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Introduction

The San Juan Bay Estuary (SJBE) is a vital coastal ecosystem supporting diverse habitats including benthic systems, coral reefs, seagrass beds, beach ecosystems, mangroves, and upland urban forests. These habitats provide essential ecosystem services such as nursery grounds for fisheries, coastal protection, water filtration, and biodiversity support. However, the SJBE faces significant environmental challenges driven by urbanization, nutrient enrichment, sedimentation, hydrological alterations, and extreme weather events. The SJBE is highly urbanized, and in many areas, historic habitat conditions have been irreversibly altered by development and ongoing pollutant inputs. While full restoration to pre-urban conditions may not be feasible across the watershed, the objective of this strategy is to restore and sustain functional habitats that provide critical ecosystem services, even within an urban setting. In addition, non-native species, such as alligators, iguanas, snakes, lionfish, and fleka fish, affect the viability of native species and can have effects on public health. While this plan does not address non-native species management, several agencies provide this service. The National Oceanic and Atmospheric Administration (NOAA) manages non-native species in Puerto Rico through fishery plans and marine monitoring. The Department of Natural and Environmental Resources (DNER) manages import permits for specific species and has a strategy to track and manage introduced non-native species. The U.S. Fish and Wildlife Service (USFWS) works with DNER on these management efforts.

This Habitat Strategy responds directly to the habitat and ecosystem issues identified in the Estuario Plan *Ensure Functioning Ecosystems* action plan, which emphasizes the protection, restoration, and long-term resilience of the SJBE's interconnected coastal and urban systems. This strategy focuses on the habitats prioritized in the action plan including benthic systems, mangroves, seagrass beds, coral reefs, riparian corridors, beach ecosystems, and upland urban forests, all of which support important ecological functions and key species in the estuary. These key species include the Antillean manatee, green sea turtle, blue land crab, and numerous rare, threatened, endemic, and endangered plant species. By aligning habitat restoration and protection efforts with these priorities, this strategy addresses the major stressors affecting the estuary system, including habitat loss and fragmentation, altered hydrology, sedimentation, pollution, urban development, and extreme weather effects.

In response to habitat degradation and declining water quality, restoration and management efforts have increased in recent years. The SJBE community is applying coordinated science-based approaches to conserve and restore critical habitats. Restoration projects in the SJBE include seagrass planting, fish and shellfish nursery habitat creation, mangrove planting, artificial reef deployment, and shoreline stabilization, supported by local, state, and federal partners. Achieving functional habitats will require strategic prioritization of sites with the highest ecological return, implementation of green, blue and gray infrastructure to reduce stressors, creation and protection of habitat refugia and connectivity, and an adaptive management framework with clear performance metrics and long-term monitoring.

This Habitat Strategy is intended to support implementation of the Estuario Plan *Ensure Functioning Ecosystems* action plan, rather than serve as a stand-alone document. In particular, it advances the habitat and ecosystem-based priorities established under the action plan by providing a framework for the protection, restoration, and stewardship of the major habitats of the SJBE system. The strategy translates the broader goals of the Plan into habitat-specific goals, objectives, and activities, while also identifying key partners, potential costs and funding sources needed to guide effective action.

The SJBE faces complex challenges including legacy effects from development, ongoing pollutant inputs, and extreme weather events and sea level rise, which complicate restoration timelines and success. This report emphasizes the importance of flexible, resilience-based management (RBM), and science-informed strategies that recognize spatial variability in habitat conditions and recovery potential. It also highlights the need for sustained funding, interagency coordination, and community engagement to achieve restoration goals. Community partnerships and targeted policy actions will be essential to balance urban uses with achievable ecological outcomes, and to ensure that restoration investments deliver measurable ecosystem services and resilience benefits for both nature and people.

The SJBE community believes that by building on past successes and emerging science, this strategy will guide effective stewardship to preserve and enhance the estuary's ecological and economic values for current and future generations.

According to McLeod and Leslie (2009) RBM is defined as an integrated management approach that considers the entire ecosystem, including humans, and the full spectrum of ways that people use, benefit from, and value nature. The main goal of RBM is to identify, prioritize, and implement management actions that enhance system resilience and human well-being by protecting processes and species that support a system's capacity to withstand stressors. In other words, an ecosystem that maintains and recovers its structure and functions in the face of disturbance and change (resilience). Such actions may include controlling pollution, sedimentation, overfishing, managing key species, and improving water quality (McLeod et al., 2019). RBM also includes strategies to build and support the capacity of people to learn, share knowledge, innovate, and adjust responses and institutions to changing external drivers and internal processes (Folke, 2016). Thus, a RBM approach will guide the implementation of this Estuario Habitat Restoration Strategy through the following management actions, common to all habitats:

- Protect a diversity of species, habitats, and functional groups.
- Maintain pathways of connectivity.
- Reduce ecosystem stressors.
- Implement marine protected areas to support estuarine resilience.
- Incorporate social and ecological indicators (resilience indicators) to assess early warnings, recovery patterns, and regime shifts in conservation planning and monitoring.
- Invest in experimental approaches to support resilience.
- Implement strategies to build social and ecological adaptive capacity.

