MANGROVE COAST COLLABORATIVE

COLABORACIÓN EN MANGLES COSTEROS

Management Brief for the Mangrove Coast Collaborative

Bahía de Jobos

National Estuarine
Research Reserve System
Science Collaborative

Rookery Bay
Research Reserve

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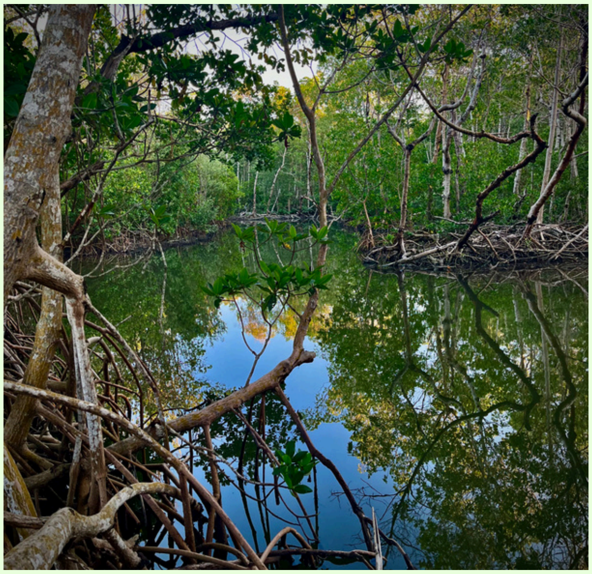

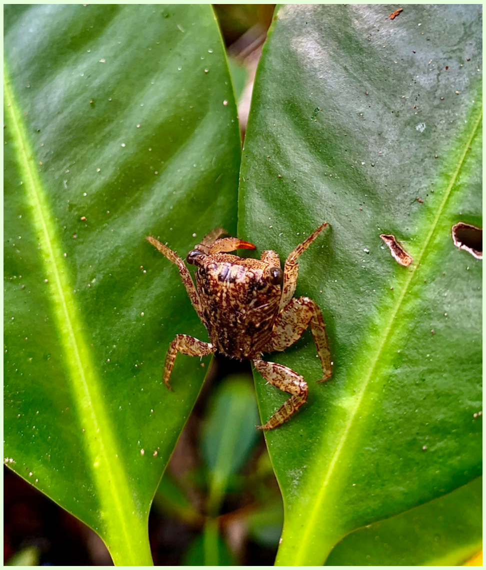

Figure 1. Participants at the MCC Mangrove Science and Management Forum, including natural resource managers, mangrove researchers, and staff from several National Estuarine Research Reserves across the Southeast U.S. and Caribbean.

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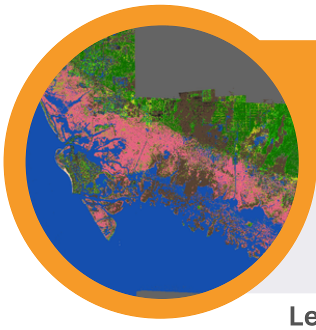
Introduction to the Mangrove Coast Collaborative

The Mangrove Coast Collaborative (MCC) is a project funded by the National Estuarine Research Reserve System (NERRS) Science Collaborative (2020-2024), intended to develop data and tools for the management of mangrove ecosystems following hurricane disturbance. The MCC project was co-created in the aftermath of the 2017 hurricane season, when Jobos Bay and Rookery Bay NERRs experienced the severe impacts of Hurricanes Maria and Irma, respectively. Following these major storms, reserve managers and partners formed a collaborative team to discuss their experiences and identify shared research needs. The team recognized the need to gain a better understanding of the extent of damage, barriers to recovery, and impacts to ecosystem services following hurricane disturbance.

The project is organized into four research objectives and associated tasks:



Task 1:

Mapping the Spatial Extent of Hurricane Effects and Recovery

Led by Dr. Digna Rueda-Roa

Task 3:

Summarizing Potential Hurricane Impacts to Mangrove Ecosystem Services

Led by Sara Mason, M.S.

Task 2:

Field Assessment and Ecological Driver Modeling

Led by Dr. Danielle Ogurcak

Task 4:

Mangrove Management Decision-Making

Led by Dr. Brita Jessen

Tasks 1 through 3 focused on generating data and tools that reserve staff could use to make management decisions, including decisions related to restoration. Task 4 focused on understanding decision-making processes, including the challenges and barriers faced by managers.

The Project Team includes natural- and social-science researchers, managers, community engagement specialists, and educators working with three advisory groups (two local and one technical). Science and educational material produced by the MCC will aid future management decisions in coastal systems frequented by hurricanes as well as continued recovery efforts for these two reserves.

Intent of the Management Brief

The MCC team developed this document to integrate the science generated throughout the project into management practices. The document is organized to provide the reader a synopsis of the methods, results, and impacts of engaging Project Advisory Committees for each project objective. The team also intends for the management brief to serve as a guide for the co-production processes utilized, providing examples of how techniques were used throughout the project and outlining the time and resources invested to achieve success. Finally, the document serves as a conduit to widely share feedback from the participants engaged throughout the project and evaluate the impact of engaging Advisory Committees and reserve staff.

Key to the Brief

During the MCC Mangrove Science and Management Forum held in Miami, FL (March 2024) the MCC Team prompted Forum participants to discuss and identify 1) limitations and uncertainties 2) assumptions, and 3) recommendations and opportunities associated with the draft tools, products, and findings generated from Tasks 1 through 4 of the MCC project. Responses were organized into the following three sections, which accompany the descriptions and key findings of each Task:

- Limitations and Uncertainties
- Assumptions and Context
- Opportunities and Recommendations

Management Applications: Following discussions held during breakout sessions convened during the MCC Forum, Project Technical Leads distilled participant comments into a list of management applications associated with the data and outputs derived from Tasks 1 through 3.

"Quotes were collected from surveys of end-users providing feedback on the outputs of the project."

Links to the project webpage are included throughout the document for easy access to the project outputs. Raw data from the project will be housed at the NOAA Centralized Data Management Office (CDMO). If you would like to view the Collaborative Science project webpage, please visit: https://nerrssciencecollaborative.org/project/Ogurcak20.

If you would like to view the Catalyst project webpage, please visit: https://nerrssciencecollaborative.org/project/Ogurcak23.

Scan the QR code to access the project webpage.

Suggested Citation: Mangrove Coast Collaborative Project Team (2025). Mangrove Coast Collaborative Management Brief. National Estuarine Research Reserve System (NERRS) Science Collaborative. 27 pp. https://nerrssciencecollaborative.org/resource/management-brief-mangrove-coast-collaborative.

This work was sponsored by the National Estuarine Research Reserve System Science Collaborative, which supports collaborative research that addresses coastal management problems important to the reserves. The Science Collaborative is funded by the National Oceanic and Atmospheric Administration and managed by the University of Michigan Water Center (NA19NOS4190058).

For more information about this document, please email: dogurcak@fiu.edu.

Co-Production and Collaboration

The MCC defined co-production following Beier et al. 2017 as a collaborative process among managers, scientists, and stakeholders to define the scope and context of a problem, form research questions, determine appropriate methods and outputs, collect data, make scientific inferences, and develop strategies for the appropriate outcomes of the generated information.

In pursuit of co-production, the MCC designed a framework to engage stakeholders in an iterative decision-making cycle as the team progressed towards project outcomes. Engagement started during project conception, as the MCC brought together staff from each reserve representing each of the sectors (Research, Education, Stewardship and Training & Engagement), academic partners, and local mangrove managers to discuss challenges and goals of the project. This interaction enhanced the project and the partnerships between these entities by aligning the products and project with local needs and desires.

Building the Collaboration: From the beginning, the MCC was focused on addressing end-user management needs and challenges, while providing users the opportunity to have input into the development of the products. The Project Team worked collaboratively to identify what each member of the team needed from the project itself, as well as the roles they were willing to fill. Through this process, the Project Team determined a shared vision early on and outlined the roles and responsibilities necessary to achieve it. The team recognized the need for continuous guidance on product development from key stakeholders, resulting in the creation of Advisory Committees. Three different Project Advisory Committees (PACs) were established, a Technical Project Advisory Committee, a local Jobos Bay NERR Project Advisory Committee, and a local Rookery Bay NERR Project Advisory Committee (Fig. 2).

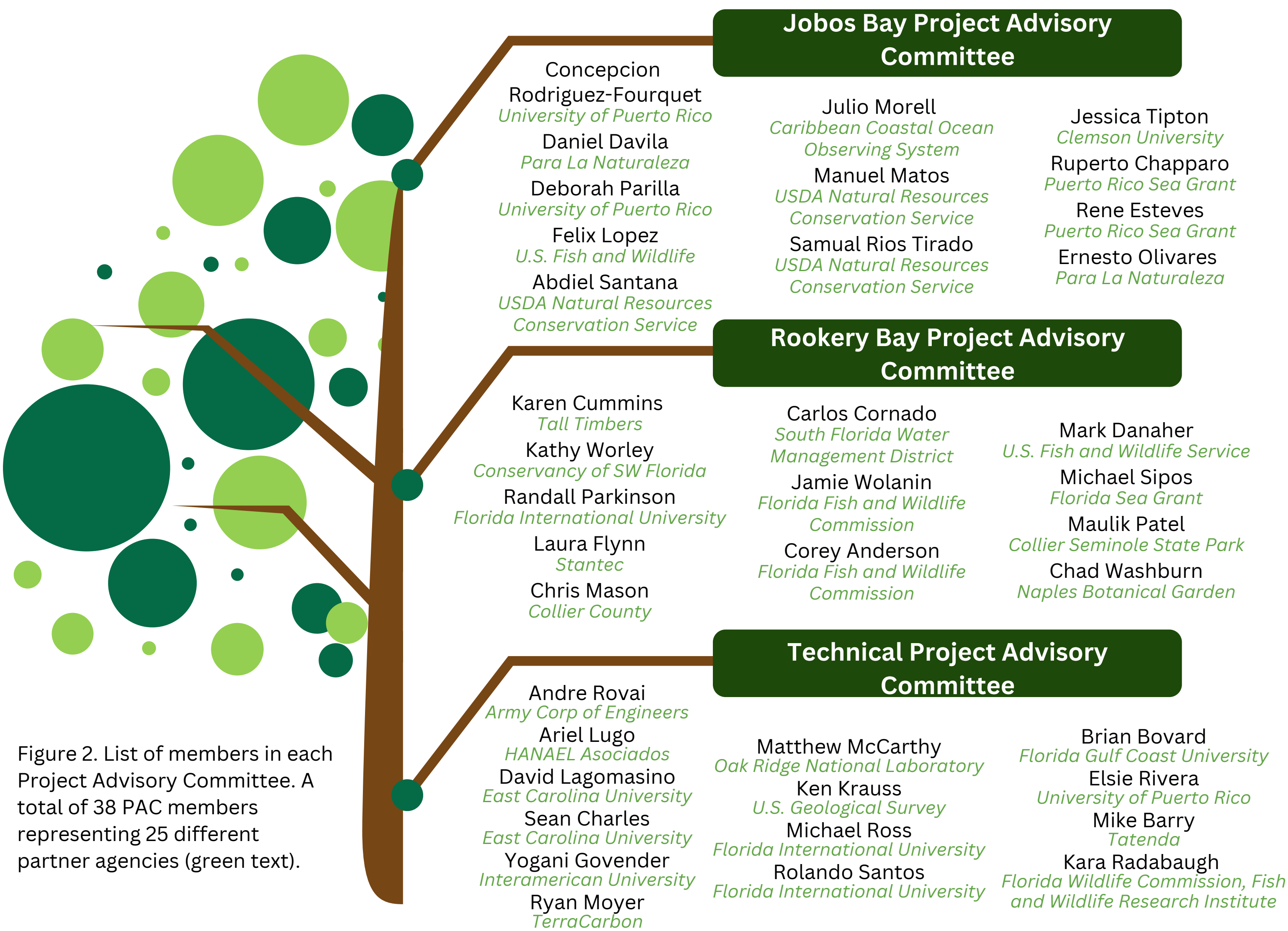


Figure 2. List of members in each Project Advisory Committee. A total of 38 PAC members representing 25 different partner agencies (green text).

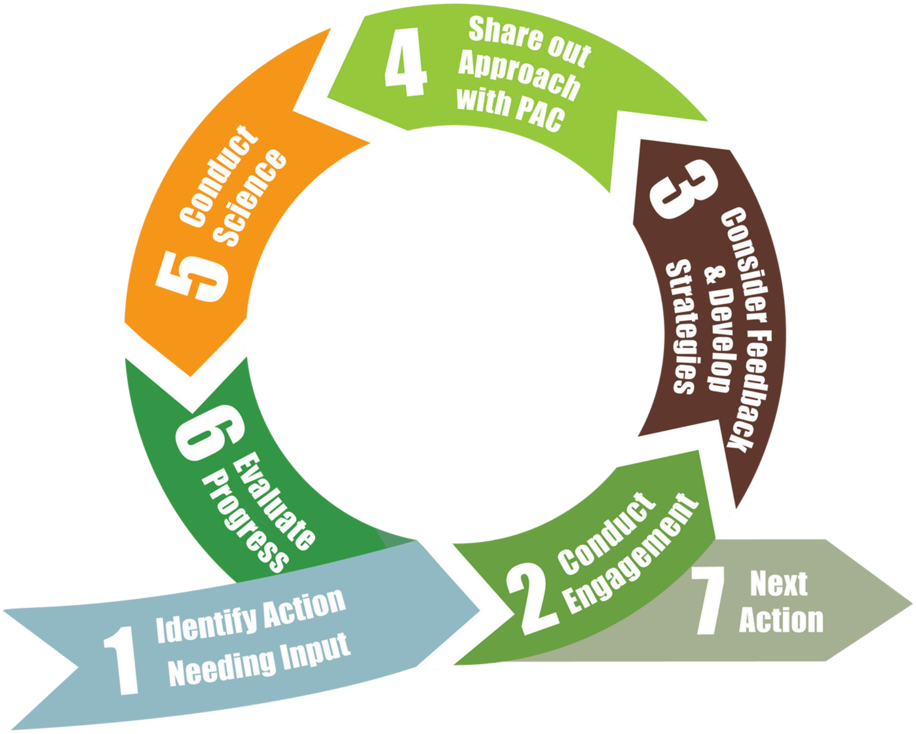


Figure 3. Modified Agile Project Management Cycle utilized for PAC engagement during the Mangrove Coast Collaborative. *Credit: NERRS Science Collaborative Graphics Team.*

Iterative Engagement: Members of the PAC attended two virtual, two-hour meetings every year. Integration of PAC member feedback was accomplished by adopting a modified Agile Project Management Cycle (Fig.3) as a framework. The cycle is iterative and was employed at each point in the project where feedback was required, allowing the project to be adaptive and promoting transparency within decision-making.

