City of Fort Pierce

Net Environmental Benefit of Ft. Pierce Marina and Storm Protection Islands Project

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December 23, 2022

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TETRA TECH

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EXECUTIVE SUMMARY (PARAGRAPH STYLE) [TT EXECUTIVE SUMMARY HEADING]

The City of Ft. Pierce recognized that simply replacing the marina facility 'in-kind' was not the solution for long term protection from potential future storms. The proposed solution was to create a permanent wave barrier configured as a carefully sculpted, but naturally appearing, artificial island breakwater to protect the marina from a 100-year storm event, as mandated by FEMA regulations. The project consists of constructing a 12 island breakwater and one peninsular structure storm protection system to harbor the marina and adjacent public waterfront areas, while providing storm protection, habitat creation, and water quality enhancement (grand total of 14.66 acres). Along with providing storm damage protection of the marina, upland infrastructure, and surrounding downtown waterfront area.

In general, the quantity and quality of the four subtidal habitat types has improved dramatically relative to pre-construction (and estimated 2004 pre-damage) conditions. The original marina basin of 11 acres was largely mud and shaded sand with less than 1 acre of submerged hard substrate. The project exceeded the mitigation and habitat condition targets. By most measures, the final success criteria were met years earlier than the year-5 goal.

As of approximately 5 years post-construction, the project created a total of 19.28 acres of habitat components that dramatically increased the structural complexity of the benthic communities and biodiversity within the project area. The project created 1.28 acres of oyster beds which increased to 1.42 acres by 2021; 1.3 acres of mangrove fringe along the islands' shores which increased to 1.55 by 2019; 6.27 acres of submerged artificial reef; 4.55 acres of coastal dune community; and 8.12 acres of seagrass beds which increased to 28.7 acres by December 2019.

The net environmental benefit of naturalistic marina barrier islands versus conventional steel and concrete were never in question. The ecological benefits of natural materials in naturalistic shapes are far superior to concrete and steel. Concerns expressed in the DEP and USACE permits questioned the net environmental benefits relative to the additional footprint and seagrass impacts required by the relatively large footprint of the marina barrier islands.

- Seagrass restoration exceeded the success criteria by 3x (28.7 acres achieved versus 8.1 acres required).
- Oyster habitat was created where none was present before, and the project exceeded success criteria (1.42 acres achieved versus 1.28 acres required).
- Mangrove habitat was created where none was present before, and the project exceeded success criteria (1.55 acres achieved versus 1.3 acres required).
- Shorebird nesting habitat was created where none was present before (4.55 acres achieved), and protected species were documented nesting within two years.
- Approximately 6.3 acres of natural limerock habitat was created in place of about 1 acre of marina bulkhead that was present before.
    - Utilization of this habitat is distinctly different than the community on adjacent marina and bulkhead structures.
    - Nearly 200 algae, sessile invertebrate, and fish species have been documented, and the area is now a popular and productive recreational fishing destination.
    - At least four species of stony coral are now present on the limerock, and their size distribution indicates both successful recruitment and long-term survival.

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Appendix A: Appendix Title

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ACRONYMS/ABBREVIATIONS (PARAGRAPH STYLE) [TOC HEADING]

Acronyms/Abbreviations	Definition
ABC	Definition
BCD	Definition
CDE	Definition
EFG	Definition

1.0 INTRODUCTION

During the 2004 and 2005 hurricane seasons, the City of Ft. Pierce Marina sustained significant damage when Hurricanes Frances and Jeanne destroyed 140 of 269 slips at the marina and damaged about 1,000 feet of bulkhead. The marina comprises a boat basin of 21 acres and is a vital component to the City's waterfront redevelopment efforts. Damage was estimated at $15 million to boats and $13 million in damages to the marina facilities.

The City of Ft. Pierce recognized that simply replacing the marina facility 'in-kind' was not the solution for long term protection from potential future storms. The proposed solution was to create a permanent wave barrier configured as a carefully sculpted, but naturally appearing, artificial island breakwater to protect the marina from a 100-year storm event, as mandated by FEMA regulations. The project consists of constructing a 12 island breakwater and one peninsular structure storm protection system to harbor the marina and adjacent public waterfront areas, while providing storm protection, habitat creation, and water quality enhancement (grand total of 14.66 acres). Additionally, the design provides storm damage protection of the marina, upland infrastructure, and surrounding downtown waterfront area.

