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Natural Resource Stewardship and Science

Inventory of Coastal Engineering Projects in Fort Matanzas National Monument

Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2013/703

ON THE COVER
Fort Matanzas, St. Augustine, Florida
Photograph by: Kate Dallas

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

This report is available from the Geologic Resources Division and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). The report and accompanying Geographic Information System (GIS) project can also be accessed through the Integrated Resource Management Applications Portal website (http://irma.nps.gov).

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Abstract

A reconnaissance-level investigation, analysis and inventory of coastal engineering projects in eight coastal national parks were completed by Oregon State University with funding provided by the National Park Service Geologic Resources Division. The coastal national parks inventoried in this study include:

1. Cape Hatteras National Seashore
2. Colonial National Historical Park
3. Fort Matanzas National Monument
4. Fort Raleigh National Historic Site
5. Gateway National Recreation Area
6. Golden Gate National Recreation Area
7. Olympic National Park
8. San Francisco Maritime National Historical Park

This report includes information on coastal engineering projects identified in, or immediately adjacent to, Fort Matanzas National Monument (FOMA). The report serves as a supplement to a Geographic Information Systems (GIS) database (the GIS data are available online at http://irma.nps.gov).

Twenty-nine coastal engineering projects were identified in and adjacent to FOMA. Of this total, 22 are coastal structures that together extend 4,660 m (15,290 ft). Three dredging projects removed a minimum of 3,299,000 m^3 (4,314,930 yd^3) of sediment from around FOMA between 1932 and 2007, while four fill projects placed an unknown volume of material on Rattlesnake Island between 1936 and 1977. In addition, beach nourishment approximately 16 km (10 mi) north of the park has placed nearly 6,000,000 m^3 (7,847,700 yd^3) since 1963.

The Matanzas River Relocation Cut and coastal structures on Rattlesnake Island have altered the natural hydrodynamics of the Matanzas River system. More than 382,280 m^3 (500,000 yd^3) of sand dredged for the Relocation Cut was placed on the island and nearby marsh, transforming the island. In addition, the Cut caused alterations in current velocity that has resulted in shoaling at the northern end of Rattlesnake Island.

Acknowledgments

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We would like to thank Kurt Foote at FOMA for his help with this project. Kurt provided a thorough tour of coastal structures in the park and helped us gain access to the park archives in St. Augustine. Paul Finer at the St. John River Water Management District assisted with aerial imagery acquisition. David Roach at the Florida Inland Navigation District shared dredging information for the Intracoastal Waterway.

Introduction

The Coastal Engineering Inventory (CEI) project aims to inventory, catalog and map coastal engineering projects in and adjacent to coastal units of the National Park Service (NPS). The primary projects that were inventoried include coastal structures, dredge and fill projects, and beach nourishment and dune construction projects. In this phase of the inventory coastal engineering projects were identified in eight coastal national parks. Prior to this study another report (Coburn et al. 2010) documented coastal engineering projects in ten additional coastal national parks. The report and GIS data are available online at http://irma.nps.gov.

In this phase of the NPS CEI project, a qualitative impacts analysis was also performed to help better understand the extent of human-altered coastal areas within each respective park. This section describes the impacts of coastal engineering projects and their influence on natural sediment transport processes. In addition to highlighting major engineering projects that are impacting local and regional sediment transport, we have also included related information pertaining to current park management concerns as expressed during the site visit.

Coastal engineering projects are usually motivated by a desire to protect the backshore environment from erosion or alter the coastal zone for a particular purpose (i.e. maintain a navigation channel, develop roadways, or restore wetlands). In order to fulfill project objectives, a suite of engineering solutions are available that are typically categorized into hard and soft engineering projects. Coastal engineering solutions often combine both hard and soft engineering approaches, such as when beaches are nourished following breakwater construction.

Hard engineering solutions include the construction of seawalls, revetments, breakwaters, sills, and bulkheads to protect the backshore from coastal erosion and sometimes flooding (see the Glossary in Appendix A for definitions). Jetties and groins are also classified as hard engineering projects and are used to alter the sediment transport regime by trapping sediment. Impacts from hard structures are highly site dependent, but may include the loss of sediment supplied to downdrift areas, localized scour in front of and at the downdrift end of structures, visual impacts, placement losses, reduction in beach access, and the alteration or reduction of habitat.