Each meeting focused on discussion of the products rather than information sharing and allowed Technical Leads to receive input and advice from the PAC to inform different parts of the developmental process. The MCC endeavored to stay mindful of the PAC members and their time, removing potential barriers to attendance and allowing them access to the necessary information. To increase time for discussion, each meeting was preceded with a "read-ahead" document containing the necessary background information, including discussion questions that would be addressed during the meeting. Through the development and implementation of the PACs via the Agile Cycle, the MCC was able to value process over individual outcomes and integrate feedback into the project.

Relationship Maintenance & Transparency:
Consistent communication within the Project Team and between end users is necessary for meaningful co-production. Several techniques employed throughout the MCC project proved useful to relationship maintenance (Fig. 4). The Project Team developed a **shared platform** (Google Drive) to allow information sharing, access to maps and data, and collaborative input and refinement of outputs. The Project Team committed to **meeting monthly** to ensure project progress and maintain constant engagement. The monthly meetings allowed the Technical Leads to **update** reserve staff as end-users on any changes to the proposed outputs and obtain feedback. By engaging in discussion between the end users and Technical Leads, the Project Team was better informed about the needs of the resource managers and able to find acceptable substitutes or solutions when challenges arose, while the end users were promptly informed about the **limitations** of science and ongoing challenges. The Project Team also considered **various methods of communication**, as means were not always the same across the different cultures. Members of the Project Team and PACs were engaged using a variety of methods, depending on which was best-suited for that particular member and occasion, allowing each member to feel connected with the project.

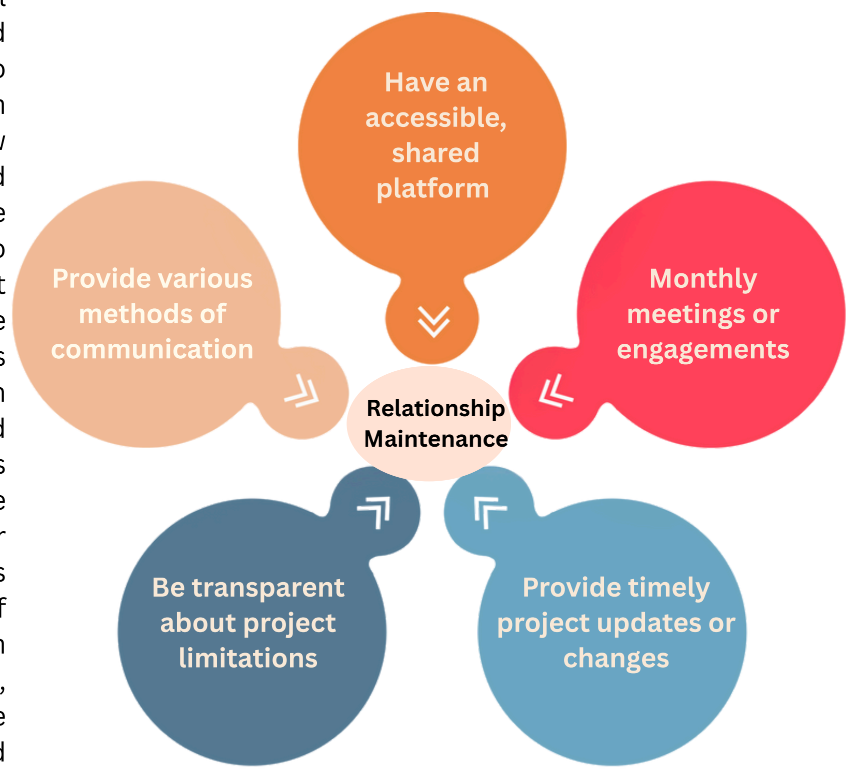


Figure 4. Relationship maintenance techniques used throughout the Mangrove Coast Collaborative.

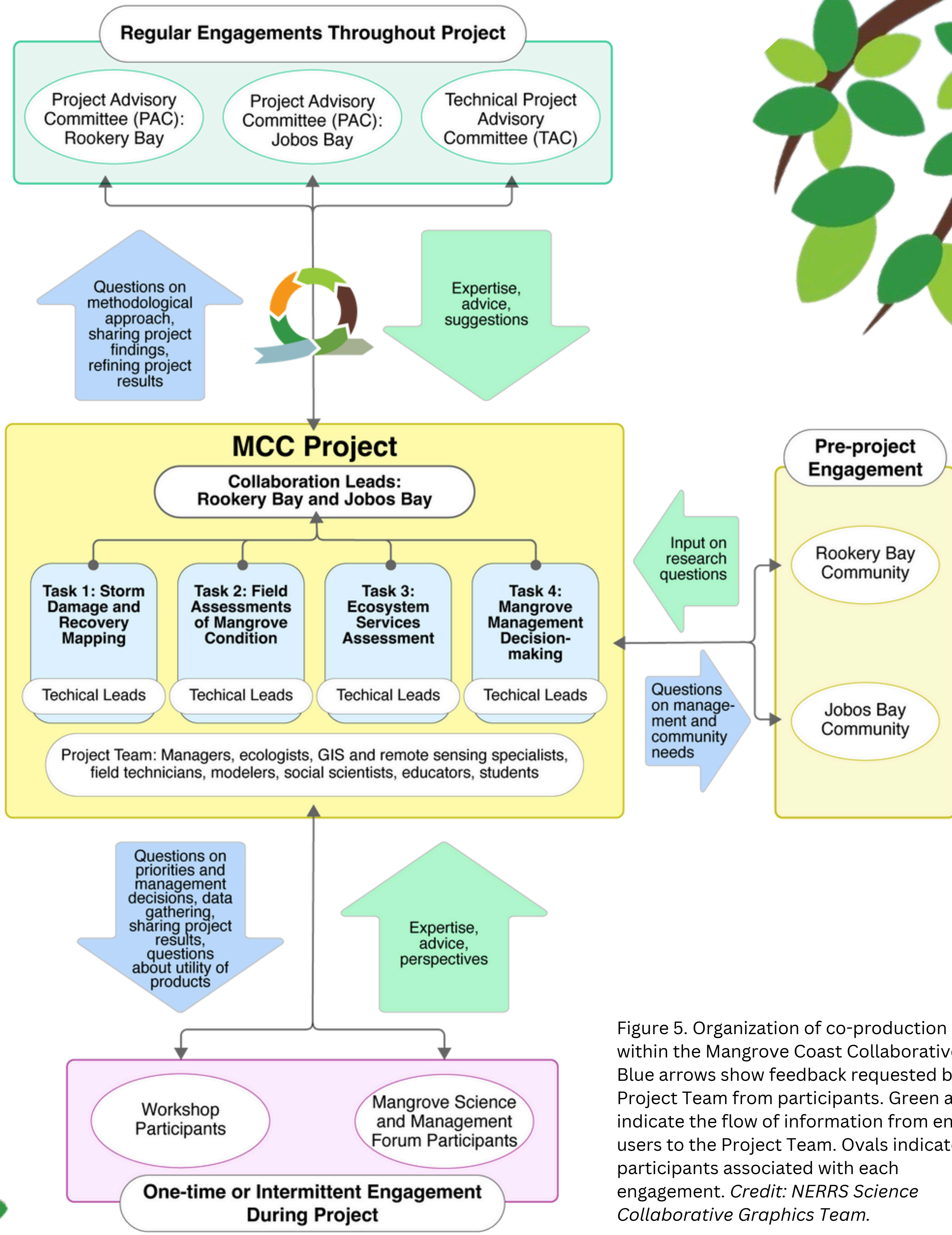


Figure 5. Organization of co-production within the Mangrove Coast Collaborative. Blue arrows show feedback requested by the Project Team from participants. Green arrows indicate the flow of information from end users to the Project Team. Ovals indicate participants associated with each engagement. *Credit: NERRS Science Collaborative Graphics Team.*

The organization of the co-production process within the MCC can be visualized in Figure 5. The Collaborative Leads would match the necessary process with the needs of the Technical (Task) Leads and would liaise between the Project Team. Pre-project engagements between local communities, reserve staff, managers, and partners were instrumental in building the scope and structure of the project. Regular engagements with PAC members were conducted via an iterative cycle (modified Agile Management Cycle) which allowed for direct input into the project approach by project partners. For details on the value of co-production on each Task, see the sections entitled *Impact of Engaging the PACs*. Lastly, one-time engagements with managers and workshop and Forum participants elicited perspectives and expertise at critical points throughout the project.

Timeline of Funding Sources & Engagements

The MCC project has been funded by several grants from the NERRS Science Collaborative (NSC). Engagements associated with each funding source played an integral part in the project trajectory (Fig. 6).

The Science Capacity grant (2019) enabled reserve staff and partners to engage in team-building by**:**

- Observing hurricane impacts at each reserve.
- Engaging stakeholders during facilitated sessions at each reserve to identify information gaps and determine major concerns and needs.
- Determining management actions to enhance resilience at both reserves.
- Defining major topics to address within a Science Collaborative project.

The Science Collaborative grant (2020-2024) funded the main MCC project. The project, consisting of a multi-disciplinary team and encompassing the four research themes (Tasks 1-4) detailed in this document, benefited from continuous engagements (Fig. 6).

The second Science Capacity grant (2023-2024) focused on expanding collaboration across reserves managing coastlines with mangroves:

- Bringing together staff from five NERRs (Rookery Bay, Jobos Bay, Mission-Aransas, Apalachicola, and Guana Tolomato Matanzas) and a research scientist from a proposed reserve in the U.S. Virgin Islands.
- Strengthening relationships and increasing knowledge of mangrove management needs across the Gulf and Southeast regions.
- Generating ideas for multi-reserve Science Collaborative Grants.

The Catalyst grant (2023-2025) extended the MCC project and focused on the following:

- Understanding the effects of subsequent hurricanes and their impacts on mangrove ecosystems.
- Continue strengthening the relationship between Jobos Bay and Rookery Bay NERRs.
- Increasing scientific knowledge of recovery and hydrological conditions of mangroves following multiple hurricanes.
- Increasing the awareness of resources and information necessary to develop tools and strategies for management of mangrove habitat resilience.
- Generating future guidance for other NERRs.

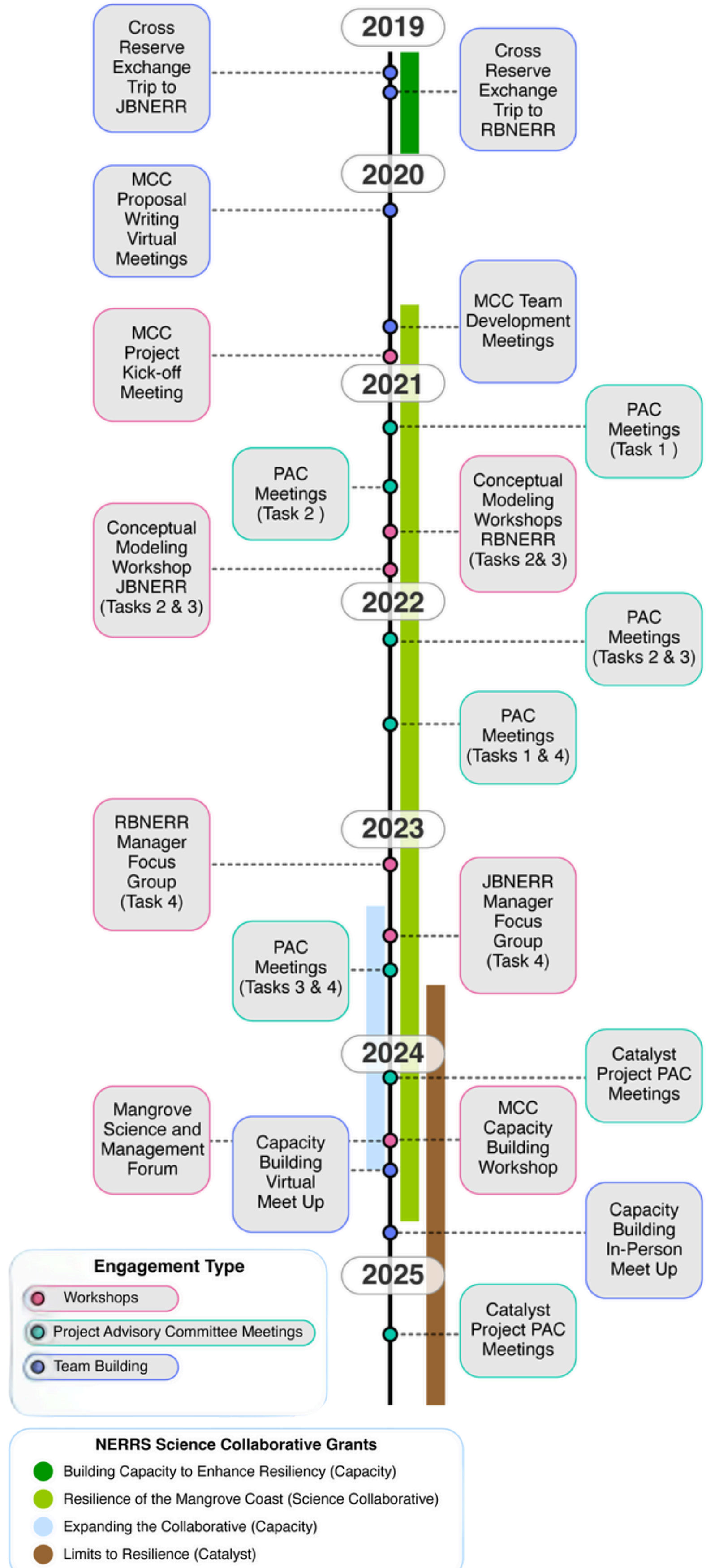
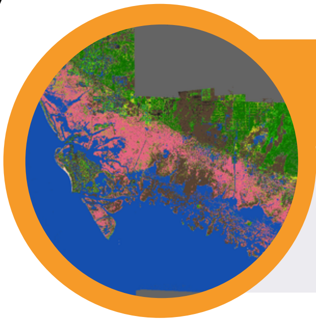


Figure 6. Timeline of grants and engagement activities conducted during the MCC project. *Credit: NERRS Science Collaborative Graphics Team.*



Task 1:

Mapping the Spatial Extent of Hurricane Effects and Recovery

About: In Task 1, the MCC team analyzed interannual changes in mangrove coverage (Fig. 7) using habitat maps derived from WorldView imagery at 2-meter resolution. These maps, developed for both Rookery Bay and Jobos Bay NERRs (including adjacent managed lands), focused on spatial domains defined in collaboration with local advisory groups. Landcover classes were defined with the input of advisory members and include the following categories: unclassified, shadow, cloud, natural non-vegetation or soil, water, marsh, dry low-relief vegetation, scrub/shrub, mixed low-relief vegetation, mixed upland vegetation, mangrove, developed/high-reflect, and natural high-reflect/sand (Fig. 8). Annual habitat maps were produced for 2014–2018 and 2020 (Jobos Bay), and 2014, 2015, 2017, 2018, and 2020 (Rookery Bay). Following the 2017 hurricane season, defoliated mangrove areas (“naked” mangroves) were primarily classified in 2018 as natural non-vegetation/soil or as water, reflecting mangrove canopy loss. By 2020, many of these areas reverted to the mangrove class, indicating canopy recovery, though some regions remained degraded (Fig. 8). Comparing mangrove classes across years (Fig. 7) highlights areas of loss and recovery and reveals spatial patterns of change. These maps allow managers to quickly locate areas of significant mangrove decline and minimal recovery, which are key targets for restoration and intervention.

