove populations, including the effects of invasive species.	Identification of key performance indicators to easily identify mangrove health.	Finalized monitoring program.	Lead: DNER Implementing partners: Estuario, USFWS, USEPA	Pending	3-5 years	TBD	USEPA, DNER, municipalities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
4. Develop partnerships with stakeholders and environmental organizations to secure funding and resources for ongoing conservation efforts.	Increase level of partnerships with stakeholders.	Collaborate with partners to secure funding for conservation efforts.	Lead: Estuario Implementing partners: DNER, USFWS, municipalities, local organizations, academia	Pending	5+ years	TBD	USEPA, DNER, municipalities
5. Plant mangroves along the shorelines in identified locations.	Improved survival and growth rates of newly planted mangroves.	Finalized planting plan.	Lead: DNER, USFWS, NRCS Implementing partners: local municipalities, local organizations, Estuario	Pending	3-5 years	TBD	DNER, USFWS, NRCS

Regulatory and Policy Requirements

Restoration of mangroves along the northern Caño Martín Peña has been a success story in the SJBE. Success will require continued legislative support to fund mangrove restorations and support from municipal and state officials to ensure existing mangroves remain and new development incorporates new mangrove buffers.

HW-07 Enhance seagrass beds in the SJBE. system

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Conduct baseline assessment of existing seagrass beds in the SJBE.	Enhanced understanding of current distribution of seagrass.	Finalized baseline assessment.	Leads: USEPA, DNER Implementing partners: Estuario, academia	Pending	0-2 years	TBD	USEPA, DNER, municipalities
2. Create a restoration plan with strategies for enhancing seagrass beds.	Identification of priority areas.	Finalized restoration plan.	Leads: USEPA, DNER Implementing partners: Estuario, municipalities, academia	Pending	3-5 years	TBD	USEPA, DNER, municipalities
3. Partner with stakeholders to conduct research on water quality and seagrass	Establish formal partnerships with local universities and key stakeholders.	Research proposal that outlines the objectives, methods, and expected	Lead: DNER Implementing partners: Estuario,	Pending	3-5 years	TBD	DNER, USEPA

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
health, using the findings to inform best management practices.		outcomes of the study, and secure necessary approvals.	municipalities, academia				
4. Establish a long-term monitoring program to track the health and growth of seagrass beds.	Development of standardized monitoring protocols for seagrass assessment.	Regular submission of monitoring reports to stakeholders.	Leads: USEPA, DNER Implementing partners: Estuario, municipalities	Pending	3-5 years	TBD	USEPA, DNER, municipalities
5. Identify strategies for restoration.	Achieve alignment of community needs and restoration objectives.	Finalize potential restoration strategies based on stakeholders.	Lead: DNER Implementing partners: Estuario, municipalities, community groups	Pending	3-5 years	TBD	DNER, USEPA, municipalities

Regulatory and Policy Requirements

The protection of seagrass habitat requires the support of local and state government to plan for long-term funding for a programmatic approach to seagrass monitoring and protection.

HW-24 Implement Law No. 112 of 2013, which created the Condado Lagoon Estuarine Nature Reserve.

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Implement public awareness and educational programs to inform local communities.	Improve community understanding of key issues.	Conducted follow-up evaluations to assess the effectiveness of the programs implemented.	Leads: DNER, Estuario Implementing partners: community representatives, Municipality of San Juan, businesses	Pending	0-2 years	TBD	DNER, municipalities
2. Establish a monitoring and evaluation framework to assess the effectiveness of management actions and compliance with Law No. 112	Establish specific, measurable indicators that.	Regularly review monitoring results and evaluate the effectiveness of management actions.	Leads: DNER, Estuario Implementing partners: community groups, community representatives, Municipality of San Juan, businesses	Pending	0-2 years	TBD	DNER, municipalities, USEPA

Regulatory and Policy Requirements

Continue to implement the law.