Soft engineering solutions include non-structural means of stabilizing the backshore or changing coastal environments through beach nourishment, dune construction, dredging, or filling. These methods add or redistribute sediment within the system and are used to widen sediment-starved beaches, maintain navigable waterways, protect coastal infrastructure, and restore wetlands. As with hard solutions, impacts vary significantly by project and location. Soft engineering projects may impact hydrodynamic and sediment transport processes, beach morphology, aquatic ecosystems, and/or beach habitats.

The overall goal of this project is to develop a greater understanding of the coastal engineering modifications in the National Park System. Along coastlines expected to be impacted by climate change, structurally modified shorelines will likely respond differently than natural coastlines, which may have a more dynamic response to coastal erosion and sea level rise. An inventory of coastal engineering modifications will provide information to allow resource managers to make better decisions about how to preserve NPS resources, establish baselines, develop desired future conditions, and balance the protection of historic resources and infrastructure with the preservation of natural systems. All of these actions will improve the ability of the NPS to manage coastal park units in accordance with NPS policies. The main NPS policies relevant to coastal engineering projects are summarized below (see NPS *Management Policies 2006* for more detail).

Maintenance of Natural Processes

Generally, NPS policy requires that natural coastal processes in parks, such as erosion, shoreline migration, deposition, overwash, and inlet formation, be allowed to continue without interference (NPS *Management Policies* § 4.8.1.1 2006). The NPS may intervene in these processes only in limited circumstances, such as when there is no other feasible way to protect natural resources, park facilities, or historic properties (NPS *Management Policies* § 4.8.1 2006).

Restoration of Natural Processes

In parks where pre-existing or new activities or structures have altered and/or are currently altering coastal dynamics, ecosystems, tidal regimes, and sediment transport rates, the NPS policy is to investigate, in consultation with appropriate state and federal agencies, alternatives for mitigating the effects of such projects and for restoring natural conditions (NPS *Management Policies* § 4.8.1.1 2006). NPS restoration actions in human-disturbed areas seek to return the area to the natural conditions and processes characteristic of the ecological zone in which the damaged resources are situated, as called for by park management plans (NPS *Management Policies* § 4.1.5 and § 4.4.2.4 2006). An example would be the restoration of shoreline processes.

Park landscapes disturbed by natural events, such as hurricanes, are allowed to recover naturally unless manipulation is necessary to 1) mitigate for excessive disturbance caused by past human effects, 2) preserve cultural and historic resources as appropriate based on park planning documents, or 3) protect park developments or the safety of people. (NPS *Management Policies* § 4.1.5 and § 4.4.2.4 2006).

Construction of Facilities

Generally, the NPS must avoid the construction of buildings, roads, and other development that will cause unacceptable impacts on park resources and values (NPS *Management Policies* § 9.1 2006). Development will not compete with or dominate park features or interfere with natural processes (NPS *Management Policies* § 9.1.1.2 2006). In shoreline areas, this means that new developments will not be placed in areas subject to wave erosion or active shoreline processes unless 1) the development is required by law; or 2) the development is essential to meet the park's purposes, as defined by its establishing act or proclamation, and

- no practicable alternative locations are available;
- the development will be reasonably assured of surviving during its planned life span without the need for shoreline control measures; and
- steps will be taken to minimize safety hazards and harm to property and natural resources (NPS *Management Policies* § 4.8.1.1 2006).

Replacement of Facilities

Park development that is damaged or destroyed by a hazardous or catastrophic natural event will be thoroughly evaluated for relocation or replacement by new construction at a different location. If a decision is made to relocate or replace a severely damaged or destroyed facility, it will be placed, if practicable, in an area that is believed to be free from natural hazards (NPS *Management Policies* § 9.1.1.5 and § 4.1.5 2006).