Management Applications:

- *Change Detection*: Track shifts in mangrove spatial distribution due to natural disturbance, recovery after storms, urban development, or encroachment into marsh habitat.
- *Prioritization*: Identify priority zones for management (areas under stress, restoration, land acquisition) and for future research.
- *Impact Assessment*: Evaluate whether management actions are achieving the intended impacts.

“Useful in assessing immediate impact and recovery from hurricanes, especially the areas most impacted by the storm.”

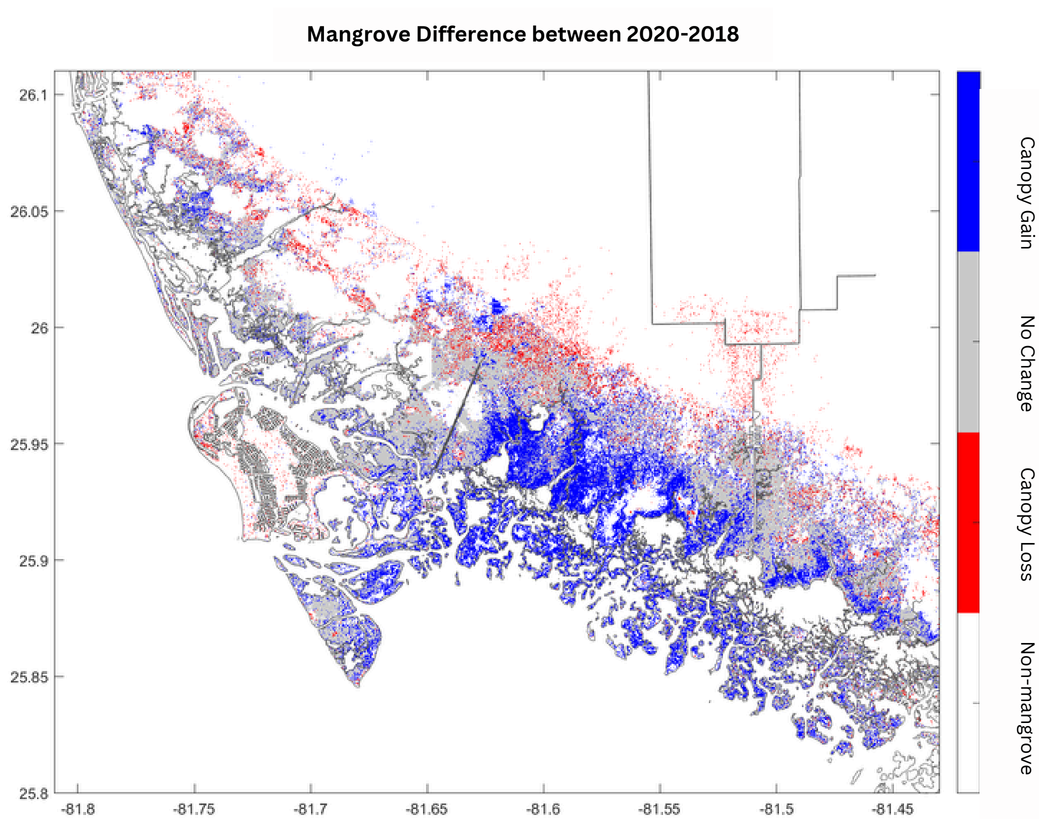


Figure 7. Change map for the Rookery Bay study area (2020 minus 2018), showing mangrove canopy gain (blue) and loss (red). The losses shown inland are likely due to misclassification of upland vegetation as mangrove in 2018.

Interannual mangrove change maps were generated by subtracting mangrove pixels in one year’s mosaic from a previous year. Figure 7 shows substantial mangrove canopy recovery in the southern half of Rookery Bay two years after Hurricane Irma (blue). These change maps allow interannual comparisons of mangrove extension and condition. While mangrove canopy increased from 2018 to 2020, coverage remained below 2017 levels in many areas, reflecting limited or slow recovery in those regions. To view the project page and time series maps in Google Earth Engine visit https://bit.ly/MCC_Maps.

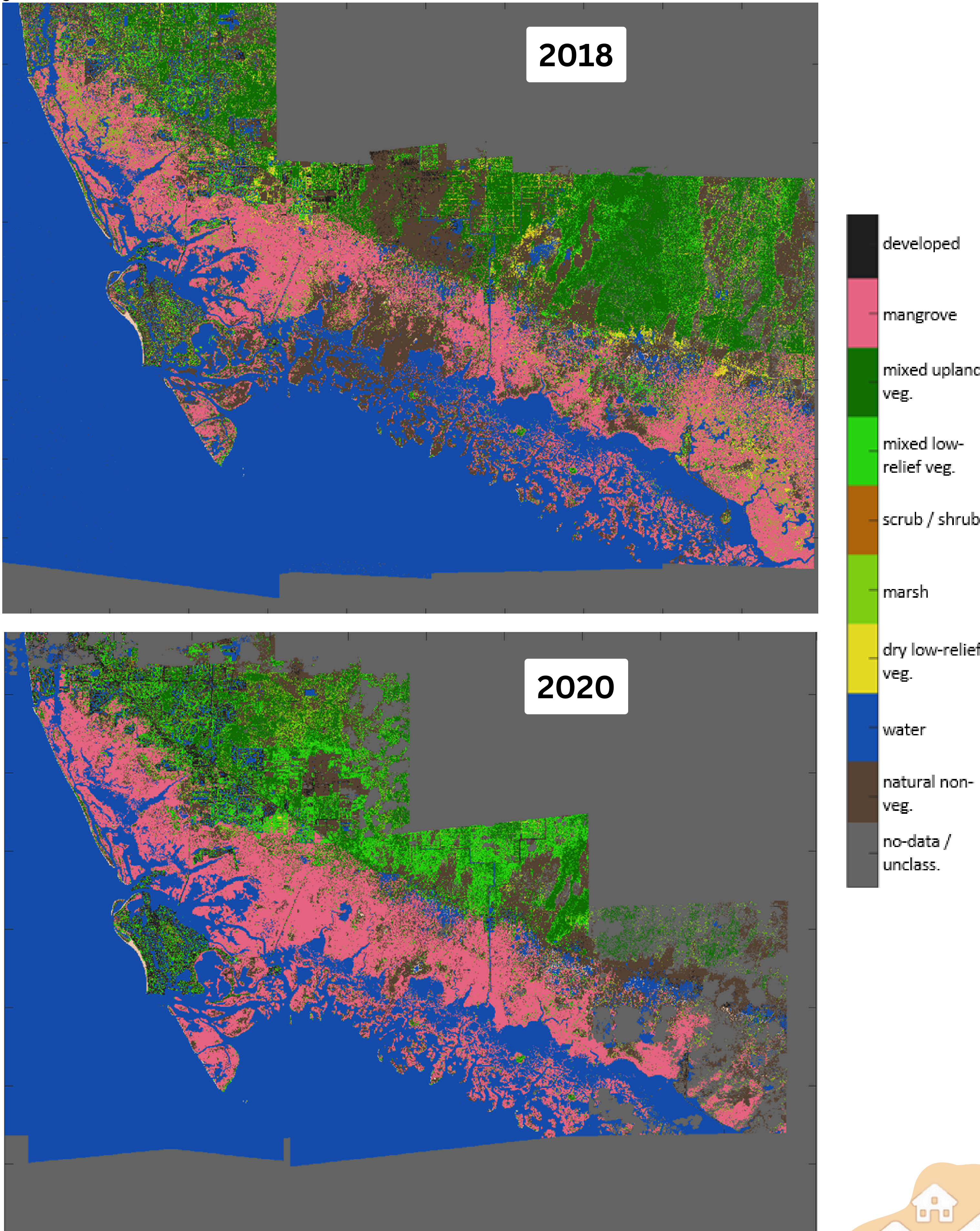


Figure 8. Maps of the 2018 and 2020 mosaics depicting mangrove coverage for the Rookery Bay study area. If you would like to view the project's habitat coverage maps, please visit: https://bit.ly/MCC_Maps.

Findings: Hurricane-driven mangrove canopy loss was clearly visible in the annual mosaic time series for both reserves, as some pre-hurricane mangrove pixels were reclassified as soil or water in post-hurricane maps. In Rookery Bay, significant canopy loss occurred along the path of Hurricane Irma's eastern eye wall in 2018 (Fig. 8, top). By 2020, much of the canopy had recovered (Fig. 7 and Fig. 8, bottom), though total mangrove coverage remained below 2017 levels due to limited recovery in some areas. The classification model performed consistently well across all annual maps, with sensitivity values ranging from 0.74 to 0.95 (on a scale from 0 to 1), correctly identifying mangrove areas between 74% and 95% of the time, which is considered a strong level of accuracy.

"This is a significant tool that will help management and restoration decisions & will positively impact all four sectors of the reserves."

Impact of Engaging the PACs: The PACs collaborated closely with Task 1 on the project, giving feedback to define regions of interest, refinement of class definitions, georeferencing improvements, and quality control of mosaics. Their inputs enhanced the final products by informing manual corrections and supporting expert validation of classification errors, resulting in more accurate and realistic mangrove maps. Given limited time and resources, the PACs advised prioritizing manual alignment to improve georeferencing accuracy. As a result, the Task 1 team focused their efforts on producing high-quality maps that better represent real-world mangrove conditions, rather than developing additional products.

Limitations and Uncertainties

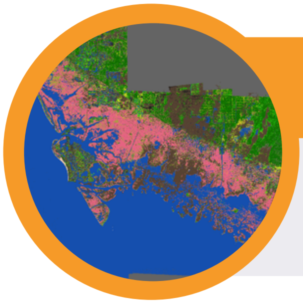
- *Detail detection*: Difficulty identifying species, seedling growth, or vegetation stress due to variable imagery and spectral limitations.
- *Regeneration detection*: Current methods often miss seedlings or young, sparse mangroves.
- *Defoliation detection*: Challenging with single-date images; time-series data helps infer these changes.
- *Species differentiation*: Current tools cannot distinguish between mangrove species.

Assumptions and Context

- *Pixel classification*: A time-series map shift from mangrove to non-mangrove may indicate defoliation or mortality.
- *Accuracy assessment*: Most reliable when combining ground-truth points from fieldwork with points identified by visually examining high-resolution historical imagery.
- *Expert verification*: Local expertise is key for validation and interpretation of maps results.

Opportunities and Recommendations

- Develop algorithms for seedling tracking.
- Integrate hyperspectral and aerial imagery for species differentiation.
- Implement real-time monitoring capabilities.
- Build tools for stress detection in mangrove communities.



Task 1:

Catalyst Project - Storm Damage and Recovery Maps

About: Following the methodology used in the MCC project, the Catalyst project assessed mangrove spatial coverage using land-cover classification maps generated with high-resolution multispectral satellite imagery and algorithms designed to detect mangroves with green canopy. The Catalyst Task 1 extended the annual time-series maps from the MCC project (2014-2020), producing additional annual maps from 2021 through 2024 to evaluate how mangroves, still in varying stages of recovery from the 2017 hurricanes at both reserves, were affected by the storms in 2022. Land-cover maps were created for both study areas and validated with feedback from Project Team members. However, the availability of WorldView imagery from 2021–2024 was limited. While the Jobos Bay study area had sufficient coverage to produce full annual maps (Fig. 9), imagery was more limited for Rookery Bay. The Team explored alternative sources, such as Planet's SuperDove imagery, and consulted with the PAC to determine the best path forward. Ultimately, PAC members recommended continuing with WorldView imagery despite its gaps, allowing for the production of partial maps for Rookery Bay that remain comparable with previous years.