The goal of the newly designed Marina was to build a safe harborage that provides adequate protection from future storms, while simultaneously promoting the well-being of the surrounding ecosystem. The renovation would serve as a pilot project for the State of Florida, with a minimum 5 years of monitoring required for the natural resources' components and 5 years of performance monitoring after completion to deem the project a success. The monitoring was for ecosystem sustainability and overall design performance. FEMA approved both the public assistance and hazard damage mitigation grant packages covering the total project cost of $33.5 million. The construction was completed in May 2014 and the final required monitoring was completed in 2019 in compliance with the requirements specified in the Florida Department of Environmental Protection (FDEP) Environmental Resource Permit No. 56-0129156-011 and U. S. Army Corps of Engineers (Corps) Permit SAJ-1993-41787 (IP-GGL).

1.1 PROJECT GOALS AND OBJECTIVES

The project design goals include:

- Design, permitting and reconstruction of the outer basin of the municipal marina consisting of floating concrete dock with 137 slips.
- Design, permitting and construction of a breakwater system to protect the marina against storm waves and currents.
- Replacement of approximately 1,000 ft of damaged steel bulkhead with concrete sheet pile bulkhead segments

The unique and innovative elements of the design were the level of effort devoted to structural/functional performance coupled with environmental protection/enhancement. Tetra Tech designed an island breakwater system to provide wave and current protection for the marina. The protection system includes an artificial island complex that serves as a first line breakwater system and includes mangrove plantings, tidal lagoon features and an artificial reef area. The island system also involves the beneficial reuse of dredged material. The design of the islands incorporated hydrodynamic modeling, field data collection and sampling, turbidity modeling, and a scaled physical model to ensure the island design would withstand a 100-year storm. The re-design of the marina island breakwater system accomplished the design goals while also accomplishing additional project objectives.

Project Objectives:

- Provide 100-yr wave/current protection
- Reduce basin currents
- Minimize changes in sedimentation patterns
- Improve access channel navigability
- Protect seagrass beds
- Provide for manatee transit
- Provide ecological enhancements with structural performance
- Protection of adjacent city waterfront

Figure 1. Project Location Map

1.2 NET ENVIRONMENTAL BENEFIT

Net environmental benefits are typically established by identifying ecosystem services and comparing their relative value over time and space. The USACE generally considers that a net environmental benefit analysis "…evaluates existence and aesthetic value of ecosystems, preservation of biodiversity, habitat for threatened/endangered species and human recreational use." (USACE 2009). The City of Ft. Pierce Marina project explicitly considered five distinct habitat enhancements (seagrass, oyster, mangrove, shorebird nesting, and limerock).

Net environmental benefits were integrated with the project objectives and design goals using environmental enhancements. The former wave & current barriers of the marina were replaced with a permanent barrier configured as a carefully sculpted, but naturally appearing, artificial island breakwater to protect the marina from a 100-year storm event, as mandated by FEMA regulations. Construction of 13 acres of nature-based breakwater islands included 21 acres of environmental enhancements:

- Oyster habitat
- Mangrove plantings
- Dune grass plantings
- Seagrass habitat improvements
- Shorebird nesting habitat

The island breakwaters now protect the entire downtown waterfront area of the city not just the marina docks. The success of the project has demonstrated that a breakwater can, in fact, perform well and be a net environmental benefit to the ecosystem. FEMA and several other federal agencies including the USACE are following the results closely because protective structures that are designed to provide a net environmental benefit are more easily permitted than the conventional structures with no net benefit tradeoffs between design and protection of the environment.

2.0 PROJECT HISTORY

The project began in April 2005. Design and regulatory permitting extended to December 2011. FEMA approved both the public assistance and hazard damage mitigation grant packages covering the total project cost of $33.5 million. Construction of the project was completed in May 2014.

The construction was completed in 2014 and the final required monitoring was completed in 2019 in compliance with the requirements specified in the Florida Department of Environmental Protection (FDEP) Environmental Resource Permit No. 56-0129156-011 and U. S. Army Corps of Engineers (Corps) Permit SAJ-1993-41787 (IP-GGL). The initial permit conditions included a minimum 5 years of monitoring required for the natural resources' components and 5 years of structural performance monitoring after completion to deem the project a success. Results of the natural resources monitoring were delivered in annual reports (Tetra Tech 2014-2019) with supplemental monitoring efforts in 2021 and 2022 (Tetra Tech 2021; this report).

The project created a total of 19.28 acres of habitat components that will increase the structural complexity of the benthic communities and in turn, increase the biodiversity within the project area. The project created 1.28 acres of oyster beds which increased to 1.42 acres by March 2021; 1.55 acres of mangrove fringe along the islands' shores; 6.27 acres of submerged artificial reef; 4.55 acres of coastal dune community; and 8.12 acres of seagrass beds which increased to 28.7 acres by December 2019.