***NEW-2* Enhance coral communities in the SJBE system.**

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Assess existing coral communities in the SJBE.	Enhanced understanding of current coral distribution.	Finalized baseline assessment.	Leads: USEPA, DNER Implementing partners: Estuario, academia	Pending	0-2 years	TBD	USEPA, DNER, municipalities
2. Develop a restoration plan for the SJBE by evaluating options such as coral transplant salvaging and relocating existing coral fragments to degraded areas.	Identification of priority areas.	Finalized restoration plan.	Leads: USEPA, DNER Implementing partners: Estuario, municipalities, academia	Pending	3-5 years	TBD	USEPA, DNER, municipalities
3. Engage with stakeholders to involve them in the process.	Improved stakeholder awareness and understanding of goals.	Completion of an initial stakeholder outreach plan.	Leads: USEPA, DNER Implementing partners: Estuario, municipalities, local organizations	Pending	0-2 years	TBD	USEPA, DNER, municipalities
4. Establish a long-term monitoring program for coral communities in the SJBE.	Developed standardized monitoring protocols for coral assessment.	Regular submission of monitoring reports to stakeholders.	Leads: USEPA, DNER Implementing partners: Estuario, municipalities	Pending	3-5 years	TBD	USEPA, DNER, municipalities

Regulatory and Policy Requirements

Success will require support from municipal and state officials to ensure existing corals remain and new development incorporates features that can enhance and support new coral growth.

***NEW-3* Continue to design and implement measures that restore degraded benthic habitats and promote the creation of benthic habitats and fish and shellfish nurseries.**

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Assess benthic habitats to identify areas in need of restoration.	Increased understanding of the current condition and diversity of benthic habitats.	Integration of benthic habitat restoration strategies into broader ecosystem management plans.	Lead: DNER Implementing partners: Estuario, academia	Pending	0-2 years	TBD	DNER, USEPA
2. Conduct a feasibility study to identify locations for potential artificial structures.	Identification of suitable locations for artificial structures.	Finalized feasibility study.	Leads: DNER, USEPA Implementing partners: Estuario, academia, municipalities, local organizations	Pending	3-5 years	TBD	DNER, USEPA
3. Engage with local stakeholders to better involve artificial structures in the planning processes.	Improved stakeholder understanding of the purpose and benefits of artificial structures.	Organized workshops to discuss potential designs and locations for artificial structures.	Leads: DNER, USEPA Implementing partners: Estuario, academia, municipalities, local organizations:	Pending	0-2 years	TBD	DNER, USEPA
4. Implement pilot projects to test installations of artificial structures(i.e. artificial structures such as taíno reefs and biohuts.	Documentation of ecological benefits observed from the pilot projects.	Completed installation of pilot artificial structures.	Leads: DNER, USEPA Implementing partners: Estuario, academia, municipalities, local organizations	Pending	5+ years	TBD	DNER, USEPA, municipalities, local organizations

Regulatory and Policy Requirements

Success will require support from municipal and state officials to ensure existing coral remain, and new development incorporates features that can enhance and support new coral growth, sustain healthy sediments, and provide habitat for marine life.

***NEW-4* Enhance and protect seascapes and their connectivity.**

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Assess existing conditions and identify areas that need intervention.	Identification of specific areas exhibiting signs of degradation or decline in health.	Finalized priority areas for intervention based on assessment data.	Leads: DNER, NRCS, USEPA, Estuario Implementing partners: municipalities, academia	Pending	0-2 years	TBD	USEPA, DNER, NRCS
2. Develop an enhancement plan for seascapes.	Develop strategies and actions for enhancement.	Finalized enhancement plan.	Leads: DNER, NRCS, USEPA, Estuario Implementing partners: municipalities, academia	Pending	2-3 years	TBD	USEPA, DNER, NRCS
3. Implement the proposed enhancement plan.	Document improvements from implemented actions.	Executed enhancement actions.	Leads: DNER, NRCS, USEPA, Estuario Implementing partners: municipalities, academia	Pending	5+ years	TBD	USEPA, DNER, NRCS
4. Establish monitoring and maintenance protocols.	Identify key performance indications to assess enhancement efforts.	Initiated monitoring and maintenance activities.	Leads: DNER, NRCS, USEPA, Estuario Implementing partners: municipalities, academia	Pending	5+ years	TBD	USEPA, DNER, NRCS