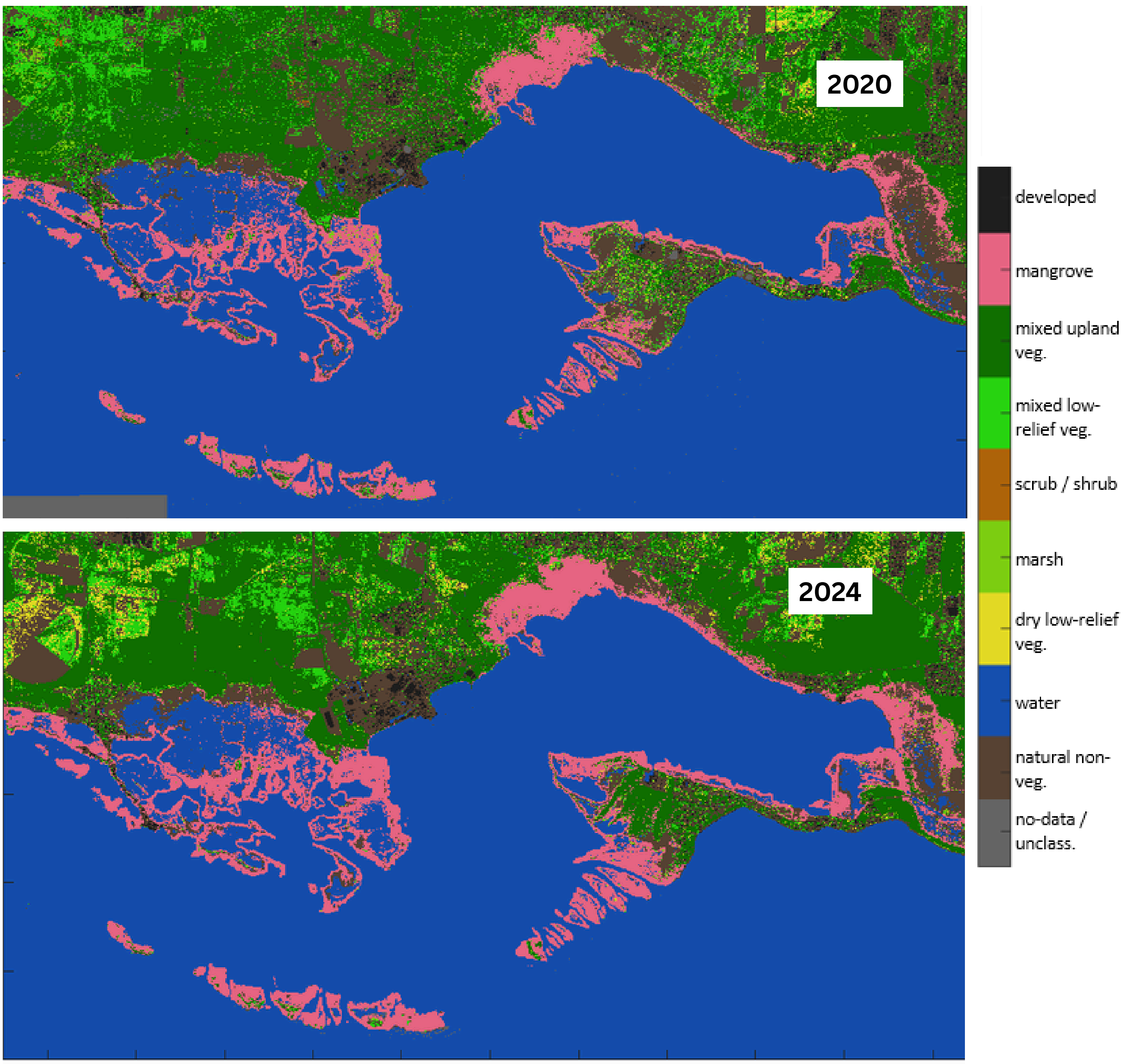


Figure 9. Maps of the 2020 and 2024 mosaics depicting mangrove coverage for the Jobos Bay study area. Maps will be located on the project page here: https://nerrssciencecollaborative.org/project/Ogurcak23

Findings: The difference between the post-María and pre-Maria mangrove maps revealed widespread canopy loss in Jobos Bay. However, since the hurricane the region shows signs of extensive mangrove regrowth (Fig. 10). The observed recovery by 2024 is likely attributable to resprouting in white and black mangroves, as well as recruitment of seedlings and saplings. However, the comparison between 2024 and 2017 (Fig 10) highlights two areas where mangrove recovery has not occurred in Jobos Bay:

- Aguirre State Forest (blue circle): Pre-hurricane hydrologic alteration created impounded conditions, resulting in poor recovery (only 83% by 2024 compared to pre-storm conditions in 2017). Ongoing hydrologic restoration efforts aim to improve conditions and support further mangrove recovery.
- Camino Del Indio (green circle): Although illegal expansion into the reserve began before Hurricane Maria, post-storm disturbances resulted in a 37% mangrove loss in the area by 2018. Illegal clearing continued in the aftermath such that mangrove canopy had decreased in the area by 45% as of 2024.

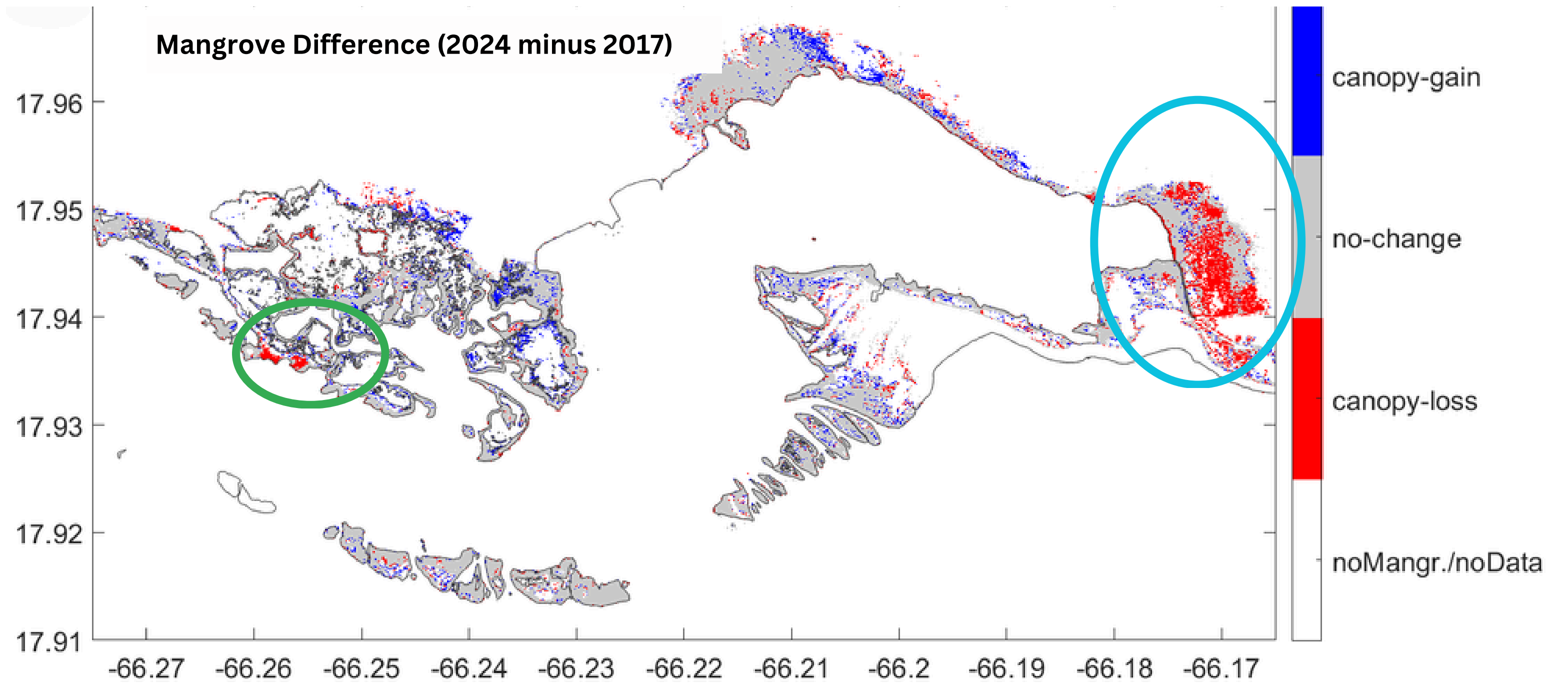


Figure 10. Change in mangrove coverage from 2024 compared to 2017 in the Jobos Bay study area.

The continuation of Task 1 mapping through 2024 enabled the team to track mangrove recovery over time since the major hurricanes of 2017 and to assess whether additional impacts from the 2022 storms hindered that recovery. Both study areas showed substantial regrowth, with minimal new impacts from the 2022 storms. By 2024, the Jobos Bay study area reached 97.8% canopy recovery, and Rookery Bay regained 95.7% of its 2017 mangrove extent by 2022. Despite this overall progress, some areas in both reserves showed limited recovery, likely due to a combination of factors, including hydrologic stress. Task 2 of the Catalyst project focused on hydrologic assessments to explore the underlying causes of reduced post-hurricane recovery.

Task 2:

Field Assessment and Ecological Driver Modeling

About: Task 2 of the MCC focused on assessing the relationships between hurricane effect and recovery in mangrove forests in each reserve. The aim was to better understand the drivers leading to mangrove degradation following hurricane disturbance. Both reserves have coastlines dominated by mangrove habitats. In the greater Caribbean region, including south Florida, three species of true mangroves can be found: *Rhizophora mangle* (red mangrove), *Avicennia germinans* (black mangrove), and *Laguncularia racemosa* (white mangrove). Task 2 focused on resilience of mangrove forests; the team defined mangrove forests as a mangrove habitat having greater than 50% canopy cover with individual trees equal to or greater than 5 m in height.

In Rookery Bay, approximately 12,000 hectares were mapped as mangrove forest prior to Hurricane Irma, with just over 50% of that forest classified as mixed species (where no one species is dominant), followed by 30% as red mangrove. By comparison, Jobos Bay has a much smaller footprint, with approximately 440 ha mapped as mangrove forest prior to Hurricane Maria. Similarly, the greatest extent of this forest was classified as a mixed mangrove species forest. The Task began by building a conceptual model of the potential relationships between ecosystem attributes, drivers of change, and ecosystem response. That information was then used to select an appropriate sampling design for the collection of field data. Subsequently, a field assessment was conducted in each reserve with the intent of using the data to test the model statistically. Input from the Advisory Committee was incorporated at several steps in the process and is described below.

Management Applications:

- Managers can use data to inform management plans and secure funding for monitoring and research.
- Data will be useful as baseline for future disturbance and should assist in planning for future impacts.

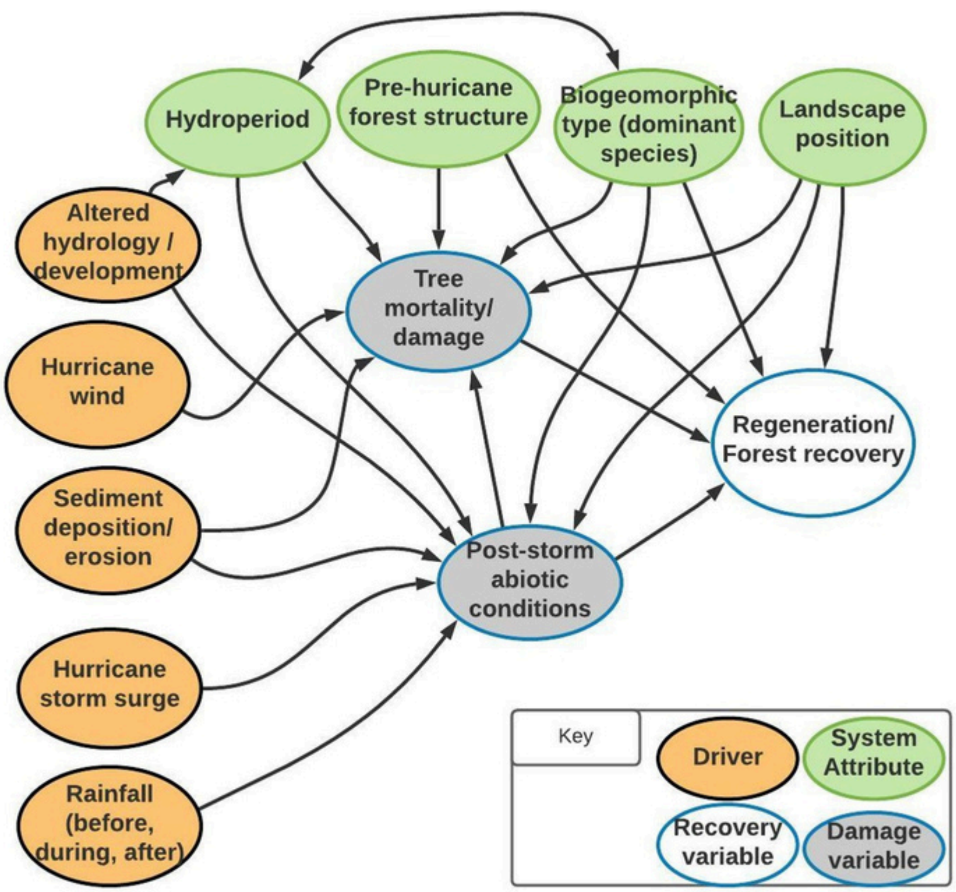


Figure 11. Conceptual model developed from the workshop held in 2021. Each factor can be categorized as either: 1) a driver associated with hurricanes or human disturbance, 2) an ecosystem attribute (pre-disturbance initial conditions), or 3) a response variable related to hurricane impact and recovery. Arrows indicate the direction of effect between factors, with factors having either direct or indirect effects on response variables.

Impact of Engaging the PACs: The sampling design and parameters measured during field campaigns were highly influenced by discussions with the Project Advisory Committees. During meetings in early 2021, PAC members were asked to suggest potential metrics to quantify mangrove degradation. The list served as a starting point for building an ecological driver model for both Jobos Bay and Rookery Bay NERRs (Fig. 11). Building conceptual models during workshops held in 2021 allowed the team to draw on the collective expertise from both scientific research and local knowledge to outline the relationships between the ecological drivers associated with hurricanes, anthropogenic drivers present at each reserve, and the responses to drivers by the ecosystem. The next step was to select metrics to serve as proxies for the often complex phenomena represented by each factor in the model.

PAC members suggested metrics they thought best served as proxies for each factor in the conceptual model. Metrics selected were either those that could be measured in the field (observed) or could be derived from geospatial datasets (Fig. 12). Based on the outcomes of these expert recommendations and considering what was feasible given logistic constraints, Task 2 undertook a field campaign to measure indicators of hurricane impact and recovery.