3.0 METHODS

Net environmental benefits were established using conventional environmental monitoring methods, tailored to each of the five distinct habitat enhancements (seagrass, oyster, mangrove, shorebird nesting, and limerock). Among these, seagrass, oyster, and mangrove are relatively readily directly measured because spatial extent of the habitat is a main indictor. Net environmental benefits of the shorebird nesting and limerock habitat are less readily established because the relevant indicators are not simple acreage of habitat but utilization by organisms.

All field activities were performed using a minimal-draft 19-ft. catamaran in order to safely navigate the entire survey/monitoring area. On-board navigation was achieved using a Trimble® DSM232 Differential Global Positioning System (DGPS). Positioning data were imported and processed using Hypack® marine surveying, positioning, and navigation software. Underwater photography was used to record representative images of resources and conditions present within the survey/monitoring area.

3.1 SEAGRASS HABITAT

3.1.1 Seagrass Survey (Mapping)

Seagrass survey activities were performed using scientific divers, Trimble® DGPS, and Hypack® to catalog the distribution and abundance of seagrasses along pre-established transects. The survey was conducted by Tt scientific divers trained in marine biological resource identification and quantification. Seagrass species and coverage data were collected along evenly-spaced transects. Divers cataloged each transect at a rate of less than 1 knot. Mapping data were transmitted back to the work platform via Pacific Crest® Environmental Data Link® (EDL II) telemetry. Positioning data were collected in WGS84 (World Geodetic System 1984) datum and transmitted back to the work platform at a rate of 1 data point per second. The Trimble® DGPS receives differential corrections from U.S. Coast Guard Continuously Operating Reference Stations and provides sub-meter horizontal accuracy.

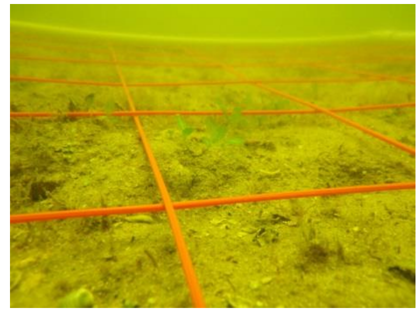
Data were processed with Hypack® Target Editor and subsequently exported in a .txt format. The raw data were imported into ArcGIS® 9 (ArcMap™ 9.3) where shapefiles were created and analyzed. Georeferenced maps of seagrass species distribution and abundance were produced. Seagrass cover was interpolated using the 3D Analyst, Spatial Analyst extensions in ArcMap™ and Xtools Pro (independent [Data East, LLC.] ArcGIS extension). Planar area calculations were performed using Xtools Pro.

Percent coverage was estimated by visually assessing the benthos at regular intervals (approximately every meter) along each transect and assigning a seagrass cover value from 0-5. The seagrass cover values were assigned based on the observed seagrass percent cover. Seagrass percent coverage was recorded throughout the survey. Greater than 15,000 data points were recorded during field operations and used in the analysis. The seagrass cover scale with respective seagrass cover ranges is presented in Table 4-1, below.

Table 4.1 Seagrass Cover Scale

Cover Scale Value	Percent Coverage
0	0%
1	<5%
2	5-25%
3	25-50%
4	50-75%
5	75-100%

3.1.2 Seagrass Monitoring



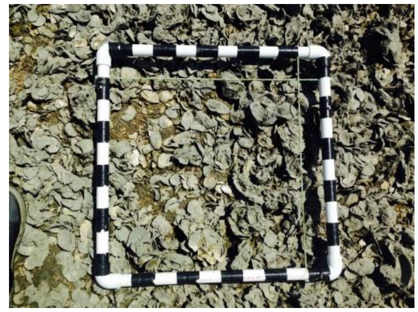
Pre-determined transects were assessed using 1 m^2 quadrats. Seagrass percent coverage was recorded at ten evenly-spaced intervals along each of the eleven transects for a total of 110 replicates. A modified Braun-Blanquet (B-B) method (Braun-Blanquet, 1932; Fourqurean et al., 2001; Kirsch et al., 2005) was used to determine seagrass cover. Each quadrat was visually inspected for seagrass and was assigned a cover-abundance scale value (B-B score). B-B scores were assigned based on cover estimates of the total resource projection over the substrate when visually inspected from directly above. The B-B scale provides presence-absence at the lower end of the scale (0, 0.1, 0.5, and 1) and a 25 percent cover range among the higher scores (2-5), thus having a measurement precision level of 25 percent. B-B scores were converted to percent coverage by using the average (mid-range mean) of each score's respective cover range. Percent cover values were then averaged over the total number of quadrats assessed along each transect to yield a total percent coverage for each transect. B-B scores along with their respective abundance category and converted percent cover value are provided below in Table 4-2.