Regulatory and Policy Requirements

Enhancing seascapes will require cooperation from municipalities through creation and enforcement of ordinances. Management strategies may also recommend legislation at the state and federal level.

HW-09 Establish management measures within the SJBE system for the land crab Cardisoma guanhumi.

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Identify critical habitats and needs for the species.	Assess current threats to habitats.	Completed data collection to map critical habitats and species distribution.	Lead: DNER, USEPA, NRCS Implementing partners: Estuario, academia, municipalities, local organizations	Pending	0-2 years	TBD	DNER, USEPA, NRCS
2. Develop a management plan.	Collect stakeholder input and academic research.	Finalized management plan.	Lead: DNER, USEPA, NRCS Implementing partners: Estuario, academia, municipalities, local organizations	Pending	3-5 years	TBD	DNER, USEPA, NRCS
3. Establish a monitoring program to track health and population metrics.	Increase frequency of monitoring activities.	Finalized monitoring program.	Lead: DNER, USEPA, NRCS Implementing partners: Estuario, academia, municipalities, local organizations	Pending	3-5 years	TBD	DNER, USEPA, NRCS

Regulatory and Policy Requirements

Species management will likely require cooperation from municipalities through creation and enforcement of ordinances. Management strategies may also recommend legislation at the state and federal level.

HW-10 Continue to implement a sea turtle recovery plan

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Identify areas within the SJBE as potential nesting areas.	Increased collaboration with stakeholders on collecting data.	Identified potential nesting areas.	Lead: DNER Implementing partners: USFWS, municipalities, Estuario	Ongoing	3-5 years	TBD	DNER, USEPA, USFWS

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
2. Enhance the population and health of the leatherback sea turtle.	Increased nesting activity.	Implemented protective measures for the species.	Lead: DNER Implementing partners: USFWS, municipalities, Estuario, academia	Pending	5+ years	TBD	DNER, USEPA, USFWS
3. Coordinate with stakeholders to educate the public on the importance of protecting sea turtle species.	Increased awareness of sea turtle conservation among the public.	Developed educational materials.	Lead: DNER Implementing partners: USFWS, municipalities, Estuario	Ongoing	0-2 years	TBD	DNER, USEPA, USFWS

Regulatory and Policy Requirements

Species management will likely require cooperation from municipalities through creation and enforcement of ordinances. Management strategies may also recommend legislation at the state and federal level.

HW-14 Protect existing populations of endangered and threatened bird species and protect and restore their habitat within the SJBE system.

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Enforce existing regulations regarding bird species and their habitat.	Increased compliance among stakeholders with existing regulations.	Conducted training sessions for regulatory agencies on laws and regulations.	Lead: DNER, USFWS Implementing partners: Estuario, municipalities, regulatory agencies	Ongoing	3-5 years	TBD	DNER, USFWS
2. Protect breeding and nesting areas in the SJBE.	Identify and map current and potential breeding and nesting areas.	Installed protection measures for breeding and nesting areas.	Lead: DNER, USFWS Implementing partners: Estuario, regulatory agencies	Ongoing	3-5 years	TBD	DNER, USFWS
3. Develop measures to control the introduction of exotic species into the SJBE.	Review current regulations and practices and identify areas for improvement.	Increased stakeholder awareness regarding risks of exotic species.	Lead: DNER, USFWS Implementing partners: Estuario, municipalities	Ongoing	5+ years	TBD	DNER, USFWS

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
4. Educate the public to increase awareness about management measures and regulations.	Increased public understanding of management measures and regulations.	Collaborated with stakeholders to promote outreach efforts.	Lead: DNER, USFWS Implementing partners: Estuario, local organizations	Ongoing	3-5 years	TBD	DNER, USFWS

Regulatory and Policy Requirements

Species management will likely require cooperation from municipalities through creation and enforcement of ordinances. Management strategies may also recommend legislation at the state and federal level.