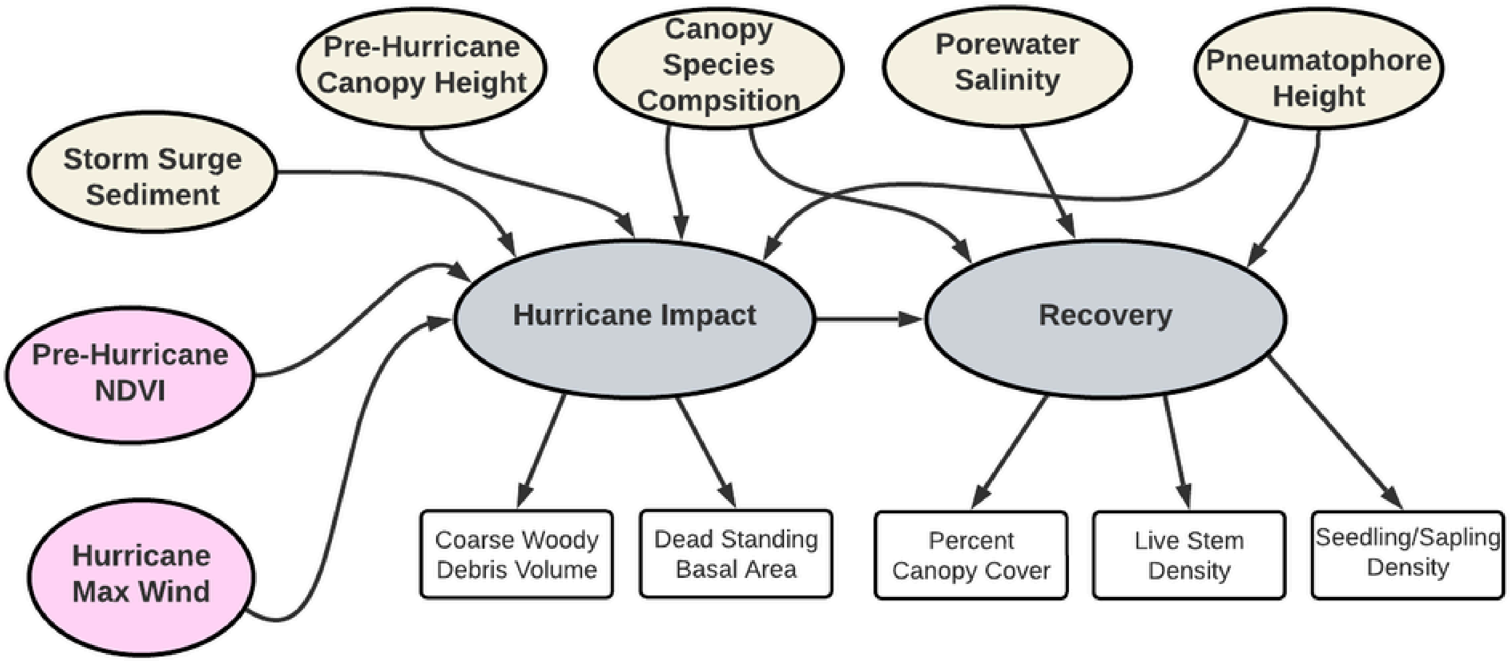
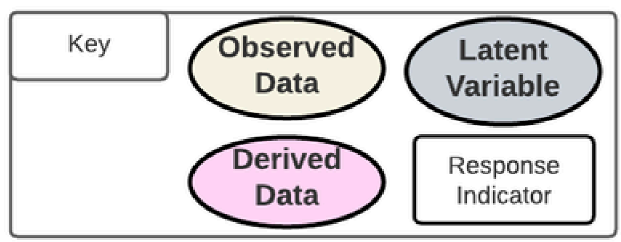


Figure 12. Refined ecological driver model with metrics identified for field sampling and modeled variables. Latent variables are concepts that are represented by multiple indicators in the model.



"[The field sampling] can be used as a data reference and analysis of mangrove data."

<u>Data Collection:</u> The field assessment was undertaken using a stratified random sampling design that ensured 1) coverage across a range of geomorphic settings and geographic locations in each reserve and 2) distribution across all present mangrove forest types (red mangrove, black mangrove, white mangrove, and mixed species forests). In Jobos Bay the field team sampled 64 plots between March 2022 and August 2022. In Rookery Bay 69 plots were sampled between February 2022 and March 2023. Hurricane Ian impacted Rookery Bay in September 2022, prior to the completion of the field campaign, leaving one-third of plots unsampled. After Hurricane Ian the team assessed the impacts to multiple areas within the Reserve and observed that effects were primarily related to storm surge with minor wind effects (partial defoliation and small broken branches). Given that the effects to forest structure differed greatly between the 2 hurricanes, it was possible to discriminate the impacts to the mangroves from each disturbance and data collection recommenced in November 2022.

A 100 m^2 circular plot was established at each randomly selected location and the center point was marked with a PVC pole. Metrics sampled at each plot included: species composition, stem diameter at breast height (stems ≥ 1 cm), percent canopy closure, average canopy height (pre and post hurricane), stem mortality/damage, porewater salinity at a depth of 60 cm below ground, prevalence of leaf stress/herbivory/disease, and presence/absence of a sediment layer associated with storm surge. Soil cores were collected and visually assessed to determine whether there was evidence of sediment deposition associated with hurricane storm surge. Regeneration (seedling / sapling counts) and height of pneumatophores were measured in four 1 m^2 subplots. The quantity of downed woody debris was assessed along three 20 m transects beginning at the center of each plot. Due to issues with instrumentation and timing of sampling, porewater was not used as a parameter in Rookery Bay's model.

The Results: A total of 8,533 and 10,001 stems ≥ 1 cm diameter were inventoried in Rookery Bay and Jobos Bay, respectively (Fig. 13). Measured stems were either growing individually or were found growing as part of a multi-stemmed tree. Multi-stemmed trees are common post-disturbance for both black and white mangroves, as both species have the ability to sprout new growth from their trunks. The distribution of size classes and species varied across plots in each reserve.

Plots having evidence of post-hurricane recovery had numerous small stems either sprouting from mature black mangrove or white mangrove, or had emerged from the sapling stage in the gaps created by the newly opened canopy. Areas of minimal recovery in both reserves, characterized by few seedlings/saplings and minimal resprouting, were almost entirely restricted to black mangrove-dominated forests. However, in Jobos Bay, several plots in fringing red mangrove forest exhibited areas of wind-related tree mortality and subsequent peat erosion. Only Jobos Bay had a substantial area of white mangrove-dominated forest prior to the hurricane. This forest is distinctive in having substantial wind damage and mortality with trees as tall as 20 m uprooted and tipped over. Yet, this forest showed rapid recovery in many areas with a high density of small diameter trees at the time of field sampling in 2022.

Figure 13. Project technicians collecting data in a black mangrove forest in Jobos Bay NERR in March 2022.

“Very detailed, but a snapshot in space and time.”

Limitations and Uncertainties

- The rapid single survey completed as part of the MCC does not attempt to integrate multiple temporal disturbance events.
- Dynamic conditions (including those related to hydrology) are unlikely to be well-represented by a single sampling event.

Assumptions and Context

- Mortality can sometimes, but not always, be attributed to storm impact rather than other contributing factors.
- Site hydrology has been influenced by hurricane disturbance at some locations.
- Maximum wind speeds for each hurricane were determined from the radius of maximum winds.
- Tropical storm force winds associated with Hurricane Ian (2022) did not have a substantive impact on mangrove forest structure in Rookery Bay.

Opportunities and Recommendations

- There is a need for increased understanding of regional hydrology and its effects on mangrove recovery and resilience.
- Consider utilizing remotely sensed datasets and technologies (e.g., drones) as part of post-storm monitoring.
- Integrate the ecological model to include pathways within the Resist-Accept-Direct (RAD) framework for management intervention.
- Investigate ways to combine long-term plot monitoring with rapid sampling.

Task 2:

Catalyst Project - Hydrology Assessment

About: Site hydrology plays an important role in post-disturbance ecosystem recovery. The Project Team investigated the role of hydrology at sites of minimal recovery as part of an 18-month Catalyst project which began in 2023. Following field assessments in each reserve (2022-2023), the team hypothesized that reduced tidal flushing and/or increased porewater salinities may be leading to areas of minimal recovery observed in each reserve. Following input from PAC members in early 2024, a decision was made to focus the hydrologic monitoring in locations of black mangrove forest in each reserve. Additional recommendations that were incorporated in the study design included: 1) establishing at least one reference site as part of the monitoring in each reserve and 2) consideration of geographic context and disturbance legacies.

Study Design and Methodology: Six monitoring locations were selected in each reserve. In Rookery Bay, this included three sites in mainland/interior black mangroves and three sites on ocean-facing islands, all of which are located on the east side of Hurricane Irma eyewall (Fig. 14). In Jobos Bay, four stations were installed at existing structural plots sampled in 2022 in black mangrove forest. However, along the western boundary of the reserve, an additional stressor of human encroachment exists that has led to loss and degradation of mangrove habitat. Therefore, two sites were selected in this area that were not coincident with structural plots sampled in 2022. These two sites include mixed species mangrove habitat in nearshore locations. The instruments deployed were non-vented In-Situ AquaTROLL 200 data loggers that record pressure, conductivity, and temperature. Two BaroTROLL loggers were deployed at each reserve to provide atmospheric compensation. At the two sites situated in mixed mangrove forest in Jobos Bay, the team deployed existing Solinst LTC Levelogger 5 LTC data loggers. Loggers were suspended on stainless steel wire to a depth of ~70 cm below the ground surface. Loggers were deployed in April 2024 and programmed to record data at 30-minute intervals. Data was downloaded in December 2024 after eight months.

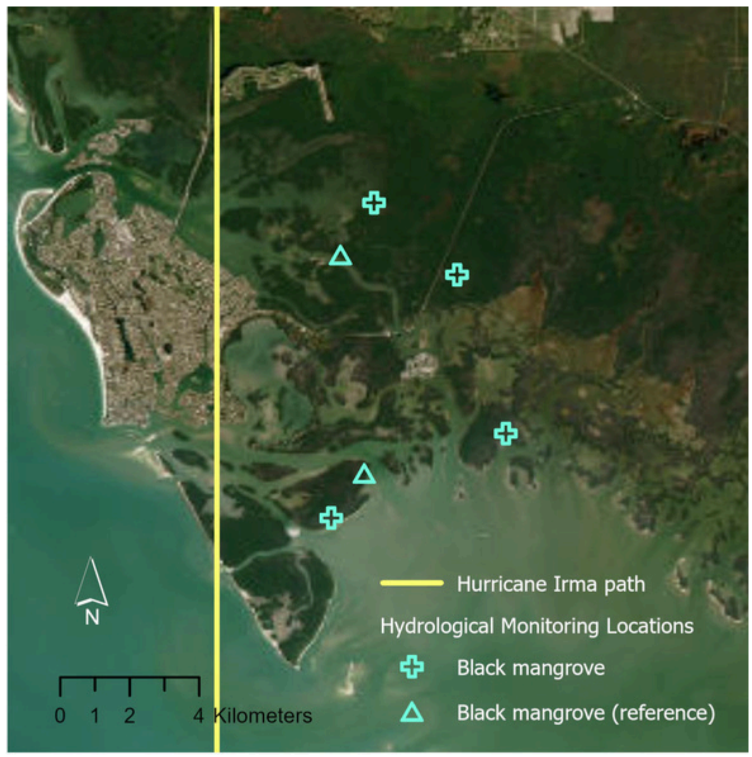


Figure 14. Map of Rookery Bay study area showing the path of Hurricane Irma and the hydrologic sampling sites. Reference sites are marked by triangles.

Project Findings: Initial assessment of data shows flooded conditions for the majority of sites over eight months (April 2024 to December 2024). Locations with minimal recovery had fewer drawdowns and had higher average flooding conditions compared to reference sites. In general, the hydrographs at Rookery Bay NERR were very similar to each other in pattern, including timing of tidal flooding and peaks associated with storm surge from tropical cyclones that affected southwest Florida between August and October 2024 (Fig. 15). In Jobos Bay NERR, the patterns of hydrographs vary considerably between sites, beyond the difference expected for the black mangrove basin forests compared to tidally-dominated mixed forests. All hydrographs in Jobos Bay NERR suggest that some level of hydrologic stress is present at each site. Associated salinities at a depth of ~70 cm did not vary much between the sites or temporally in Rookery Bay. There was a greater difference between average pore water salinities at the Jobos Bay monitoring locations, ranging from sites that are hypersaline to those that are receiving freshwater inputs. Upon reviewing the data during the February 2025 PAC meetings, Advisory Committee members recommended repositioning the logger at each site to more shallow depths to capture changes in salinities that could be affecting propagule germination and establishment.