Table 4.2 Braun-Blanquet Cover-Abundance Scale

B-B Score	Abundance value	Percent cover value (converted)
0	Not present	0
0.1	Solitary specimen	0
0.5	Few with small cover	1
1	Numerous but less than 5% cover	2.5
2	5 to 25% cover	15
3	25 to 50% cover	37.5
4	50 to 75% cover	62.5
5	75 to100% cover	87.5

3.2 OYSTER HABITAT

3.2.1 Oyster Habitat Quality Monitoring



Haphazardly placed Vexar® mats (18 inches square in size with thirty-six (36) high shell fraction cochina fragments attached to each mat) were secured at the sampling locations throughout the selected constructed islands. The monitoring design came from a study conducted by Lisa Wall titled, "Recruitment and Restoration of the oyster, *Crassostrea virginica*, in Areas with Intense Boating Activity in Mosquito Lagoon, Florida in 2001."

Thirteen (13) mats were sampled along both the protected and exposed sides of Tern Island and 1 or 2 two mats each for freeform islands with created oyster habitat (Fishhook, Snook, Starfish, and Manatee) for a total of 19 monitoring stations. The mats were removed in order to count the number of recruited oysters during monitoring. Once removed, the live oysters on each substrate shell were counted and the mats were subsequently returned to their original sampling locations. Photographic and written documentation of each mat were collected and will be used to track oyster recruitment and abundance over extended periods. All collected data was utilized to find the number of spat or live oysters per recruitment mat and per meter square. An average was taken for the number of species found per meter squared area.

Additionally, oyster recruitment was monitored with a combination of quadrats placed along transects, and using haphazardly placed quadrats. At each, the number of live oysters was counted within each ¼-m^2 quadrat.

Water quality parameters were collected using a YSI multi-parameter probe and data logger. Data collected included temperature, dissolved oxygen, pH, and conductivity. Finally, data were collected on both floral and faunal diversity found within and around created oyster habitats, with particular attention paid to attached organisms and algae that may foul oyster habitat and affect spat settlement.

A nearby reference site was established for comparison to the project location. This natural oyster reef, located adjacent to the southeast portion of Jack Island. Three transects with a total of 18 quadrats (6 quadrats per transect) were monitored within the reference oyster habitat. The number of live oysters was counted within each ¼-m^2 quadrat.

3.2.2 Oyster Habitat Extent and Topographic Complexity Monitoring

Topographic complexity measurements were collected from the intertidal oyster habitat during low tide on Friday 12 March 2021. We selected a variant of the chain-rugosity method modified from the well-established methods (Luckhurst and Luckhurst 1978; and McCormick 1994). As shown in Frost et al. (2005) and Beck (1998), there are not meaningful differences among the three main methods to measure topographic complexity in ecological contexts (chain rugosity, serial vertical profile, 3-d photogrammetry). A total of 41 rugosity transects were collected, mostly in pairs of “lower” and “upper” intertidal, with 4 transect origins placed where the current beach intersects the groins (n= 19 lower, 18 upper, and 4 beach). Transect length was 2 meters (m) for most transects (n=37), and the first 2 pairs were 5 m and 1 m straight length. Selection of each transect origin was haphazard within the belt of intertidal oyster habitat on boulders (no transect origins were on the mattresses or oyster bags, but some transects crossed these features). Field measurements differentiated between “In” versus “Out” of oyster habitat (i.e., “Out” of oyster habitat included portions of boulders that were outside of the intertidal zone (areas that predominantly remain dry, gaps with sand/mud, and gaps between boulders that were deeply sub-tidal). Rugosity totals for each transect included only the portions that were “In” oyster habitat.

Separately, the linear extent of oyster habitat along the islands’ coastlines was mapped using the same “In” versus “Out” approach (Tetra Tech 2018). Field observations also noted the typical width of oyster habitat on boulders was 1.25 meters, and the typical width on mattresses was 0.3 meters. Note that current measurements were used because conditions changed from the as-built conditions. In general, the mattresses are currently at a relatively steep angle leading to a narrower portion of the mattress within the intertidal zone.