HW-13 Enhance and protect critical plant species within the SJBE.

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Support nurseries to supply critical plant species.	Strengthened partnerships between nurseries and stakeholders.	Improved inventory of critical plant species.	Leads: DNER, USFWS Implementing partners: Estuario, municipalities, local nurseries	Pending	0-2 years	TBD	DNER, USFWS
2. Develop management plans for critical species.	Established, measurable indicators to assess effectiveness of management plans.	Finalized management plans for critical plant species.	Leads: DNER, USFWS Implementing partners: Estuario	Pending	3-5 years	TBD	DNER, USFWS
3. Establish protection zones to support propagation.	Identify areas as potential protection zones.	Created guidelines to protect and manage protection zones.	Leads: DNER, USFWS Implementing partners: Estuario, municipalities	Ongoing	3-5 years	TBD	DNER, USFWS
4. Educate the public on the importance of critical species.	Increased public awareness of critical plant species and their ecological roles.	Created educational resources focusing on the importance of critical species.	Leads: DNER, USFWS Implementing partners: Estuario, municipalities, local community organizations.	Ongoing	0-2 years	TBD	DNER, USFWS

Regulatory and Policy Requirements

Management will likely require cooperation from municipalities through creation and enforcement of ordinances. Management strategies may also recommend legislation at the state and federal level to ease permitting requirements for projects incorporating critical plant species.

HW-17 Determine historic and present recreational fishing areas in the SJBE and develop a plan to adequately manage recreational fishery resources.

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Identify areas used by recreational fisherman.	Increased understanding of fish species catch and popular fishing areas.	Discussed commonly fished areas and usage patterns with sport fishers.	Lead: DNER Implementing partners: Estuario, USFWS, NMFS, Sea Grant Puerto Rico, community groups	Ongoing	0-2 years	TBD	DNER
2. Engage with stakeholders to determine perceived challenges regarding fishery resources.	Increased network and involvement of stakeholders.	Compiled analysis of stakeholder feedback.	Lead: DNER Implementing partners: Estuario, USFWS, NMFS, Sea Grant Puerto Rico, community groups	Ongoing	0-2 years	TBD	DNER
3. Identify areas in need of support regarding protection and management.	Comprehensive mapping of vulnerable habitats that require additional protection and management efforts.	Conducted field assessments to gather data on habitat conditions.	Lead: DNER Implementing partners: Estuario, Sea Grant Puerto Rico, community groups:	Pending	0-2 years	TBD	DNER

Regulatory and Policy Requirements

Fisheries management may require changes to seasonal and geographical size and bag limits to some fish species. Education and enforcement of new and existing fishing regulations will also be critical.