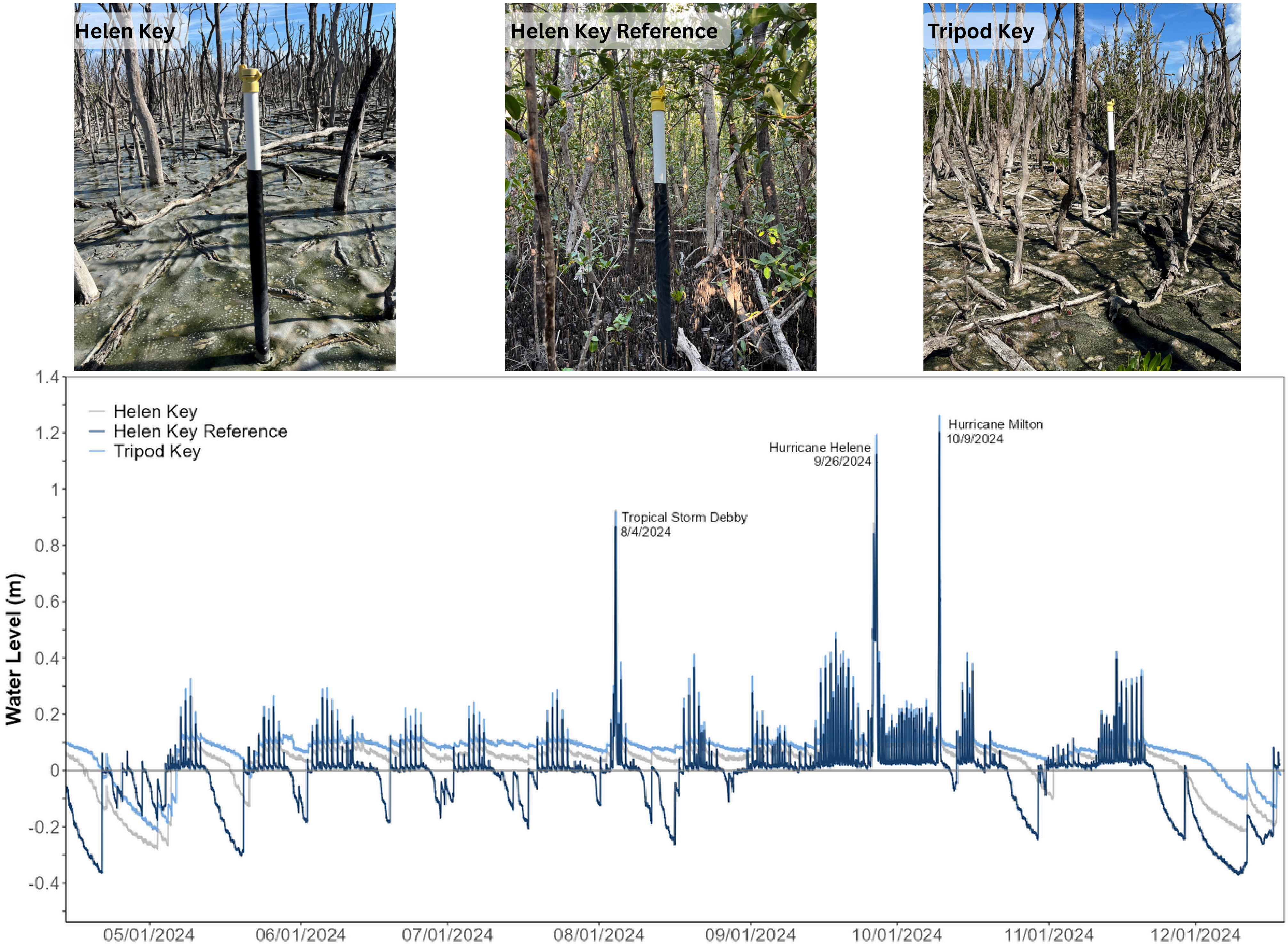
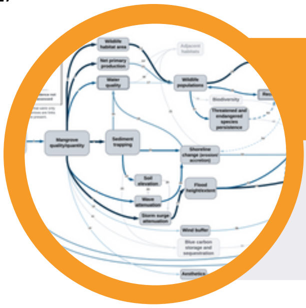


Figure 15. Hydrographs of ocean-facing monitoring locations in Rookery Bay NERR (sites shown in photos). Water level (m) is reported relative to local ground surface. Hydrology graphs will be located on the project page here: https://nerrssciencecollaborative.org/project/Ogurcak23



Task 3:

Summarizing Potential Hurricane Impacts to Mangrove Ecosystem Services

About: Task 3 of the MCC project worked with both Jobos Bay NERR and Rookery Bay NERR to identify the ecosystem services at each reserve perceived to be most at risk from mangrove system changes after a large storm event. Workshops were hosted at both Rookery and Jobos Bay, bringing together local stakeholders to decide which ecosystem services provided by each reserve's mangrove systems were most important to examine. This selection was done after co-development of an Ecosystem Service Conceptual Model (ESCM) that describes each reserve's socio-ecological mangrove system (see Fig. 16 for an explanation of how ESCMs are structured). The ESCM traces how mangrove ecosystem changes could influence ecological, biophysical, and ultimately social and economic outcomes (ecosystem services) at each reserve. The strength of evidence for each linkage is depicted in the ESCM using arrow color and size and the criteria for each level is provided in Table 1.

Management Applications:

- Identification of research priorities for graduate student projects or to include in management plans.
- Securing research funding for the study of linkages highlighted in the gap map.
- Utilization of the gap map could help identify important outcomes to monitor.
- Ecosystem Services Conceptual Models can be used by managers to consider ecosystem services outcomes of a management decision or changing mangrove system.
- Education and outreach materials - the conceptual model can help illustrate connections between the mangrove system and the public or individual homeowners.
- Supporting advocacy efforts to help policy-makers understand the importance of mangroves and their associated services.

Impact of Engaging the PACs: The ESCM was co-developed with the groups who attended the workshops (which included many PAC members); linkages between stressors and ecosystem services were considered for each reserve. The ESCM was then used by workshop participants to identify key ecosystem services for each reserve. The team used the key ecosystem services as a framework to develop the ESCM Evidence Gap Map (Fig. 17).

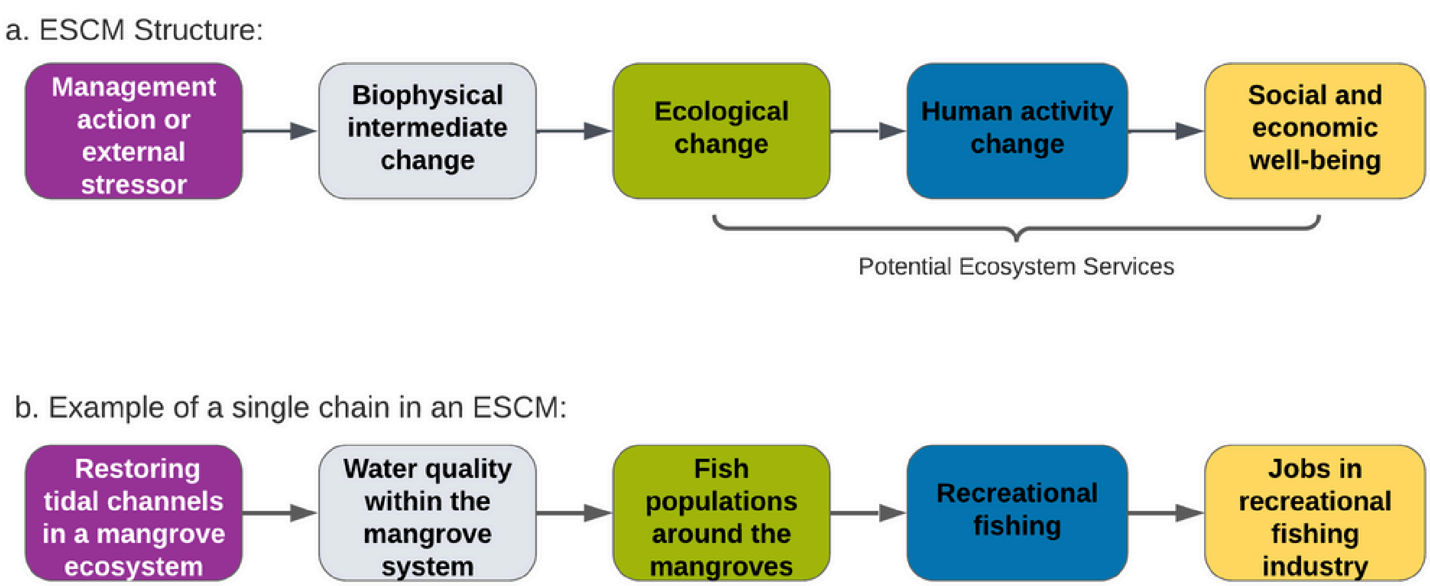


Figure 16. Example of an Ecosystem Services Conceptual Model's structure and a single chain within it. These models illustrate the way that a stressor or management intervention cascades through an ecological system, changing the ecosystem services.

“[The ESCM] allows us to visualize the connections between the services and the potential impacts of mangrove degradation in every aspect.”

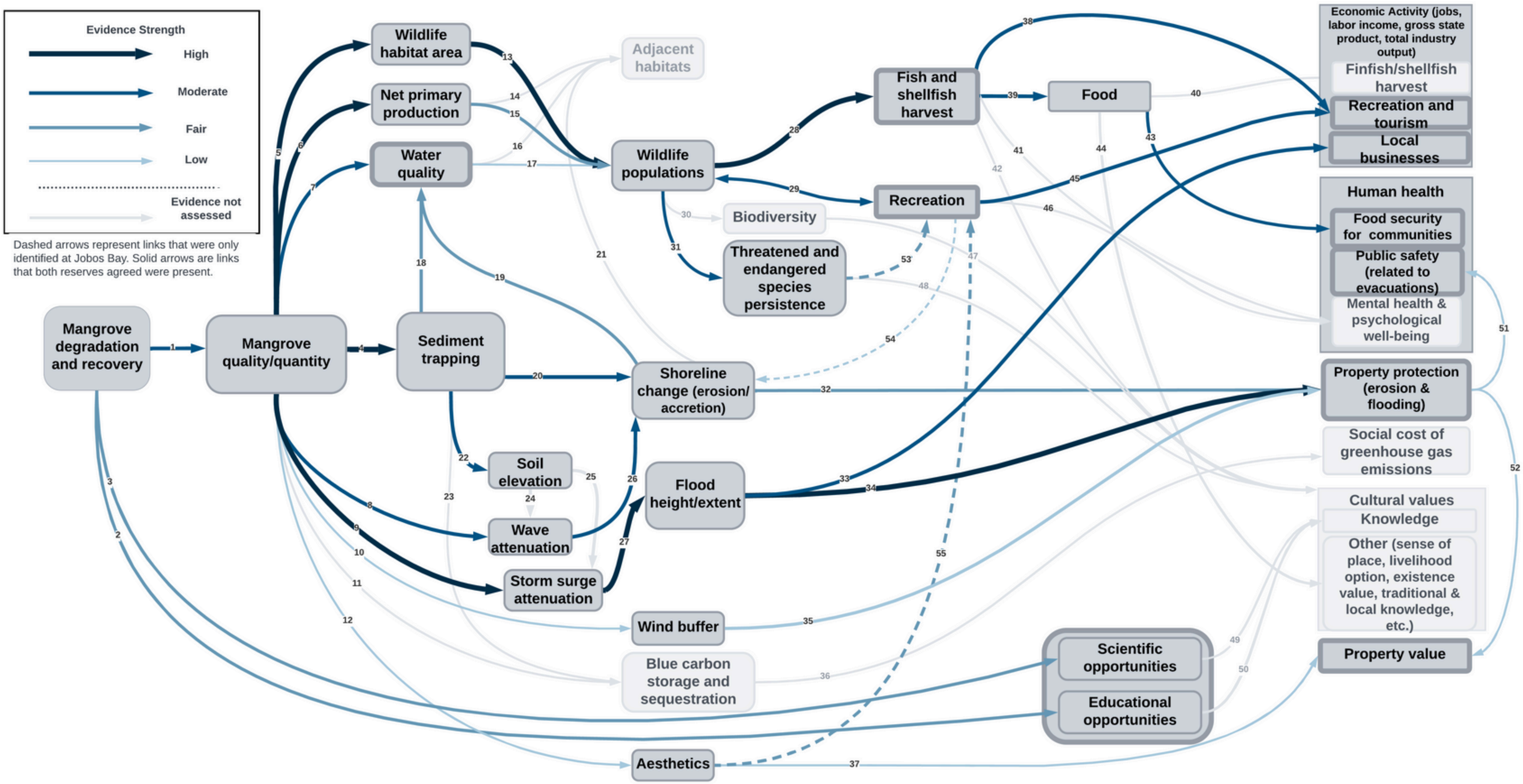


Figure 17: ESCM Evidence Gap Map for the mangrove systems at both reserves. The evidence gap map was created from linkages represented in the ESCM, illustrated by the colored arrows. If you’d like to view the full report, please visit the link here: https://bit.ly/442UXFg

CRITERIA				
Confidence Level	Evidence Types	Results Consistency	Methods	Applicability
High	Multiple	Direction and magnitude of effects are consistent across sources, types of evidence, and contexts	Well-documented and accepted	High
Moderate	Several	Some consistency	Some documentation, not fully accepted	Some
Fair	A few	Limited consistency	Limited documentation, emerging methods	Limited
Low	Limited, extrapolations	Inconsistent	Poor documentation or untested	Limited to none
None	None	N/A	N/A	N/A

Table 1: Strength of evidence criteria matrix, adapted from Tallis et al. 2019.

"Using the Gap Map allows us to clearly see areas that need research, as well as potential future impacts of restoration decisions."

Opportunities and Recommendations

- Product could be adapted to be more dynamic and interactive, enabling users to input estimated changes and the anticipated result of how the system would be expected to change.
- Incorporating risk assessment into the model to help evaluate the risk of making a "wrong decision" as a way to consider how high the stakes are for trusting the information included in the evidence library.
- Expand to include case studies with specific example sites where services have been impacted by a particular storm.
- Create one-page fact sheets to make the document more accessible to particular user groups like policy-makers or homeowners.
- Connect the product to applications for benefit-cost analysis (BCA) - use the conceptual model to help ensure ALL costs and benefits are included in a BCA.
- Good education tool to share with external audiences to help share details about the mangrove system.

Limitations and Uncertainties

- Do end-users have the knowledge needed to interpret and/or use the product?
- Some evidence search terms are specific, how do we know the right terms were used to find relevant evidence?
- Evidence searches limited to research published in English.
- There may be gaps in the evidence we found due to publication bias (i.e., only publishing "interesting" results) as well as funding bias (i.e., there are certain research topics that are "trendy" to fund).

Assumptions and Context

- The key services selected are relative to people's values and services are perceived as valuable based upon the individuals who find it important.
- All users who are benefitting from these services at each reserve were not necessarily engaged to select key services, assume that representatives attending workshops raised important points.

Task 4: Mangrove Management Decision-Making

About: Task 4 of the MCC focused on the decision-making processes by mangrove managers and the application of the Resist-Accept-Direct (RAD) framework (Schuurman et al. 2020) following hurricane impacts to lands they manage. The RAD framework considers management responses to ecosystem transformation categorized among three approaches, which can be used alone or in combination with each other. **Resist** actions are focused on preserving current or historical ecosystem structure, composition, and functions. **Accept** actions allow the system to change with no intervention from managers. **Direct** actions actively shape ecological conditions via management interventions to bring the ecosystem to a different state that is more aligned with the new emerging climate. To investigate managers' decision-making processes and use of the RAD framework, the MCC team hosted focus groups in both Jobos Bay and Rookery Bay NERR in 2023, in addition to conducting semi-structured interviews.