3.3 MANGROVE HABITAT

Mangrove monitoring transect locations were identified in the Plan (2009) and adjusted in the field as necessary during the Time Zero monitoring event to capture representative conditions on site and ensure adequate spacing between transects (Tetra Tech 2014). Four permanent mangrove transects were established on the western perimeter of the Island and five on the eastern/southern perimeter by recording the beginning and end of each transect using a Trimble® Differential Global Positioning System (DGPS) and marking with PVC stakes. During the Year Five monitoring event, scientists located the established transects on the west side of the Island using a handheld GPS unit. Transects on the east side of the island were not able to be monitored due to the extent of beach erosion caused by Hurricanes Matthew and Irma. Each of the four mangrove transects are 30 meters (m) in length.

Permanent quadrat stations were determined in the field during the Time Zero monitoring event by haphazardly selecting locations at various meter intervals along one mangrove transect and applying the same intervals at successive mangrove transects. The same quadrat stations are monitored during each event. Six quadrats were placed along each of the four mangrove transects during the Year Five monitoring event for a total of 24 mangrove stations. A two square-meter (2-m^2) quadrat centered on the transect was used to sample mangrove habitat. Transects run from north to south/east to west. Table 1 provides the established mangrove transect designations and coordinates.

Mangrove habitat data collected for each 2-m^2 quadrat during the Year Five monitoring event consists of percent cover (canopy) of all vegetation documented. Both mortality count (number of live/dead planting units) and height measurements of planting units are no longer able to be documented due to planting unit expansion and the degree of natural recruitment along transects (. Therefore, a revised version of the percent cover criterion (80% cover of planted mangroves=80% cover by mangroves; less than 5% exotic cover) will be used to determine the success of mangrove habitat creation.

3.4 LIMEROCK HABITAT

Colonization and utilization of limerock habitat was measured with a combination of quadrats, transects, and roving surveys. Quadrat and transect surveys collected approximately repeated measures from 15 transects and 45 quadrats (3 quadrats per transect) within the limerock habitat. Quadrat methods followed the BEAMR approach (Makowski et al. 2009). Transect and roving surveys followed Loya (1978). Roving surveys were focused on cumulative species richness of algae, plants, sessile invertebrates, and fish. Motile invertebrates (e.g. worms, snails, crabs, echinoderms) were noted but were significantly under-represented by all methods and their data are not representative. Each species ID and survey type was consolidated into simple presence-absence in the summary tables shown below. Please refer to the individual annual monitoring reports for quantitative and semi-quantitative results.

3.5 NESTING SHOREBIRD HABITAT

Nesting shorebird habitat was monitored and maintained as a component of the mangrove and coastal dune community monitoring, including control of exotic and undesirable plants.

Utilization by shorebirds for nesting was monitored with a combination of regularly scheduled roving surveys during nesting relevant seasons, and opportunistic observations during other habitat monitoring events.

Additionally, reports sourced from other formal groups (Audubon) and citizen science were included, following appropriate quality control protocols.

4.0 RESULTS AND DISCUSSION

Results below are abridged for succinctness (Table 4-1). Full results are available in the relevant monitoring reports (Tetra Tech 2014-2021). Note that 2022 data for limerock habitat monitoring is included for the first time in this report. These new data were consolidated into simple presence-absence for comparison with prior data into the summary tables below (Table 5-1, Table 5-2, Table 5-3).

In general, the quantity and quality of the four subtidal habitat types has improved dramatically relative to pre-construction (and estimated 2004 pre-damage) conditions. The original marina basin of 11 acres was largely mud and shaded sand with less than 1 acre of submerged hard substrate. The project exceeded the mitigation and habitat condition targets. By most measures, the final success criteria were met years earlier than the year-5 goal.

As of approximately 5 years post-construction, the project created a total of 19.28 acres of habitat components that dramatically increased the structural complexity of the benthic communities and biodiversity within the project area. The project created 1.28 acres of oyster beds which increased to 1.42 acres by 2021; 1.3 acres of mangrove fringe along the islands' shores which increased to 1.55 by 2019; 6.27 acres of submerged artificial reef; 4.55 acres of coastal dune community; and 8.12 acres of seagrass beds which increased to 28.7 acres by December 2019.

Table 4-1: Summary habitat quality indicators at select intervals.

Habitat	2004*	2014	2015	2016	2017	2018	2019	2022
Seagrass (acres)	15.9	14.9	23.4	15.4	26.0	28.7	28.7	
Oyster (acres)	<1	<1	1.28				1.42	
Oyster (oysters per m^2)	<1	0	6.9	41.6	2.7	34.1		
Mangrove (%)	0	7.5	9.8	6.8	9.9	13.9		
Limerock algae species**	5	29	19					15
Limerock invertebrates species**	15	50	39					42
Limerock fish species**	10	27	12					37
Shorebird nesting (nesting pairs)***	0	34						

* estimated using informal surveys of nearby structures.