354 ***NEW-6* Enhance coastal dunes, coastal forests, and beach thickets.**

355 **Activities**

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Assess existing conditions and identify areas that need intervention.	Identify specific areas exhibiting degradation or decline in health that require intervention.	Analyzed collected data to identify specific areas of concern and assess severity of degradation.	Leads: DNER, USEPA Implementing partners: Estuario, municipalities, academia, scientific community, environmental nongovernmental organizations (NGOs) and consultants	Pending	0-2 years	TBD	DNER, USEPA, municipalities
2. Develop plans to enhance, restore, and create coastal habitats.	Establish measurable indicators to assess the effectiveness of enhancement actions.	Incorporated stakeholder input and finalized habitat enhancement plan.	Leads: DNER, USEPA Implementing partners: Estuario, municipalities, academia, scientific community, environmental NGOs and consultants	Pending	3-5 years	TBD	DNER, USEPA, municipalities
3. Implement developed plans to enhance, restore, and create coastal habitats.	Active community participation in enhancement activities.	Secured necessary resources to conduct enhancement activities outlined in plan.	Leads: DNER, USEPA Implementing partners: Estuario, municipalities, academia, scientific community, environmental NGOs and consultants	Pending	5+ years	TBD	DNER, USEPA, municipalities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
4. Establish a monitoring and maintenance protocol for coastal habitats.	Identify specific maintenance and monitoring needs.	Developed standardized protocols for monitoring and maintenance.	Leads: DNER, USEPA Implementing partners: Estuario, municipalities, academia, scientific community, environmental NGOs and consultants	Pending	3-5 years	TBD	DNER, USEPA, municipalities

356 **Regulatory and Policy Requirements**

357 Management will likely require cooperation from municipalities through creation and enforcement of
358 ordinances. Management strategies may also recommend legislation at the state and federal level to limit
359 development and increase buffers around these critical areas.

360 ***NEW-7* Enhance and protect forests and landscape connectivity in the upper watershed.**

361 **Activities**

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Assess existing conditions and identify areas that need intervention.	Identify specific areas exhibiting degradation or decline in health that require intervention.	Analyzed collected data to identify specific areas of concern and assessed severity of degradation.	Leads: DNER, USEPA Implementing partners: Estuario, municipalities, academia, scientific community	Pending	0-2 years	TBD	DNER, USEPA, municipalities
2. Develop plans to enhance upper watershed forests and landscape connectivity.	Establish measurable indicators to assess the effectiveness of enhancement actions.	Incorporated stakeholder input and finalize the habitat enhancement plan.	Leads: DNER, USEPA Implementing partners: Estuario, municipalities, academia, scientific community	Pending	3-5 years	TBD	DNER, USEPA, municipalities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
3. Implement plans to enhance upper watershed forests and improve landscape connectivity.	Active community participation in enhancement activities.	Secure necessary resources to conduct enhancement activities.	Leads: DNER, USEPA Implementing partners: Estuario, municipalities, academia, scientific community	Pending	5+ years	TBD	DNER, USEPA, municipalities
4. Establish a monitoring and maintenance protocol for forests in the upper watershed.	Identify specific maintenance and monitoring needs,	Developed standardized protocols for monitoring and maintenance.	Leads: DNER, USEPA Implementing partners: Estuario, municipalities, academia, scientific community	Pending	3-5 years	TBD	DNER, USEPA, municipalities

Regulatory and Policy Requirements

Management will likely require cooperation from municipalities through creation and enforcement of ordinances. Management strategies may also recommend legislation at the state and federal level to limit development and increase buffers in and around these critical areas.

**NEW-8* Enhance and protect herbaceous wetlands.*

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Assess existing conditions and identify areas that need intervention.	Identify specific areas exhibiting degradation or decline in health that require intervention.	Analyzed data to identify specific areas of concern and assess the severity of degradation.	Lead: DNER Implementing partners: Estuario, municipalities, academia, scientific community, environmental NGOs and consultants	Pending	0-2 years	TBD	DNER, USEPA, municipalities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
2. Develop plans to protect, enhance, and create herbaceous wetlands.	Establish measurable indicators to assess the effectiveness of enhancement actions.	Incorporate stakeholder input and finalize the plan.	Lead: DNER Implementing partners: Estuario, municipalities, academia, scientific community, environmental NGOs and consultants	Pending	3-5 years	TBD	DNER, USEPA, municipalities
3. Implement plans to protect, enhance ,and create herbaceous wetlands.	Active community participation in enhancement activities.	Secured necessary resources to conduct enhancement activities as outlined in the plans.	Lead: DNER Implementing partners: Estuario, municipalities, academia, scientific community, environmental NGOs and consultants	Pending	5+ years	TBD	DNER, USEPA, municipalities
4. Establish a monitoring and maintenance protocol for herbaceous wetlands.	Identify specific maintenance and monitoring needs,	Developed standardized protocols for monitoring and maintenance.	Lead: DNER Implementing partners: Estuario, municipalities, academia, scientific community, environmental NGOs and consultants	Pending	3-5 years	TBD	DNER, USEPA, municipalities

Regulatory and Policy Requirements

Management will likely require cooperation from municipalities through creation and enforcement of ordinances. Management strategies may also recommend legislation at the state and federal level to limit development and increase buffers in and around these critical areas.