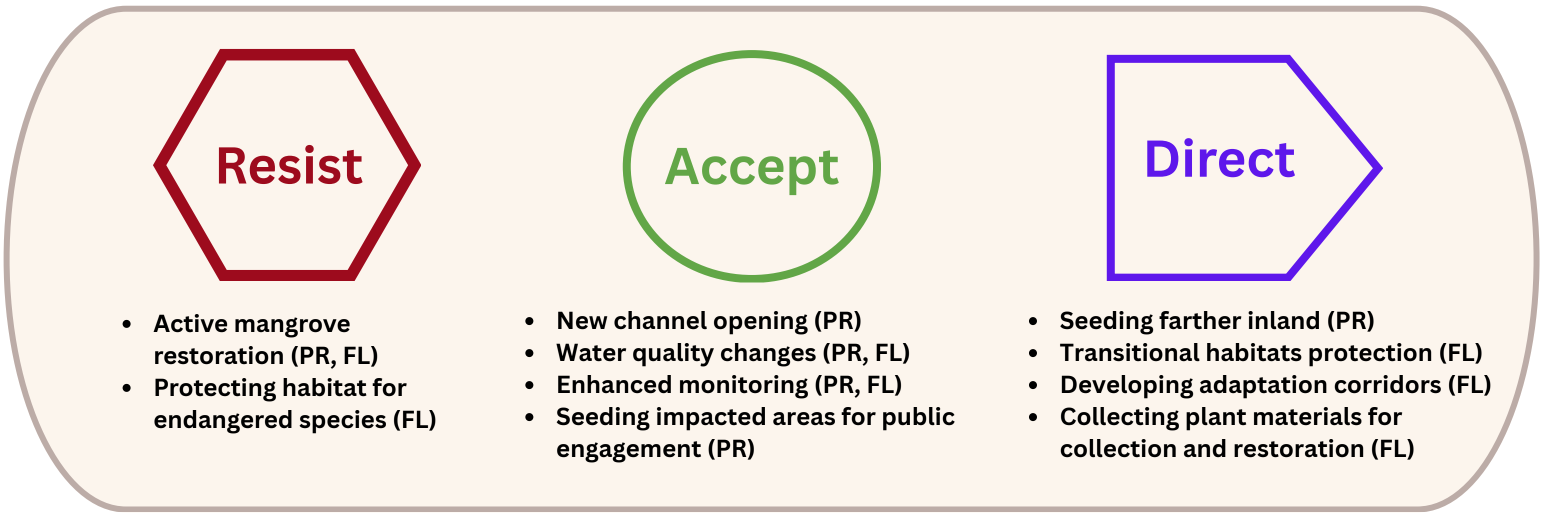


Figure 18: Post-hurricane management actions identified during each focus group (FL, PR, or both) categorized as either Resist, Accept, or Direct

Focus Group Engagement: In February (RBNERR) and June (JBNERR) of 2023, resource managers were invited to participate in guided discussions focused on policies and strategies for mangrove management and restoration in each region, including identifying barriers to the implementation of strategies and determining the usefulness of the RAD framework in decision-making. The Puerto Rico focus group hosted 11 participants, mainly from the Puerto Rico Department of Natural Resources, and included a representative from the U.S. Virgin Islands to discuss and compare hurricane impacts between the two islands. The Florida focus group consisted of eight participants from a variety of conservation organizations in South Florida.

Both reserves faced challenges such as long-term effects of co-stressors (drought and sea level rise), high costs associated with restoration, restriction of natural water or flow, and public awareness and public value of natural resource benefits. Given the challenges, most managers preferred to monitor changes to a system for several years following a hurricane event before attempting any restoration. Many managers expressed needs such as vulnerability assessments, cost-benefit analyses, knowledge of historic land change, and projections of the success of different types of restoration, in addition to a need for the actual tools and data to enable effective monitoring.

The Puerto Rico focus group concluded that the current plan for longer term observation prior to action and more of an "Accept" approach conflicted with pressures from NGOs and public desire to conduct post-event planting (Fig. 18). However, future effects of sea level rise may result in the managers changing to a "Direct" approach.

The Florida focus group discussed the development of novel systems and environmental conditions after a hurricane, which made them aware of areas where long-term monitoring data is lacking and needs to be collected (Fig. 18). The group expressed a concern that their current decision to "Accept" the impacts and change may be the result of a lack of data.

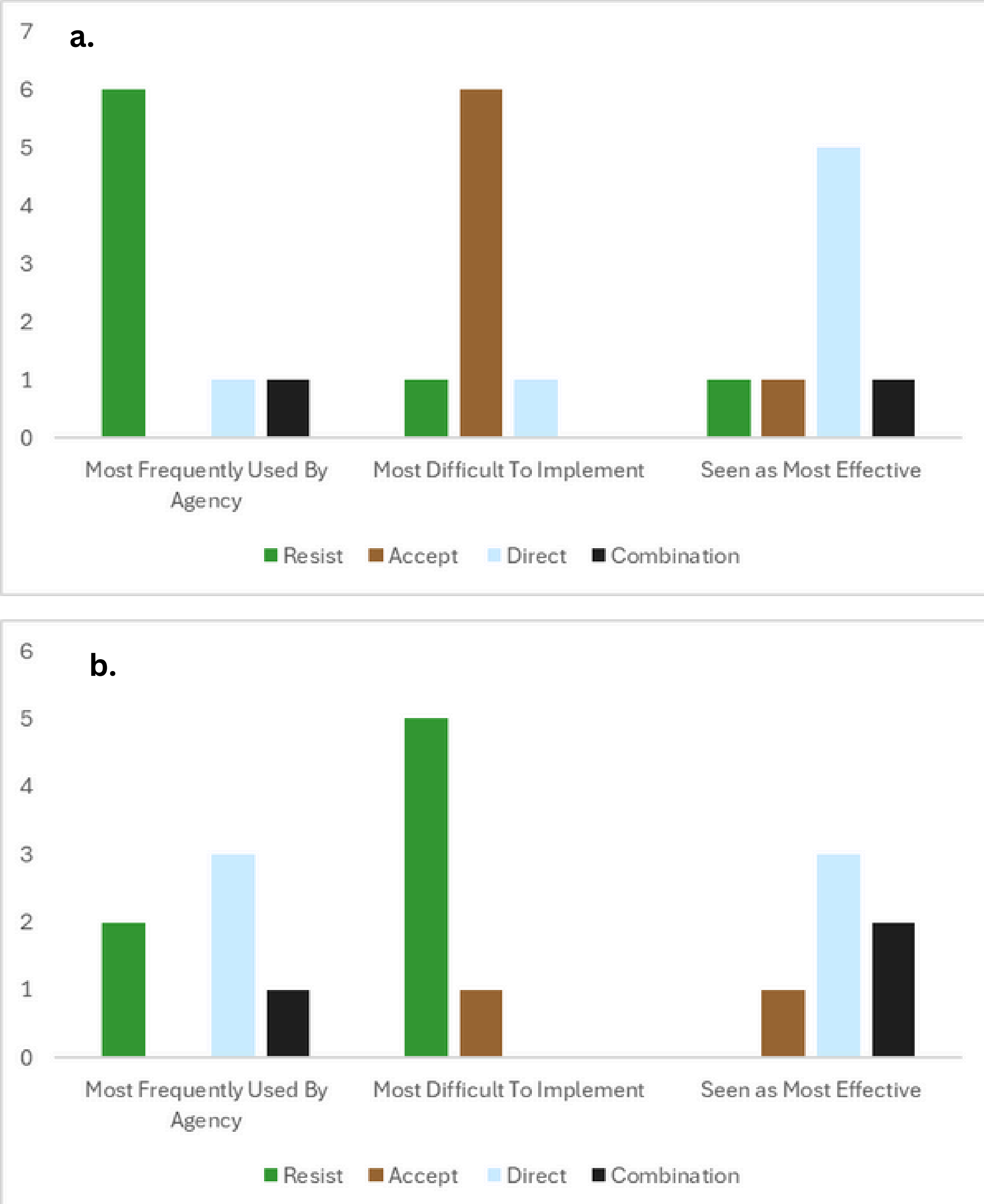


Figure 19. Interview responses related to RAD from managers in a. Florida and b. Puerto Rico. Responses were grouped by which form of management (Resist, Accept, Direct, or Combination) managers perceived to be most frequently used by their agency, the action most difficult to implement, and which action was most effective.

<u>Individual Interview Engagement:</u> Semi-structured interviews were conducted with 14 managers from Florida and Puerto Rico to further understand information needed to conduct adaptive management (Fig. 19). Participants were asked about the following: 1) the connections between the environment and the communities in the areas they manage, 2) assessments made following hurricanes and barriers to post-hurricane management, and 3) which RAD action is most frequently used by their agency, including which is most difficult to implement, and which they believe is the most effective. All of the participants recognized the connection humans have with the environment, and the importance of engaging with their community and respecting those connections when making decisions. Many resource managers expected that most communities would prefer actions following the "Resist" pathway and would require education on why "Direct" or "Accept" actions were selected.
Following hurricanes, interviewees differentiated between short term assessments (taking inventory, assessing structures, addressing mangrove drainage, etc.) and long-term assessments (understanding ecosystem shifts and where limited resources will have the greatest impact).

Given the severe impacts hurricanes can have and the frequency of hurricanes in both reserves, many managers cited limited funding and lengthy management processes as barriers to successfully restoring mangroves in their areas, thus preventing them from responding to large impacts quickly enough.

Florida managers lean more towards the "Resist" approach compared to the Puerto Rico managers, who preferred a "Direct" approach (Fig. 19). The difference in opinion may be a result of different agency priorities or differing objectives and limitations faced. However, both groups viewed "Direct" approaches as the most effective compared to others. This common belief highlights future management approaches where collaboration may occur.

<u>Impact of Engaging the PACs:</u> Manager focus groups were conducted in both Jobos Bay and Rookery Bay NERRs (Fig. 20), during which participants explained their decision steps, participated in a RAD visioning exercise, and then discussed barriers and incentives to RAD. The MCC team focused on understanding the policies and strategies for mangrove management and restoration priorities, identifying barriers to implement adaptive management strategies, and determining whether the RAD framework was useful to managers.

Figure 20. Manager focus group at Jobos Bay NERR in June 2023.

Scan the QR code or visit https://bit.ly/MCCProjectGlossary to view the glossary

The Need for a Project Glossary: Achieving the goals of the MCC required the combined expertise of geoscientists, ecologists, social scientists, educators, practitioners, coastal managers, and local knowledge holders in both regions. Participants in Project Advisory Committees spanned geographies, disciplines, and cultures, and as such, contributed distinct perspectives. During meetings with the Advisory Committees, the team quickly discovered the need for a shared lexicon of terms used in the context of the project. The MCC Terminology Team (Terms Team) was formed to address this need. Consisting of both Project Team members and PAC members, the group worked over the course of 18 months to define key terms used during the MCC Project. The Terms Team considered several perspectives and consulted with specialists as they sought to find best-use definitions for the project. The process of creating a project glossary included careful consideration of terms requiring definition, the context in which terms are used in different ways by different user groups, and the primary audience for the glossary (end-users of the MCC). A total of 29 terms are included in the glossary. The references associated with each term are those that the Terms Team found most influential to the definitions adopted and believed would be most useful for the MCC network. View the Glossary by visiting: https://bit.ly/MCCProjectGlossary.

Opportunities and Recommendations

- All participants of focus groups and interviews stated a strong interest to develop a suite of options under climate scenarios using the RAD method.
- Based on this interest, developing inter-agency working groups and training opportunities for RAD-based collaborative discussions for U.S. mangrove systems is an important next step.
- Managers identified several needs for continued multi-disciplinary research including: public perceptions of mangrove recovery, long-term effects of drought, and monitoring data for hydrologic reconnection of mangroves and salt marshes.
- Implementing adaptive and/or novel management options for changing systems will be contingent on agency priorities, rules, and public support. Therefore, continued co-collaboration is an essential need.

Limitations and Uncertainties

- Sample size: only able to do interviews and one focus group at each location.
- Managers with prior experience or understanding of RAD may have an easier time responding to some of the questions.
- There was some translation needed in the focus group in Puerto Rico; interviews were all conducted in English (which may have limited sample size).
- While anonymity was offered to all participants, some hesitation may have existed to criticize the priorities or decisions within one's professional organization.

Assumptions and Context

- Information gained through the focus groups and interviews are representative of the management communities in Puerto Rico and Florida.
- Managers' goals of healthy and sustained ecosystems were generally aligned; however, some agencies may have objectives that differ (e.g., prioritizing human recreation vs. wildlife essential habitat).
- Managers attending the focus group or interview had a leadership voice in the decision-making of the resource organization they represented.

Forum

Mangrove Science and Management Forum

About: The Mangrove Science and Management Forum was held on March 12th and 13th, 2024, in Miami, Florida at the International Center for Tropical Botany at Florida International University. Over 60 participants gathered, representing 37 institutions, ranging from federal, state, and regional governments, academia, and nonprofits (Fig. 21). The Forum brought together a newly coalescing community of mangrove scientists and managers in the southeastern U.S. and Caribbean and served as a platform to communicate the complexities of the project results, and encouraged and incorporated perspectives from the participants regarding limitations and data gaps in mangrove science and management.

"[I enjoyed] the discussions of RAD. This is the ultimate problem of our time. We know a lot about the science, we have hard decisions to make."

During the Forum, the Project Team shared methods and results from the MCC project, and asked participants to discuss potential applications, adaptations, and limitations of the outputs produced. The gathering provided opportunities to make connections across scientific disciplines and geographies and generate new ideas for collaborative science relating to the management of mangroves (Table 2).

Figure 21. Participants at the MCC Mangrove Science and Management Forum are seen here discussing collaborative opportunities. If you'd like to view the highlights from the Forum, please visit the link here: https://bit.ly/MCCMangroveForum.