** data = # of taxa, not necessarily # of species

*** showing only protected species, not total nests

The marina limerock average biological cover is now at least 55% (this figure excludes cyanobacteria and drift algae). The increase in biological cover far exceeds the 2%-5% increase stated in the Habitat Monitoring Plan. An added environmental benefit is that the shallower marina islands (Tern, Snook, Fishhook, Starfish, Eel) host communities that are distinctly different than on the deeper marina islands (Conch, Pelican, Tarpon). The deeper communities have less algae cover, greater coral density, and far greater fish diversity.

The nature of the community on the limerock has changed dramatically over time. Most of these changes are attributable to successional maturation of the communities. Additionally, hurricanes: Matthew (2016), Irma (2017), and Dorian (2019) affected the area, and significant flooding and freshwater releases from water management canals have altered the communities. As an example of community change over time, the 2014-2015 communities were overwhelmingly dominated by sponges, and macroalgae species were present but not abundant. By 2019/2022, this had reversed. Although approximately the same sponge and algae taxa were present, the dominant taxa was the green algae *Caulerpa verticillata*.

4.1 NET ENVIRONMENTAL BENEFIT

The net environmental benefit of naturalistic marina barrier islands versus conventional steel and concrete were never in question. The ecological benefits of natural materials in naturalistic shapes are far superior to concrete and steel. Concerns expressed in the DEP and USACE permits questioned the net environmental benefits relative to the additional footprint and seagrass impacts required by the marina barrier islands. A suitable and serviceable Fort Pierce marina requires protection from waves, currents, and management of sediment to prevent shoaling. The conventional approach is to use bulkheads, sheet pile, and scheduled maintenance dredging.

The net environmental benefit of the conventional approach is usually negative, neutral, or slightly positive. This is because concrete and steel are low quality habitat substrates, and because such engineering is implemented with a minimal surface area. These same design and engineering requirements can be accomplished with naturalistic wave and current barriers constructed of natural materials. The environmental benefits of this approach versus concrete and steel are massively positive.

Environmental cost of this naturalistic approach is due to the larger footprint. The marina islands removed approximately 8.9 acres of seagrass, and removed/occupied, approximately 4.2 acres of soft/motile sediment habitat. Consequently, the main success criteria in the environmental permits were for seagrass restoration.

Because this naturalistic approach required a larger footprint additional environmental benefits can be incorporated, such as deliberately providing distinct habitats of ecologically relevant size. Additional 5-year success criteria covered mangroves, oysters, limerock/hardbottom, substrate, and shorebird nesting habitats. All success criteria were met before the third year of monitoring (Tetra Tech 2014-2021; Table 5-1, Table 5-2, Table 5-3).

The net environmental benefit of naturalistic marina barrier islands versus conventional steel and concrete were never in question. The ecological benefits of natural materials in naturalistic shapes are far superior to concrete and steel. Concerns expressed in the DEP and USACE permits questioned the net environmental benefits relative to the additional footprint and seagrass impacts required by the relatively large footprint of the marina barrier islands.

- Seagrass restoration exceeded the success criteria by 3x (28.7 acres achieved versus 8.1 acres required).
- Oyster habitat was created where none was present before, and the project exceeded success criteria (1.42 acres achieved versus 1.28 acres required).
- Mangrove habitat was created where none was present before (1.3 acres achieved versus 1.55 acres required).
- Shorebird nesting habitat was created where none was present before (4.55 acres achieved), and protected species were documented nesting within two years.
- Approximately 6.3 acres of natural limerock habitat was created in place of about 1 acre of marina bulkhead that was present before.
    - Utilization of this habitat is distinctly different than the community on adjacent marina and bulkhead structures.

- Nearly 200 algae, sessile invertebrate, and fish species have been documented, and the area is now a popular and productive recreational fishing destination.
- At least four species of stony coral are now present on the limerock, and their size distribution indicates both successful recruitment and long-term survival.

The project created a total of 19.28 acres of habitat components that will increase the structural complexity of the benthic communities and in turn, increase the biodiversity within the project area. The project created 1.28 acres of oyster beds which increased to 1.42 acres by March 2021; 1.55 acres of mangrove fringe along the islands' shores; 6.27 acres of submerged artificial reef; 4.55 acres of coastal dune community; and 8.12 acres of seagrass beds which increased to 28.7 acres by December 2019.