Regulatory and Policy Considerations

This strategy recognizes that changes in local, territorial, or federal regulations including permitting, water quality standards, land use policies, and funding mechanisms can affect protection and restoration strategies, costs, and timelines. This strategy commits to ongoing review of regulations and guidance to reduce delays in implementation timelines. Estuario will track regulatory changes and assess implications for projects and priorities so that actions, timelines, and performance measures can be modified without jeopardizing the necessary ecological outcomes or fiscal accountability needed for success.

It is also important to note that permitted urban uses and restoration goals may be in conflict, which could affect the benefits of implementing the activities in this strategy. Improving coordination between development permits and habitat restoration is an important component for success. The municipalities within the SJBE watershed develop the Territorial Plan, which regulates land use, zoning, and urban development. This plan is prepared in accordance with the Municipal Code of Puerto Rico (Law No. 107), which requires that each municipality update their development guidelines every eight years. This process can help with establishing buffer zones, green infrastructure requirements, and ecological corridors to support this Habitat Restoration Strategy. The lead implementors for the key activities identified in this strategy should coordinate with the municipalities to determine how modifications to the Territorial Plan could support habitat restoration and conservation.

Benthic Systems

Status

Benthic systems in the SJBE have been extensively studied, with about half of the benthic habitats mapped using side scan sonar technology (Rivera, 2005). This mapping has revealed diverse and ecologically important habitats, including submerged aquatic vegetation (SAV) beds predominantly made up of *Halophila decipiens* and red algae, as well as large bivalve beds dominated by *Mytilopsis domingensis*. These habitats are found on a variety of substrates ranging from natural, undisturbed bottoms to dredged zones and artificial structures, highlighting the complexity and variability of benthic environments in the estuary. Notably, SAV tends to be more abundant in less disturbed areas, while bivalve beds are especially concentrated in the San José Lagoon, an area historically known for large aggregations of Perna species (Lugo and Bauzá Ortega, 2024, p. 33).

The benthic macrofaunal community is largely dominated by polychaetes, with more than 250 taxa identified, although the community structure is characterized by a few dominant species (PBS&J, 2009). Species richness and dominance are notably higher along dredged channels, indicating that human activities such as dredging significantly influence benthic community composition. To assess these benthic systems, researchers use a Benthic Index that considers family-level diversity and sensitivity to pollution. Some sites considered pristine, such as Piñones Lagoon, have low index values similar to polluted areas. This suggests that factors beyond pollution, such as limited water flushing due to distance from the ocean, also play a crucial role in shaping benthic conditions. Additional stressors such as sediment toxicity and frequent disturbances of the bottom sediment are linked to reduced benthic diversity in certain locations (Lugo and Bauzá Ortega, 2024).

Furthermore, the accumulation of nutrient-rich muck in sediments creates low oxygen conditions and elevated sulfide concentrations, which adversely affect infaunal biodiversity and disrupt essential processes such as nutrient cycling. These conditions impair the overall function and resilience of the benthic ecosystem. To address these issues, restoration efforts are focused on reducing nutrient inputs to improve sediment quality and promote recovery of benthic communities. Continuous monitoring of environmental factors such as temperature and dissolved oxygen is conducted to better understand their effects on benthic system resilience and guide future management strategies (Lugo and Bauzá Ortega, 2024).

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In summary, the benthic systems in the SJBE are diverse but face challenges from both non-anthropogenic and anthropogenic influences. While certain areas maintain complex benthic communities, others suffer from pollution, sediment toxicity, and physical disturbances, underscoring the need for ongoing restoration and monitoring efforts to sustain these vital ecosystems.

Key Species

Key species in benthic systems include Polychaetes (*Dominant meiofauna*), bivalves (*Mytilopsis domingensis*, Perna species), blue crabs (*Callinectes sapidus*), red mangrove oysters (*Crassostrea rhizophorae*), flat tree oysters (*Isognomon alatus*), and diverse benthic invertebrates inhabiting mud and sediment substrates. Non-halophytic upland species near benthic areas include *Tabebuia heterophylla* and the native palm, *Roystonea borinquena* (Lugo and Bauzá Ortega, 2024).

Goals and Objectives

- Attain and maintain sediment quality that supports diverse benthic communities and ecosystem functions.
- Reduce nutrient and pollutant inputs from land sources.
- Monitor benthic diversity and sediment conditions to guide adaptive management.
- Protect functional group diversity.