Forum Aims

- Foster dialogue among scientists and managers about the development and usage of tools and data for understanding mangrove recovery and managing for resilience.
- Inform the research and management community of co-production strategies used to achieve greater collaboration.

"The breakouts were useful for hearing ideas and sharing relevant expertise. That seemed to help lead to collaborative conversations later as people got to know who was in the room and what their role was"

Table 2: Takeaways and directions for future collaboration in mangrove research outlined in group discussions at the MCC Forum.

Important Considerations	Collaborative Opportunities
• How do our local communities view mangrove movement and migration? • Different perspectives of mangroves exist at their northern range compared to locations where mangroves are dominant along the coastline: mangroves as "invasive" vs. "protected". • Need to educate the public on strategies for coastal wetland management so decisions related to resisting change versus managed retreat are well understood.	• The mangrove-urban interface is a new challenge for mangrove research and management. • Language and education matters. • There is a continued need for shared methodologies, transferability of monitoring data, and data and protocol accessibility. • Regional hydrology has changed substantially along many coastlines. It is important to manage for current conditions as we cannot often restore historic conditions. • Participants identified a need to develop and study effective nature-based solutions.

Forum

Expanding the Collaborative: Capacity-building across NERRs

About: Having collaborated on the MCC project since 2020 with the goal of better understanding the effect of tropical cyclones on recovery and resilience of mangrove-dominated estuaries, Rookery Bay NERR and Jobos Bay NERR sought to expand collaboration across the region with other reserves managing for mangroves. To this end, capacity-building funds were used to bring together staff from three reserves (Mission Aransas NERR, Apalachicola NERR, and Guana Tolomato Matanzas NERR) and a proposed reserve from the US Virgin Islands (Fig. 22). The objective was to widely share the products generated during MCC project; participants were invited to take part in the Mangrove Science and Management Forum and to discuss shared management needs related to mangroves and disturbance during a single capacity-building day held on March 14th, 2024 (Fig. 23). Participants discussed challenges and opportunities for collaboration, created lists of knowledge gaps and available resources, worked toward a shared vision for cross-reserve collaborations of the mangrove-dominated/populated NERRs, and outlined a framework for developing future proposals.

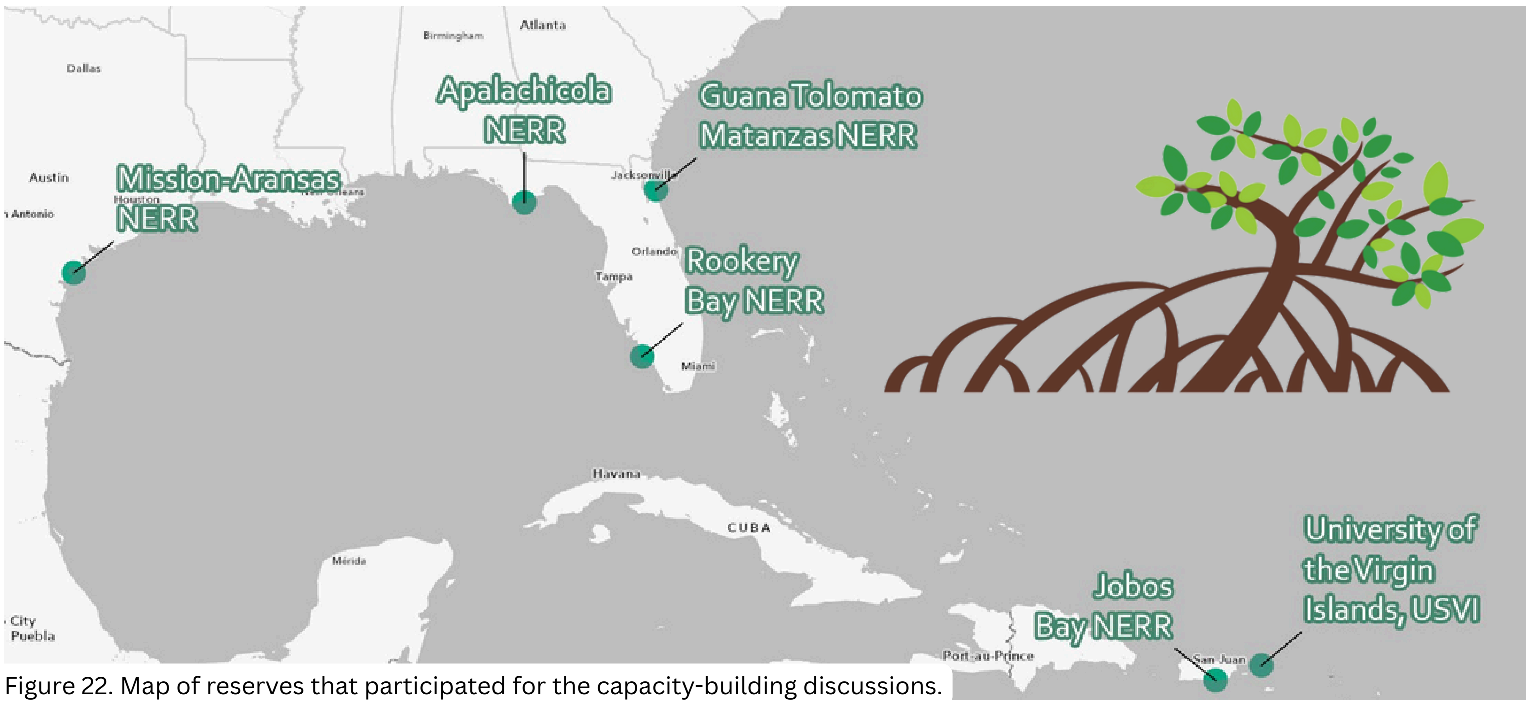


Figure 22. Map of reserves that participated for the capacity-building discussions.

As an incipient group (NERRs managing for mangroves), members collectively recognized 1) the importance of continued engagement with one another, as well as 2) the difficulty in maintaining momentum given resource constraints and competing demands for everyone's time. The group outlined several steps which they intend to use to pursue future collaborative science funding opportunities (Fig. 24).

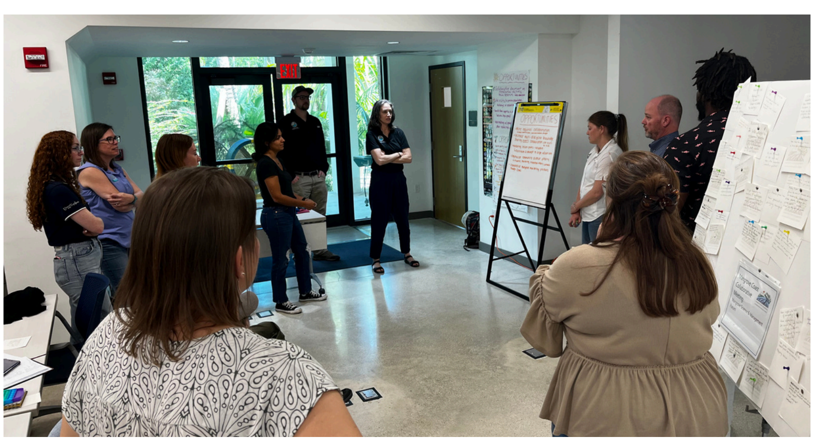


Figure 23. Participants gather to discuss collaborative opportunities and research needs.

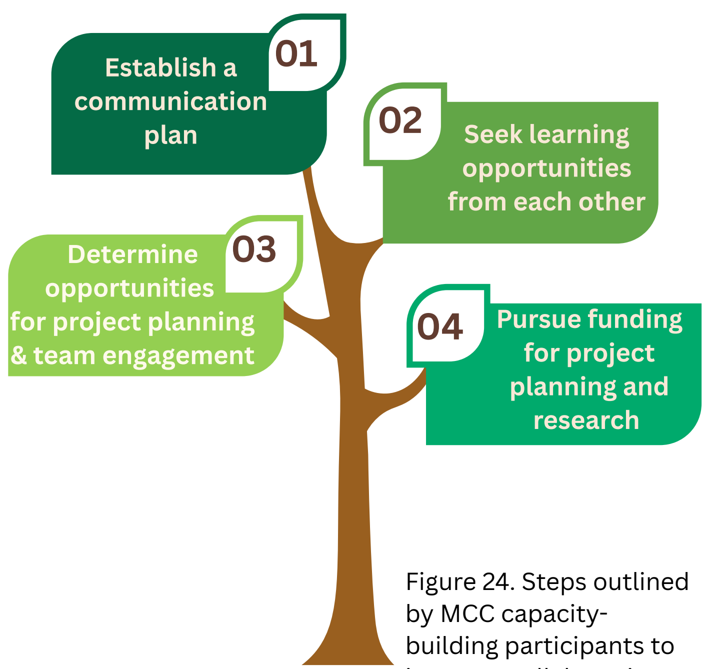
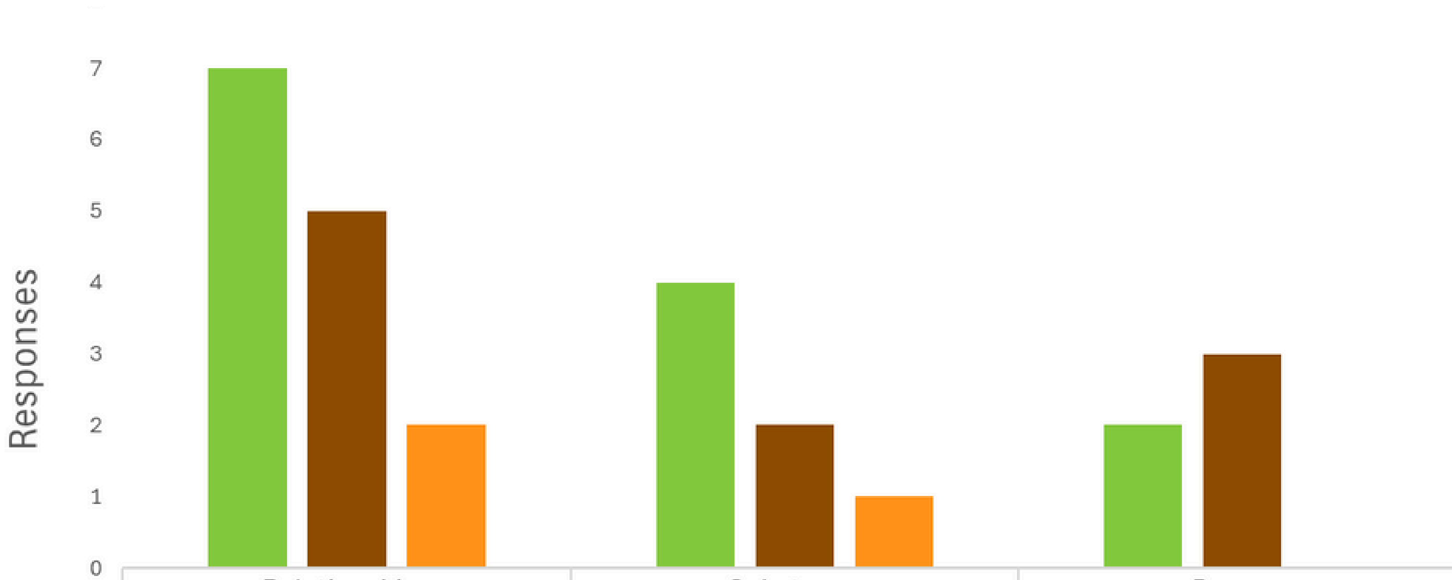


Figure 24. Steps outlined by MCC capacity-building participants to increase collaboration.

Outcomes of Co-production in the Mangrove Coast Collaborative

Value of Intentional Engagement: The project led to an increased understanding of the perceptions of external stakeholders that participated in the MCC. During the final PAC meetings held in February 2025, all participants were asked to consider their time as MCC PAC members and to select what they considered to be the most useful aspect of the engagements conducted throughout their participation in the MCC Advisory Committee meetings. Members were asked to select a single option from the following:

1. **Relationships** - opportunities to work with colleagues/partners or form new working relationships
2. **Substance** - current or future outcomes and/or benefits from the product
3. **Process -** how feedback and comments were used in problem-solving and product creation



	Relationships	Substance	Process
TAC	7	4	2
RB PAC	5	2	3
JB PAC	2	1	0

Component Identified as Most Valuable

Figure 25. Responses from the respective PACs when prompted to identify the most valuable component of the engagements conducted during the Mangrove Coast Collaborative project (2020-2025).

The results of the surveys are shown in Figure 25. Most PAC members identified relationships formed through participation as the most valued benefit, followed closely by the project's substance (e.g., data and results). The PACs did find value in the process, but it was not identified as the component they valued the most. This result was not surprising to the Project Team given that collaborative engagements were intentionally designed to allow for relationships to develop or mature and to inform the substance of the project. PAC members also remarked that they found the categories outlined in the survey to be related and many said that they found value in all three components.

Lessons Learned

Lesson 1: Collaboration

Collaborative processes built during the project were essential to achieve project success.

Lesson 2: Team Agility

With ~ 50% Project Team turnover, momentum was maintained via consistent communication.

Lesson 3: Fit for Funding

Funding from the NSC encouraged investment in relationships to produce actionable science.

Next Steps

- Continue to grow relationships between JBNERR, RBNERR, and project partners.
- Use mapping products from **Task 1** to provide location-specific information for future restoration.
- Use field assessments from **Task 2** as baseline data to compare to future storm impact assessments.
- Use the Gap Map from **Task 3** to identify gaps in research to inform reserve management.
- Reference the RAD framework discussed in **Task 4** to assess restoration interventions needed in each Reserve.
- Apply for future funding to expand efforts to address mangrove management needs in the Gulf, Southeast, and Caribbean NERRs.

by the NUMBERS

12
Hydrologic Sites

34
Evidence Library Entries

90%
PAC retention rate

55
Ecosystem Service links analyzed

13,090
Trees Measured

22
Managers engaged

112,883
acres mapped

90
engaged participants

133
Plots established

80
engagements with partners or reserve staff

If you want to interact with our data and learn more, check out our Story Map: Collaboration on the Coast!

Or check out our project page: Mangrove Coast Collaborative / Colaboración en Mangles Costeros: Understanding Links between Degradation, Recovery, and Community Benefits