***NEW-9* Implement a project to incentivize and recognize individual property owners that manage their yards as part of a biodiversity conservation area.**

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Assess areas that could potentially be identified as a biodiversity conservation area.	Identify specific properties and their owners.	Analyzed data to identify areas with high biodiversity value and assess the ecological integrity of potential conservation areas.	Lead: DNER Implementing partners: Estuario, municipalities	Pending	0-2 years	TBD	DNER, USEPA, municipalities
2. Develop plans to incentivize proper maintenance of properties.	Establish measurable indicators to inform property owners of proper maintenance.	Finalized incentive plans with stakeholder input.	Lead: DNER Implementing partners: Estuario, municipalities	Pending	3-5 years	TBD	DNER, USEPA, municipalities
3. Implement developed plans to incentive biodiversity.	Active community participation in enhancement activities.	Secured necessary resources to conduct enhancement activities.	Lead: DNER Implementing partners: Estuario, municipalities	Pending	5+ years	TBD	DNER, USEPA, municipalities
4. Establish a monitoring and maintenance protocol to measure progress.	Identification of specific maintenance and monitoring needs,	Development of standardized protocols for monitoring and maintenance.	Lead: DNER Implementing partners: Estuario, municipalities	Pending	3-5 years	TBD	DNER, USEPA, municipalities

Regulatory and Policy Requirements

Establishment and recognition or requirement of “Puerto Rico Friendly” plants in development permits may assist in supporting this action. Establishing local ordinances for fertilizer bans and other management practices may also assist in this effort.

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Public Policy for Integrated and Resilience-Based Ecosystem Management

Baseline

Law No. 112 established the Condado Lagoon Estuarine Nature Reserve in 2013. By establishing a commission for community management and a conservation plan for the development and conservation efforts, this law establishes an approach for integrated resilience-based ecosystem management within the legislative structure in Puerto Rico.

There are many protected natural areas and urban forests within the SJBE, as outlined in Table 3. These areas provide critical refuge for threatened and endangered species, greenspace within metropolitan centers, and education for nature based solutions. However, these areas require management to remain viable, as invasive plants and nuisance species seek to compete for space. The Piñones State Forest is one of the earliest examples of recognition for the preservation of natural space in Puerto Rico. Located to the east of Torrecilla Lagoon, it is an excellent example of preservation and management of natural ecosystems in what would have otherwise given way to eastern urban sprawl of the San Juan metropolitan area. Connectivity of these spaces is important to allow species to migrate without threat from urban centers. The San Juan Ecological Corridor was established in 2003 to provide this connectivity.

Table 3. List of Protected Natural Areas and Urban Forests within the SJBE.

Name	Year Established
Old Aqueduct of the Piedras River	2006
Piñones State Forest	1919
San Patricio Urban Forest	1998
Urban Forest of the New Millennium	2003
Doña Inés Mendoza Urban Forest	2003
San Juan Ecological Corridor	2003
Botanical Garden of the University of Puerto Rico	1971
Green Island Reef Nature Reserve	2014
Martin Peña Canal Nature Reserve	2003
Las Cucharillas Swamp Nature Reserve	1976
Condado Lagoon Nature Reserve	2013
Buffer Zone of the Ciénaga Las Cucharillas River	Not applicable
Karst Conservation Area	1999
Sendra Sisters Protected Natural Area	2011
Los Frailes Protected Natural Area	2006