Recurring Extreme Weather Events and Other Stressors and Impacts

Changes in sediment quality and benthic environmental parameters can be influenced by rising temperatures and increased rainfall, including long-term trends in sediment oxygen levels, sulfide concentrations, acidity, and alterations caused by human-built infrastructure and sea level rise. Therefore, it is important to track shifts in benthic species composition and diversity, particularly among infaunal and epifaunal communities, to understand biological responses linked to sediment and benthic habitat conditions. In addition, there are emerging concerns related to coastal acidification within benthic environments, where nutrient influxes from stormwater and accumulated land-based sediments elevate hydrogen sulfide levels, reduce oxygen availability, and increase sediment acidity. These changes challenge the survival and shell formation of calcium carbonate-dependent benthic organisms. Further research is needed to better understand acidification effects on benthic sediments and the biological resilience of shell-building species.

Key Activities

Key Activities	Performance Measures	Targets	Lead Implementor(s) and Partner(s)	Timeframe	Estimated Costs	Potential Funding Sources
1. Based on the monitoring results, develop projects that include sediment restoration efforts, target contaminated sediments removal, and improve benthic habitat quality within the estuary.	Evaluate changes in benthic habitats due to restoration projects.	Performed assessments to identify and prioritize locations within the SJBE that require sediment restoration and removal based on ecological significance and current habitat quality.	Lead: DNER Implementing partners: municipalities, academia, community groups, U.S. Army Corps of Engineers (USACE)	5+ years	$350,000	U.S. Environmental Protection Agency (USEPA), DNER, municipalities, USACE, academia
2. Monitor and manage sediment quality to reduce toxicity and disturbances that negatively affect benthic biodiversity and ecosystem functions.	Reduce levels of contaminants in sediments within the SJBE.	Developed and implemented management strategies aimed at reducing toxicity and disturbances, such as source control measures, sediment remediation, or habitat restoration.	Leads: DNER, Estuario Implementing partners: municipalities, academia, community groups	0-2 years	TBD based on strategies and monitoring needed	USEPA, DNER, municipalities
3. Support restoration efforts aimed at enhancing benthic habitat complexity and resilience by promoting the recovery of submerged aquatic vegetation and benthic key species.	Increase established vegetation and bivalve beds.	Identified specific areas within the SJBE where submerged aquatic vegetation and key benthic species have been degraded or lost, prioritizing sites for restoration efforts.	Leads: DNER, Estuario Implementing partners: municipalities, academia, community groups	3-5 years	$500,000	USEPA, DNER, municipalities

Coral Reefs

Status

The SJBE contains a "broken chain of poorly developed reefs" lying mostly about a mile offshore, extending eastward from San Juan to Punta Vacía Talega (Kaye, 1959). These reefs consist of thin coral colonies growing on a shallow eolianite platform aligned with eolianite ridges. Healthy Caribbean reef crests can attenuate up to 97% of incoming waver energy (Ferrario et al., 2014)

Coral communities are most prominent in the Condado Lagoon, and, as well as along the offshore coast from Cataño to Loíza (Rodríguez et al., 1992). Within this reef chain is the Arrecife marine reserve, which harbors threatened reef-building corals including *Acropora palmata* and *Orbicella annularis* (Lugo and Bauzá Ortega, 2024).

Corals in the SJBE grow best under transparent waters with strong currents and stable temperature, salinity, and low nutrient conditions. They are stressed by fluctuations in salinity and temperature, nutrient enrichment, and sediment deposition that reduces water clarity. These stressful conditions are more pronounced within the lagoons compared to offshore Atlantic Ocean waters (Lugo and Bauzá Ortega, 2024).

Key Species

The reef-building corals *Acropora palmata* (elkhorn coral, branching) and *Orbicella annularis* (boulder star coral, massive), both ESA-listed as Threatened, are particularly important within the Arrecife marine reserve. The reef system also includes a variety of thin coral colonies growing on eolianite platforms, forming a chain extending from San Juan to Punta Vacía Talega (Loíza). These coral communities thrive in locations with clear, transparent waters, strong currents, and stable temperature, salinity, and nutrient conditions but are sensitive to environmental stressors such as sedimentation, nutrient enrichment, and fluctuating salinity and temperature (Lugo and Bauzá Ortega, 2024; Kaye, 1959; Rodríguez et al., 1992). One important key species is the long-spined sea urchin (*Diadema antillarum*) due to its role as algae control in coral reefs and to the ongoing recovery from the 1983–1993 Caribbean-wide die-off.

Goals and Objectives

- Identify coral reef chemical, physical, and ecological stressors.
- Identify where coral growth is possible and necessary.
- Monitor coral reef area cover and species diversity.
- Protect and restore water quality to support coral reefs.
- Preserve key reef-building corals, including threatened species *Acropora palmata* and *Orbicella annularis*.
- Monitor environmental conditions affecting coral reefs to guide management.
- Conserve critical reef habitats, especially within protected areas such as the Arrecife marine reserve.
- Identify and implement novel restoration techniques such as artificial reefs deployment, coral colonies gardening and transplantation.
- Protect functional group diversity.
- Identify key groups of herbivores that can support coral reef larval recruitment and recovery.