The project objectives included protection of seagrass beds, ecological enhancement with structural performance, and protection of the city waterfront. These objectives were tested with the passage of several tropical systems (Tropical Storm Ana in 2015, Hurricane Matthew in 2016, Hurricane Irma 2017) during the reporting period. Although the project area was impacted by these natural high energy events, the city waterfront suffered no impacts and the net environmental benefits of the project were well beyond the permitted success criteria in the environmental permits.

5.0 FIGURES AND TABLES

Cumulative species lists were collected during select monitoring events. Roving, transect, and quadrat data from all surveys were consolidated into simple presence-absence in the summary tables below (Table 5-1, Table 5-2, Table 5-3). Limerock / hardbottom surveys focused on algae, sessile invertebrates, and fish. Motile invertebrates (e.g. worms, snails, crabs, echinoderms) were noted but were significantly under-represented by all methods and their data are not representative.

Table 5-1: Cumulative algae species, select monitoring events.

ID	2014	2015	2022
Algae	**29**	**19**	**15**
Acanthophora spicifera	X	X	X
Acetabularia sp.	X		X
Batophora sp.	X		
Bryopsis sp.	X		X
Caulerpa cupressoides	X	X	
Caulerpa prolifera	X		
Caulerpa racemosa	X	X	X
Caulerpa sertularioides	X	X	X
Caulerpa verticillata	X	X	X
Ceramium sp.	X	X	
Chaetomorpha	X		
Codium isthmocladum	X	X	

ID	2014	2015	2022
Codium sp.	X		X
Dasya sp.	X	X	X
Dictyopteris	X		
Dictyota sp.	X	X	X
Digena sp.	X		
Filamentous sp.		X	
Gelidiella sp.		X	
Gelidium sp.	X		
Gracilaria sp.	X	X	X
Halimeda discoidea			X
Halimeda opuntia		X	
Hypnea sp.	X	X	
Laurencia sp.		X	X
Padina sp.	X	X	X
Penicillus dumetosus			X
Penicillus pyriformis			X
Rosenvingia intricata	X		
Rosenvingia sp.	X		
Sargassum hystrix	X		
Sargassum pteropleuron	X		
Sargassum sp.	X		
Spyridea sp.	X		
Stypopodium zonale	X		
Ulva sp.	X	X	
Unidentified filamentous green		X	
Wrangelia sp.		X	

Table 5-2: Cumulative invertebrate species, select monitoring events.

Species/Group ID	2014	2015	2022
Annelid			
Branchioma sp.		X	X
Sabellidae	X		
Terebellidae		X	X
Bivalve			
Crassostrea virginica	X	X	X
Pinna sp.	X		X
Bryozoan			
Bracebridgia sp.	X		X
Bugula sp.	X	X	X
Hippopodina sp.	X		
Schizoporella sp.	X	X	
Scrupocellaria sp.	X	X	
Unidentified	X		
Cnidaria: Anemone			
Aiptasia sp.			X
Ceriantharia		X	
Cnidaria: Coral			
Astrangia poculata	X	X	
Oculina robusta			X
Phyllangia americana			X
Siderastrea radians			X
Cnidaria: Hydroid			
Aglaophenia sp.	X	X	X
Gymnangium sp.	X	X	X
Halopteris sp.	X		X
Macrorhynchia philippia	X		X
Pennaria sp.	X		
Schizoporella sp.	X		X
Sertularella diaphana	X		
Thyroscyphus ramosus	X		

Species/Group ID	2014	2015	2022
Thyroscyphus sp.	X	X	X
Unidentified	X		
Zyzzyus warreni	X		X
Cnidaria: Jellyfish			
Aurelia aurita			X
Cassiopea sp.			X
Cnidaria: Octocoral			
Carijoa riisei	X	X	X
Leptogorgia virgulata	X	X	
Cnidaria: Zoanthid			
Zoanthus sp.		X	
Crustacean			
Cirripedia (Barnacle) sp.	X	X	X
Mithrax sp.		X	
Panulirus argus	X	X	
Stenorhynchus seticornis	X	X	X
Echinoderm			
Arbacia punctulata		X	
Diadema antillarum		X	
Echinometra lucunter	X	X	X
Eucidaris tribuloides			X
Isostichopus badionotus		X	
Luidia senegalensis			X
Lytechinus variegatus		X	
Ophiocoma sp.	X		
Gastropod			
Aliger gigas (queen conch)			X
Bittiolum varium		X	
Siphonaria pectinata			X
Sponge			
Agelas sp.	X		X
Aka coralliphaga	X		X