Coral reefs are critical ecosystems that provide numerous ecological, economic, and social benefits in the SJBE. Coral communities contribute significantly to marine biodiversity and the overall health of coastal environments. Coral communities in the SJBE are found in various locations, with their most significant presence occurring where the estuary connects to the ocean. Key sites include Dos Hermanos in Condado and Boca de Cangrejos in Torrecilla, as well as along the coastline from Cataño to Loíza (Rodríguez et al. 1992). These areas are characterized by a unique blend of estuarine and marine influences, which support diverse coral species. Part of this chain of fringe coral reefs is protected within the marine reserve known as Arrecife, where two threatened reef-building coral species are found: *Acropora palmata* (elkhorn coral) and *Orbicella annularis* (boulder star coral). The protection of these species is crucial, as they play a significant role in reef structure and function.

In 2008, Estuario initiated a project to enhance marine biodiversity by placing 45 artificial reefs on the bottom of the Condado Lagoon. This goal of this initiative was to create an underwater corridor that would support marine life. Within two years of construction, the project had documented 49 species of fish, and the fish population in this part of the lagoon had doubled. Additionally, approximately 2,500 colonies of coral now grow on the surfaces of these artificial reefs, demonstrating the potential for habitat restoration and enhancement in the SJBE (Bauzá-Ortega, 2015).

Coral reefs are a vital component of the SJBE system, providing essential ecological services and supporting diverse marine life. However, they are increasingly threatened by environmental stressors and human activities. Understanding the specific dynamics of coral reefs in this watershed is crucial for stakeholders to implement effective conservation strategies. Prioritizing the health of coral communities, identifying and designating marine protected areas, and creating and implementing management plans in these areas, can help ensure the resilience of these ecosystems and the myriad benefits they provide to the SJBE.

Objectives

- Strengthen public policy that supports integrated and resilience-based ecosystem management.
- Increase the number of natural protected areas.

Actions

***NEW-1* Complete an inventory of natural protected areas in the San Juan Metro Region and ensure each has and is implementing a Comprehensive Management Plan.**

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Review existing management plans to assess their effectiveness and identify gaps or areas needing improvement.	Increased understanding of threats to biodiversity in natural protected areas.	Understand needs and gaps in existing management plans.	Leads: DNER, USFWS Implementing partners: Estuario, municipalities, academia, scientific community, environmental NGOs and consultants	Pending	3-5 years	TBD	DNER, USEPA, municipalities
2. Engage with local stakeholders to gather input on management priorities and challenges faced by each protected area.	Enhanced collaboration among stakeholders.	Collect stakeholder feedback to identify common management priorities across different protected areas.	Lead: DNER Implementing partners: Estuario, municipalities, academia, community groups. environmental NGOs and consultants	Pending	3-5 years	TBD	DNER, USEPA, municipalities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
3. Develop or update comprehensive management plans for each protected area.	Ensure management plans adhere to environmental regulations and policies.	Finalized management plans.	Leads: DNER, USFWS Implementing partners: Estuario, municipalities, community groups, academia, scientific community, environmental NGOs and consultants	Pending	5+ years	TBD	DNER, USEPA, municipalities

Regulatory and Policy Requirements

The success of this action will require that established protected areas receive the funding required to manage the area in accordance with the legislative mandates that established these areas.

HW-06 Designate the Torrecilla Alta-Vacia Talega area as part of the Piñones State Forest Nature Reserve.