Recurring Extreme Weather Events and Other Stressors and Impacts

Coral reefs in the SJBE are vulnerable to increasing water temperatures, salinity fluctuations, and ocean acidification. These factors can cause coral bleaching, reduce calcification rates, and impair reef growth and resilience. Sea level rise may alter light availability and water depth around reefs, potentially affecting coral distribution and condition. Additionally, more frequent and intense storms can increase sediment runoff and physical damage to reef structures. Maintaining stable water quality and reducing localized stressors such as nutrient enrichment and sedimentation are critical to enhancing coral reef resilience in the face of these changing environmental conditions.

Key Activities

Activities	Performance Measures	Targets	Lead Implementor(s) and Partner(s)	Timeframe	Estimated Costs	Potential Funding Sources
1. Reduce sediment and nutrient inputs to improve water clarity and reef habitat quality.	Improved water quality through turbidity measurements in the SJBE.	Outlined specific strategies for reducing sediment and nutrient input, such as implementing best management practices (BMPs).	Lead: DNER Implementing partners: municipalities, academia, community groups	5+ years	TBD based on projects implemented	USEPA, DNER, municipalities
2. Monitor coral reefs for effects from environmental conditions such as temperature, salinity, and nutrient levels.	Collect data routinely to identify long-term trends.	Scheduled and conduct regular data collection intervals. Periodically analyze collected data.	Leads: DNER, Estuario Implementing partners: municipalities, academia	0-2 years	TBD based on monitoring needed	USEPA, DNER
3. Protect and manage critical reef areas and threatened coral species.	Increase in critical reef areas for their protection and management.	Identified key species, habitat conditions, and current threats in the Arrecife marine reserve.	Leads: DNER, USFWS Implementing partners: municipalities, academia, community groups	0-2 years	Agency staff time	USEPA, DNER, USFWS
4. Implement novel coral reef restoration techniques.	Increase in coral colonies recruitment and area cover.	Identified key species.	Leads: DNER, U.S. Fish and Wildlife Service (USFWS) Implementing partners: municipalities, academia, community groups	3-5 years	TBD based on type of restoration practices	USEPA, DNER, USFWS
5. Identify and map the current conditions of corals within the SJBE.	Review current maps and identify gaps in need of being surveyed.	Identified current conditions on corals.	Leads: DNER, Estuario Implementing partners: municipalities, academia, community groups	0-2 years	TBD based on mapping needs.	USEPA, DNER, USFWS

Seagrasses

Status

Seagrass beds constitute a major portion of the benthic environment in the SJBE, covering approximately 60% of the benthic substrates in areas such as Condado Lagoon (LG2 Environmental Solutions and CSA Ocean Sciences, 2021). Five seagrass species have been recorded, listed in order of relative coverage: turtle grass (*Thalassia testudinum*), paddle grass (*Halophila decipiens*), nonnative aggressive growing species *Halophila stipulacea*, manatee grass (*Syringodium filiforme*), and shoal grass (*Halodule wrightii*). Macroalgae are also a prominent component of these beds, often thriving under nutrient-enriched conditions, which can lead to competition with seagrasses and affect their abundance (Lugo and Bauzá Ortega, 2024).

Seagrass growth relies heavily on water transparency and low nutrient concentrations. When waterbodies become eutrophic, macroalgae tend to flourish at the expense of seagrasses. Additionally, seagrass coverage tends to decline with increasing water depth and reduced light availability, highlighting their sensitivity to changes in water quality and clarity (Lugo and Bauzá Ortega, 2024).

Unlike coral reefs, which require strong currents and stable environmental conditions, seagrasses are adapted to relatively calm waters. However, they remain vulnerable to declines in water quality, requiring clear waters with low nutrient inputs to maintain thriving and resilient beds.

Key Species

Five seagrass species have been recorded: shoal grass (*Halodule wrightii*), manatee grass (*Syringodium filiforme*), paddle grass (*Halophila decipiens*), turtle grass (*Thalassia testudinum*), and nonnative *Halophila stipulacea* (Lugo and Bauzá Ortega, 2024; LG2 Environmental Solutions and CSA Ocean Sciences, 2021). Seagrass-dependent species include the endangered Antillean manatee (*Trichechus manatus manatus*; and endangered juvenile green sea turtles (*Chelonia mydas*). Commercially important invertebrates include the queen conch *(Lobatus gigas*) and the Caribbean spiny lobster (*Panulirus argus*). Other species to consider as key species are the red cushion starfish (*Oreaster reticulatus*). *Halophila stipulacea* is an aggressive non-native species (Indo-Pacific origin, first documented in the Caribbean off Grenada in 2002) that is rapidly displacing native seagrasses across the region, including in Puerto Rico. Thus, is important to monitor its spread and ecological effects.