Species/Group ID	2014	2015	2022
Aka sp.	X		
Callyspongia armigera	X	X	
Callyspongia sp.	X		X
Cinachyra sp.			X
Dysidea etheria	X	X	X
Ectyoplasia ferox	X		
Ectyoplasia sp.	X		X
Halichondria melanodocia		X	
Haliclona hogarthi		X	
Haliclona sp.			X
Hymeniacidon heliophila		X	
Monanchora sp.	X		X
Mycale americana		X	
Mycale angulosa		X	
Mycale armigera		X	
Mycale microstigmatosa	X		
Mycale sp.	X		X
Myrmekioderma gyroderma	X		
Niphates sp.	X		
Phorbas sp.	X		X
Plakortis sp.	X		
Tedania ignis		X	
Unidentified	X		
Tunicate			
Aplidium stellatum	X	X	X
Ascidia nigra	X	X	X
Botrylloides sp.	X	X	X
Clavelina picta		X	
Didemnum sp.	X	X	X
Polycarpa sp.	X	X	X
Tridemnum sp.	X		
Total Invertebrate IDs	**50**	**39**	**42**

Table 5-3: Cumulative fish species, select monitoring events.

Species/Group ID	2014	2015	2022
Abudefduf saxatilis (Sgt. Major Pintano)	X	X	X
Abudefduf taurus (Night Sgt)			X
Anisotremus virginicus (Porkfish)	X	X	X
Anthias sp. (Swallowtail Seaperch)			X
Archosargus probatocephalus (Sheepshead)	X	X	
Blenniidae (Blenniinae)		X	
Centropomus undecimalis (Snook)	X		X
Centropristis striata (Black Seabass)	X		
Chaetodipterus faber (Atlantic Spadefish)			X
Clupeidae (Atlantic Herring)		X	
Colomesus Psittacus (Banded Puffer)			X
Coryphopterus glaucofraenum (Bridled Goby)			X
Epinephelus itajara (Atlantic Goliath Grouper)			X
Epinephelus morio (Red Grouper)			X
Eucinostomus melanopterus (Flagfin mojarra)	X	X	X
Gerres cinereus (Yellowfin Mojarra)			X
glass minnows	X		
Haemulon flavolineatum (French Grunt)	X		X
Haemulon plumierii (White Grunt)			X
Haemulon Sciurus (Blue Stripped Grunt)			X
Haemulon sp. (Grunt)	X	X	
Holacanthus bermudensis (Blue Angelfish)			X
Holacanthus ciliaris (Queen Angelfish)	X		
Holacanthus townsendi (Hybrid Angelfish)			X
Hypoplectrus guttavarius (Shy Hamlet)			X
Lachnolaimus maximus (Hogfish)			X
Lagodon rhomboides (Pinfish)	X	X	
Lutjanus apodus (Dogtooth Snapper)			X
Lutjanus griseus (Mangrove Snapper)	X	X	X
Lutjanus kasmira (Blue Stripe Snapper)			X

Species/Group ID	2014	2015	2022
Lutjanus sp. (Snapper)	X		
Lutjanus synagris (Lane Snapper)		X	
Menidia menidia (Atlantic Silverside)			X
Monacanthidae (Filefish)	X		
Mugilidae (Mullet)	X		
Ocyurus chrysurus (Yellowfin Snapper)			X
Orthopristis chrysoptera (Pigfish)			X
Parablennius marmoreus (Seaweed Blenny)			X
Pomacanthus (Marine Angelfish)	X		
Pomacanthus arcuatus (Gray Angelfish)	X		
Pomacanthus paru (French Angelfish)	X		X
Pomacentridae (Clownfish)	X		
Pterolis volitans (Red Lionfish)	X		
Scarus coelestinus (Midnight Parrotfish)			X
Scarus guacamaia (Rainbow Parrotfish)			X
Scarus sp. (Parrotfish)	X		
Scarus taeniopterus (Princess Parrotfish)	X		X
Scorpaen plumieri (Spotted Scorpionfish)	X	X	
Serranus subligarius (Belted Sandfish)	X		
Sparisoma aurofrenatum (Redband Parrotfish)			X
Sparisoma rubripinne (Redfin Parrotfish)			X
Sphoeroides sp. (Pufferfish)	X		
Sphoeroides spengleri (Bandtail Pufferfish)	X	X	
Sphoeroides testudineus (Checkered Pufferfish)			X
Sphyraena barracuda (Great Barracuda)	X		X
Stegastes diencaeus (Longfin Damselfish)			X
Stegastes nigricans (Dusky Farmerfish)			X
Xyrichtys sp. (Razorfish)			X
Total Fish IDs	**27**	**12**	**37**

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APPENDIX A: APPENDIX TITLE