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Conduct a detailed ecological assessment of the Torrecilla Alta-Vacia Talega.	Assessment of the health and quality of different habitat types within the area.	Finalized ecological assessment.	Lead: DNER Implementing partners: Estuario, municipalities, academia, scientific community	Pending	3-5 years	TBD	DNER
2. Develop a formal proposal for the designation.	Inclusion of detailed ecological assessment findings that support the need for designation.	Finalized designation proposal.	Lead: DNER Implementing partners: Estuario, municipalities	Pending	0-2 years	TBD	DNER
3. Collaborate with stakeholders to navigate the regulatory processes.	Improved knowledge among stakeholders regarding the regulatory requirements and processes.	Collaborate with stakeholders to compile and draft necessary documentation.	Lead: DNER Implementing partners: Estuario, municipalities, regulatory agencies	Pending	3-5 years	TBD	DNER

Regulatory and Policy Requirements

This action will require a legislative action to designate this area as part of the Piñones State Forest Nature Reserve. Champions in the local communities and legislature will be required to achieve this designation.

HW-19 Identify areas in the SJBE to be designated marine protected areas and continue coral reef restoration projects.

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Perform a detailed ecological assessment to identify critical habitats, biodiversity hotspots, and areas that would benefit from protection.	Evaluate the health and stability of identified habitats.	Analyzed data to identify critical habitats and biodiversity hotspots.	Lead: DNER Implementing partners: Estuario, NOAA, municipalities, academia, scientific community, environmental NGOs and consultants	Pending	0-2 years	TBD	DNER, USEPA, NOAA
2. Implement reef and coral restoration projects.	Increase in fish and invertebrate populations associated with restored reefs.	Established regular monitoring schedule to assess coral growth, health, and associated biodiversity.	Lead: DNER Implementing partners: Estuario, NOAA, academia, scientific community, environmental NGOs and consultants	Pending	3-5 years	TBD	DNER, USEPA, NOAA
3. Create a monitoring and evaluation framework to assess the effectiveness of the designated marine protection areas and restoration projects.	Establish a comprehensive set of indicators to evaluate ecological health, biodiversity, and the success of restoration efforts.	Established data collection protocols and initiate regular monitoring activities.	Lead: DNER Implementing partners: Estuario, NOAA, academia, scientific community, environmental NGOs and consultants	Pending	3-5 years	TBD	DNER, USEPA, NOAA

Regulatory and Policy Requirements

Legislative action will be required to designate marine protected areas. Champions in the local communities and legislature will be required to achieve this designation. Success will require support from municipal and state officials to ensure existing coral remain, and new development incorporates features that can enhance and support new coral growth, sustain healthy sediments, and provide habitat for marine life.

HW-20 Approve a management for the San Juan Ecological Corridor

Activities

Activity	Performance Measures	Milestones	Responsible Stakeholder(s) and Partner(s)	Status	Timeframe	Estimated Costs	Potential Funding Sources
1. Conduct a comprehensive review of existing ecological data and needs.	Clear documentation of gaps in existing ecological data.	Conducted a thorough literature review of existing studies, reports, and databases.	Lead: DNER Implementing partners: Estuario, municipalities, community groups	Pending	0-2 years	TBD	DNER, USEPA, municipalities
2. Engage with stakeholders and the local community to gather input.	Collect feedback from participants.	Identify and categorize key stakeholders.	Lead: DNER Implementing partners: Estuario, municipalities, community groups	Pending	0-2 years	TBD	DNER, USEPA, municipalities
3. Draft management plan.	Effective incorporation of feedback and suggestions.	Finalize draft management plan.	Lead: DNER Implementing partners: Estuario, municipalities, community groups	Pending	3-5 years	TBD	DNER, USEPA, municipalities
4. Implement management plan, including buying land in the San Juan Ecological Corridor.	Enhanced stakeholder awareness and support for the management plan and land purchases.	Finalized final management plan.	Lead: DNER Implementing partners: Estuario, municipalities	Pending	3-5 years	TBD	DNER, USEPA, municipalities

Regulatory and Policy Requirements

In 2024, the requirement for DNER to prepare a Conservation Management Plan was established by law (12 L of PR § 216i). The law required DNER to establish a committee and furnish the committee with materials and office space. DNER was required to prepare an Integrated Conservation and Management Plan in coordination with the committee.

References

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