Goals and Objectives

- Attain and maintain water, sediment and light quality for seagrass recovery and expansion.
- Monitor restoration project progress and performance.
- Develop and share best practices for seagrass restoration.
- Reduce nutrient enrichment and improve water clarity.
- Protect functional group diversity.
- Monitoring the spread and ecological effects of aggressive non-native species such as *Halophila stipulacea.*

Recurring Extreme Weather Events and Other Stressors and Impacts

Extreme weather events and sea level rise are anticipated to significantly influence seagrass distribution, abundance, and survival in the SJBE. Key factors such as shifts in water temperature, salinity, pH, water depth, and nutrient loading operate synergistically, creating complex challenges that require thorough study and modeling to inform effective restoration and management strategies.

Key Activities

Activities	Performance Measures	Targets	Lead Implementor(s) and Partner(s)	Timeframe	Estimated Costs	Potential Funding Sources
1. Develop and implement a SJBE-wide Seagrass Restoration Plan to guide recovery and expansion efforts.	Approve restoration plan for seagrasses in the SJBE.	Developed clear restoration objectives, including specific targets for seagrass coverage metrics.	Leads: DNER, Estuario Implementing partners: municipalities, academia, community groups	3-5 years	$100,000	USEPA, DNER
2. Establish or update water quality targets including light quality optimized for seagrass growth, including light availability, sediment quality, and nutrient thresholds.	Measure positive changes in water quality indicators.	Collaborated with water quality experts and other relevant stakeholders to gather input on current research regarding water quality parameters that support optimal seagrass growth.	Leads: DNER, Estuario Implementing partners: municipalities, academia	0-2 years	$100,000	USEPA, DNER
3. Monitor restoration progress and share best practices to enhance ongoing and future seagrass protection efforts.	Implement best practices to improve seagrass restoration success.	Compiled a guide of best practices based on successful strategies used in seagrass restoration efforts.	Leads: DNER, Estuario Implementing partners: municipalities, academia, community groups	0-2 years	TBD based on monitoring needed	USEPA, DNER
4. Evaluate and monitor the ecological effects of non-native species and develop control measurement if necessary.	Limit expansion in SJBE seagrass beds,	Compiled data of potential ecological effects and develop control strategies.	Leads: DNER, Estuario Implementing partners: municipalities, academia, community groups	0-2 years	TBD based on monitoring needed	DNER, NOAA

Beach Ecosystems

Status

The SJBE contains interconnected sandy beaches, beach thickets, and sand-dune systems that function as a dynamic coastal ecosystem shaped by wind, waves, tides, and offshore currents. These habitats support diverse assemblages documented by Cerame Vivas (2000) and DNER (2005) and are essential for sand storage, shoreline protection, nutrient cycling, and wildlife habitat (Lugo and Bauzá Ortega, 2024). Wave energy, reef barriers, and seasonal wind patterns strongly influence whether beaches accumulate or lose sand. Without functional reef barriers, sand is more likely to be lost offshore, reducing natural recovery potential (Díaz Velázquez and Canals Silander, 2020; Lugo and Bauzá Ortega, 2024). Historical and ongoing human actions, including sand mining for construction, sand harvesting and placement associated with airport and road fill, and coastal development, have removed dune buffers, altered sediment transport, raised soil levels in mangroves, and enabled establishment of nonnative or terrestrial species that change habitat structure (Lugo and Bauzá Ortega, 2024).

Key Species

Sandy and rocky beach assemblages support diverse infaunal and epifaunal communities and are inhabited by crustaceans such as hermit crabs (*Coenobita spp.*) and the Atlantic ghost crab (*Ocypode quadrata*). Dune and thicket vegetation, including sea grape (*Coccoloba uvifera*), sea side bean (*Canavalia rosea*), Bayhops (*Ipomoea pes-crapae*), Batatilla (*Ipomoea imperati*), and Ink berry (*Scaevola* plumieri) , among other coastal plants, help stabilize the sand, provide wind buffering, and produce a distinct zonation from the strand to inland thickets (Lugo and Bauzá Ortega, 2024). These dune-backed beaches also serve as important nesting habitat for sea turtles, notably hawksbill (*Eretmochelys imbricata*), green (*Chelonia mydas*), and leatherback (*Dermochelys coriacea*). (Cerame Vivas, 2000; DNER, 2005; Lugo and Bauzá Ortega, 2024; Federal Emergency Management Agency [FEMA], 2018).

Goals and Objectives

- Preserve and restore the integrated beach ecosystem (sandy beaches, beach thickets, and sand dunes) to maintain natural sand transport, shoreline stability, and habitat function.
- Protect native beach, dune, and thicket species and the functional diversity they represent.
- Restore and protect reef barriers, submerged dunes, and nearshore features that retain sand and support natural beach recovery.
- Stabilize dunes using native vegetation and conserve freshwater resources to sustain dune communities and prevent saltwater intrusion.
- Monitor beach morphology, sediment dynamics, vegetation structure, and biotic use (including sea turtle nesting) to support adaptive management.
- Prevent harmful practices (e.g., sand mining) and limit development that reduces dune/beach buffering capacity and degrades adjacent mangrove and wetland habitats.

Recurring Extreme Weather Events and Other Stressors and Impacts

High-energy storm waves and hurricanes can exceed normal high-tide levels, overtop dunes, cause severe beach erosion, and damage infrastructure (Fields and Jordan, 1972; Lugo and Bauzá Ortega, 2024). Sea level rise and chronic inundation reduce beach area, alter dune groundwater lenses, and increase vulnerability of thickets and other inland habitats (Lugo and Bauzá Ortega, 2024). Reduced reef function, whether from natural causes or anthropogenic loss, diminishes nearshore sand retention and raises the probability of sand being lost to deeper offshore zones (Díaz Velázquez and Canals Silander, 2020; Lugo and Bauzá Ortega, 2024). Wind stress and salt spray shape thicket zonation but can also limit recruitment where extreme events or altered sediment supply occur (Lugo and Bauzá Ortega, 2024).

Key Activities

Activities	Performance Measures	Targets	Lead Implementor(s) and Partner(s)	Timeframe	Estimated Costs	Potential Funding Sources
1. Implement erosion control and sand-nourishment projects that align with natural coastal processes, as well as reducing human foot traffic.	Observed changes in shoreline stability, measured erosion/accretion rates.	Identify and prioritize specific locations for nature-based and human foot traffic erosion control and sand nourishment.	Lead: DNER Implementing partners: Estuario, municipalities, academia, USACE, community groups	3-5 years	TBD based on selected projects	DNER, USEPA, USACE, municipalities
2. Protect and restore offshore reef barriers and submerged dune features to improve sand retention and recovery.	Area of reef/submerged dune features protected/restored.	Completed assessments of reef and submerged dune functionality.	Lead: DNER Implementing partners: Estuario, academia, USACE, community groups	5+ years	TBD based on selected projects	DNER, USEPA, USACE, municipalities
3. Restore and stabilize sand dunes using native vegetation reproduced in the SJBE nursery.	Identification of vegetation survival and growth rates.	Restored dune sites with stabilized profiles and native plant cover.	Lead: DNER Implementing partners: Estuario, municipalities, community groups	5+ years	TBD based on selected projects	DNER, USEPA, municipalities
4. Protect and restore beach thicket forests and maintain zonation patterns to preserve wind-buffering function.	Area of beach thicket protected or restored.	Identified and restored degraded thicket areas plus the establishment of long-term monitoring.	Lead: DNER Implementing partners: Estuario, municipalities, academia, community groups	5+ years	TBD based on selected projects	DNER, USEPA, municipalities
5. Integrate dune conservation into land-use and water-resource planning to prevent saltwater intrusion and support vegetation.	Inclusion of dune conservation measures in land-use plans.	Guidelines incorporated into municipal and regional planning documents.	Lead: DNER Implementing partners: Estuario, municipalities, regulatory agencies	3-5 years	Agency staff time	DNER, USEPA, municipalities, OGPe

Mangroves

Status

Mangrove forests in the SJBE are primarily dominated by white mangroves (*Laguncularia racemosa*), which have the highest tree density, basal area, and biomass among mangrove species (Lugo and Bauzá Ortega, 2024). Non-mangrove species such as *Tabebuia heterophylla* and the native palm *Roystonea borinquena* occur at mangrove upland edges, reflecting elevational gradients and habitat transitions (Gleason and Cook, 1926; Lugo and Bauzá Ortega, 2024).

White mangroves possess smaller, wider leaves with lower stomatal density compared to red (*Rhizophora mangle)* and black mangroves (*Avicennia germinans*). Their leaf mass per area and specific leaf area resembles black mangroves but differ from red mangroves, which have the largest, heaviest leaves and highest stomatal density (Lugo and Bauzá Ortega, 2024).

Non-halophytic species such as *Pterocarpus officinalis*, *Amphitecna latifolia*, and the nonnative *Thespesia populnea* grow in transitional zones with fluctuating water tables and salinity up to 30 parts per thousand (ppt). These species experience drought stress when freshwater runoff declines; notably, *Thespesia populnea* shows greater drought tolerance (Rivera de Jesús, 2020).

Branoff (2019) developed an urban index for mangroves based on vegetation cover, land use, population, and road density, ranging from low urbanization at Piñones (1%) to high at CMP (100%). Along with this gradient, total tree species increased due to human introductions, white mangrove dominance rose, and black mangrove presence declined. Urban mangroves showed higher leaf nitrogen, indicating reduced water use efficiency, elevated sediment heavy metals (Cu, Pb, Zn), shallower water depths, and shorter flooding durations (Lugo and Bauzá Ortega, 2024).

Key Species

White mangrove (*Laguncularia racemosa*) is the dominant mangrove species in the SJBE, exhibiting the highest tree density, basal area, and biomass. Other important mangrove species include red mangrove (*Rhizophora mangle*) and black mangrove (*Avicennia germinans*). Non-mangrove species found within mangrove zones include *Pterocarpus officinalis*, *Amphitecna latifolia*, and the nonnative *Thespesia populnea*, which tolerate fluctuating water tables and salinity levels. These species contribute to the structural diversity of mangrove forests and reflect elevational gradients and proximity to upland habitats (Lugo and Bauzá Ortega, 2024; Rivera de Jesús, 2020). Many fish, reptiles, insects, and bird species use mangrove habitats for some portion of their life cycles. A wide diversity of invertebrates and crustaceans also rely on mangrove prop roots as habitat for at least part of their life cycles.

Goals and Objectives

- Maintain the structure, function, and ecological processes of mangroves and prevent further loss, fragmentation, or degradation (USFWS, 1999).
- Encourage the use of living shorelines incorporating mangroves and other estuarine species to stabilize shorelines and improve habitat quality.
- Protect, restore and manage mangrove shorelines to support species diversity and provide suitable habitat for fisheries, reduce coastal flooding, and provide riparian buffers.
- Where appropriate, reduce the linear extent of disturbed, eroding, and hardened shorelines to allow for mangrove restoration and replanting in order to provide suitable forage and improved habitat quality.
- Protect functional group diversity.

Recurring Extreme Weather Events and Other Stressors and Impacts

Mangroves in the SJBE are shaped by both natural ecological drivers and human influences, particularly urbanization that alters hydrology through impervious surfaces, channelization, and stormwater routing. These changes affect hydroperiods and contaminant transport, affecting mangrove growth and species composition. Sea level rise is expected to drive mangrove migration upland, potentially displacing freshwater wetlands. However, urban development may restrict this natural migration, creating challenges for mangrove persistence. Increasing winter temperatures are also contributing to the northward expansion of mangroves into areas previously dominated by salt marshes, with implications for local biodiversity and ecosystem function. Living shorelines using mangroves offer a natural solution to coastal erosion and flooding, enhancing habitat quality and resilience in the face of sea level rise and extreme weather events.

Key Activities

Activities	Performance Measures	Targets	Lead Implementor(s) and Partner(s)	Timeframe	Estimated Costs	Potential Funding Sources
1. Develop projects to include reproduction. Planting, and monitoring urban mangrove to restore and improve habitat quality.	Assess changes in habitat quality metrics.	Evaluated the current hydrology of mangrove areas, identifying factors affecting water flow, salinity levels, and overall hydrological system.	Leads: DNER, USFWS Implementing partners: municipalities, academia, community groups	5+ years	TBD based on selected projects	DNER, USFWS
2. Engage community and stakeholders to align coastal development with mangrove conservation.	Increase in relevant stakeholders participating in mangrove conservation activities.	Identified stakeholders to collaborate with on aligning development with mangrove conservation.	Leads: DNER, Estuario Implementing partners: municipalities, academia, community groups	3-5 years	$75,000	USEPA, DNER
3. Identify and map current mangrove habitats to determine restoration activity locations.	Review current maps and identify gaps in need of being surveyed.	Identified current conditions on mangroves.	Leads: DNER, Estuario Implementing partners: USFWS, municipalities, academia, community groups	0-2 years	TBD based on mapping needs	USEPA, DNER, USFWS

Upland Urban Forests

Status

Upland urban forests and subtropical moist secondary forest patches within the SJBE watershed are fragmented and embedded in a highly urbanized landscape. Tree inventories report 2,548 ha of mangrove plus subtropical moist secondary forests which is about 11.8% of the watershed, and an average urban tree cover of 24.1% in 2011 (Brandeis et al. 2014; Tucker Lima et al. 2013). The watershed contained an estimated 10.1 million trees in 2011 that stored 319,737 metric tons of carbon and sequestered roughly 28,384 metric tons of carbon per year (Brandeis et al., 2014). These upland forest patches are often small, occur as remnant fragments or planted street/park trees, and are affected by invasion from nonnative ornamental and street trees in developed areas.

Key Species

Dominant species in moist forest patches and urban plantings include the non-native African tulip tree (*Spathodea campanulata*) and native Santa María (*Calophyllum antillanum*), alongside a mix of remnant native subtropical species at forest edges. Mangrove species (red, black, white) dominate shoreline and fringe areas, but transitional upland edges contain Tabebuia and native palms noted in regional inventories.

Goals and Objectives

- Conserve and increase functioning upland urban forest cover in priority SJBE areas.
- Increase native tree recruitment and planted native canopy species in urban neighborhoods by planting new street/park trees with native, drought and salt tolerant species.
- Reduce non-native tree dominance in remnant forest patches through removal.
- Maintain and enhance urban forest ecosystem services, such as increasing annual carbon sequestration and quantifying energy savings from tree shade in developed areas.
- Protect functional group diversity.

Recurring Extreme Weather Events and Other Stressors and Impacts

Hurricanes, tropical storms, and increasingly intense rainfall events cause direct tree mortality, canopy loss, and increased disturbance that opens space for non-native species establishment; urban forest mortality can be substantial following major storms (Tucker Lima et al., 2013). Urbanization stressors such as impervious surfaces, altered hydrology, heat island effects, soil compaction, and pollution for street trees increase baseline mortality and favor certain non-native or planted ornamental species (Tucker Lima et al., 2013). Mortality rates for street trees were lower in higher income neighborhoods, indicating potential equity considerations for urban tree canopy and maintenance investments (Tucker Lima et al., 2013).

Key Activities

Activities	Performance Measures	Targets	Lead Implementor(s) and Partner(s)	Timeframe	Estimated Costs	Potential Funding Sources
1. Inventory, prioritize, and map upland forest fragments and potential planting sites.	Identify potential planting sites.	Completed a prioritization map which displays urban forests and potential areas to increase connectivity.	Leads: DNER, U.S. Department of Agriculture (USDA) Implementing partners: municipalities, academia, community groups	3-5 years	$250,000	DNER, USDA
2. Plant trees on streets and in parks to maximize stormwater interception and cooling.	Increase in tree survival rates for urban tree plantings.	Established annual planting targets and maintenance plans.	Leads: DNER, Estuario, USDA Implementing partners: municipalities, academia, community groups	3-5 years	TBD based on the number and type of trees	DNER, USDA

Activities	Performance Measures	Targets	Lead Implementor(s) and Partner(s)	Timeframe	Estimated Costs	Potential Funding Sources
3. Establish post-storm assessments to promote the vitality of urban trees and canopies.	Create follow-up actions in post-storm scenarios.	Developed metrics to evaluate urban trees and canopies, including structural integrity, canopy cover, and signs of damage.	Leads: DNER, USDA Implementing partners: municipalities, academia, community groups	3-5 years	$100,000	DNER, USDA
4. Invest resources into community engagement and workforce development for urban forests.	Increase community engagement.	Engaged with community stakeholders to foster awareness, participation, and ownership of urban forestry initiatives.	Leads: DNER, Estuario, USDA Implementing partners: municipalities, academia, community groups	5+ years	$75,000	DNER, USDA

Habitat Response Monitoring

Habitat response monitoring will establish reliable and cost-effective methods to systematically monitor and evaluate the execution and performance of the restoration actions. Monitoring and evaluation are essential to determine whether restoration projects were executed correctly as designed, and that the restoration goals were accomplished. Also, it helps to ensure that project and program resources are used efficiently and effectively (NOAA, 2026). Table 1 presents the key species, community, monitoring metrics and goals to be assessed as part of the habitat response monitoring.

Table 1. Key species, community, monitoring metrics, and goals to be assessed by ecosystem type as part of the habitat response monitoring

Ecosystem	Key species	Community	Metrics	Goals	Monitoring Frequency
Benthic Systems	Polychaetas	Benthic macroinvertebrates	Percent area cover	An increase in area cover.	5 years
Coral Reefs	Elkhorn coral (*Acropora palmata* and Bourder star coral (*Orbicella annularis*)	Coral colonies	Percent area cover at permanent monitoring stations, biodiversity index	An increase in area cover and abundance of coral key species.	Quarterly
Seagrasses	Turtle grass (*Thalassia testudinum)*	Submerged aquatic vegetation (seagrass and macroalgae)	Percent area cover and species composition in permanent monitoring stations	An increase in area cover.	Quarterly
Seagrasses	Nonnative *Halophila stipulacea*	Submerged aquatic vegetation (seagrass and macroalgae)	Percent area cover	A decrease in abundance and area cover.	Quarterly
Beach Ecosystems	Sea grape (*Coccoloba uvifera*), Sea side bean (*Canavalia rosea*), Bayhops (*Ipomoea pes-crapae*), Batatilla (*Ipomoea imperati*), Saltmarsh cordgrass (Spartina sp.)	Coastal native plant	Percent survival rate, planted individual growth rate (millimeters per year [mm/year])	An increase in abundance. and plant length.	One month after planting and yearly after

Ecosystem	Key species	Community	Metrics	Goals	Monitoring Frequency
	and Ink berry (*Scaevola* plumieri)				
Beach Ecosystems	Beach profiles	Sand dunes	Sand dune growth rate (mm/year)	An increase in sand dunes height.	Yearly
Mangroves	Red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), and White mangrove (*Laguncularia racemosa*)	Aerial measurement of mangrove forest area cover	Percent survival rate and area cover, planted individual growth rate (mm/year)	An increase in area cover and growth rate.	One month after planting and yearly after
Upland Urban Forests	Non-native African tulip tree (*Spathodea campanulata*	Protected areas and forest within the SJBE watershed	Percent survival rate, aerial area cover, planted individual growth rate (mm/year)	An increase in area cover and growth rate.	One month after planting and yearly after

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