Cooperative Conservation

Under NPS policy, park superintendents are required to monitor state government programs for managing state-owned submerged lands and resources within NPS units. When there is potential for such programs to adversely impact park resources or values, superintendents will make their concerns known to appropriate state government officials and encourage compatible land uses that avoid or mitigate potential adverse impacts. When federal acquisition of state-owned submerged lands and resources within NPS units is not feasible, NPS will seek to enter into cooperative agreements with state governments to ensure the adequate protection of park resources and values (NPS *Management Policies* §3.4 2006).

In addition, the NPS has the authority under 36 C.F.R. §1.2(a)(3) to apply general NPS regulations, such as special use permit requirements, on or in waters that are subject to the jurisdiction of the United States, or in areas within their ordinary reach up to the mean or ordinary high water line, even if the submerged lands are non-federally-owned and regardless of whether the park has exclusive, concurrent, or proprietary jurisdiction. Waters subject to the jurisdiction of the United States refers to three types of waters: (1) navigable (as defined in 33 C.F.R. § 2.36(a), (2) non-navigable but located on lands for which the U.S. has acquired title or control and has accepted or retained exclusive or concurrent jurisdiction, and (3) waters made subject to U.S. jurisdiction by certain international agreements and statutes (33 C.F.R. § 2.38).

Methods

Coastal engineering terminology was adapted from the NPS Coastal Engineering Inventory pilot project (Coburn et al. 2010) and through discussion with the NPS Geologic Resources Division. The NPS selected eight coastal national parks in which coastal engineering projects were identified, inventoried and mapped. Projects in the inventory include coastal structures, dredging, filling, beach nourishment, and dune construction.

A digital park boundary shapefile for all of the inventoried parks was downloaded from the NPS Integrated Resources Management Applications Portal (https://irma.nps.gov). Georeferenced digital orthophoto imagery was obtained from each park and added to ArcMap 10.0 to create a basemap.

A visual inspection of the orthophoto imagery was completed and locations of all discernible coastal structures were digitized using ArcMap. A site visit to the park, along with staff correspondence, was used to complement and confirm initial findings based on examination of the imagery and to identify other coastal engineering projects. A comprehensive online and hardcopy literature search was undertaken to obtain attribute data for each project (year of construction, material, year of maintenance, cost, lead construction agency, and volume). Unless otherwise specified, costs presented in the report are in project-year dollars.

A coastal engineering project was considered distinct if there was any discernible, physical separation between it and an adjacent engineering project. A series of bulkheads constructed by individual interests, for example, would be classified as one structure as long as no identifiable gaps were observed between them. Some projects, such as dredge projects that place dredge spoil on the beach, serve multiple purposes (i.e., dredging and beach nourishment). In these cases, the primary reason for the project was ascertained and the project was classified accordingly. Projects that occurred repeatedly in one place (e.g. inlet dredging) were counted as one project.

Overview statistics were calculated to summarize the coastal engineering projects within each park. The percentage of shoreline armored by coastal structures was found by totaling the length of bulkheads, breakwaters, groins, revetments, seawalls, and sills and dividing it by the total length of shoreline. Structure length and shoreline length were determined using ArcMap. The structure length used in calculating the percentage of shoreline armored for individual structures was merely the length of the structure. For groin fields (defined here as three or more groins) the length was set as the length of the groin field along the shoreline, while for jetties the width of the mouth of the inlet was used.

An ArcGIS 10.0 file geodatabase for each park was compiled using ArcMap. Each geodatabase includes a park boundary feature class and identified coastal engineering projects separated into three feature classes: 1) coastal structures 2) dredge and fill projects and 3) beach nourishment and dune construction projects. The GIS projects also contain an ArcMap document for data viewing (.mxd), data layer files (.lyr), FGDC-compliant metadata (.xml and.txt), FAQ metadata (.html), a table attribute file (.pdf), and a README file (.pdf). Location information for dredge, fill, beach nourishment, and dune construction projects was often non-existent or vague. Therefore, not all of these projects are included in the GIS data, and those that are included have only approximate locations.

Results

Twenty-nine coastal engineering projects were documented in and adjacent to FOMA, and one major beach nourishment project was identified 16 km (10 mi) north of FOMA. Of this total, seventeen are coastal structures located within FOMA with a total length of 2,018 m (6,621 ft) (Table 1 & Figure 1). Within the park, coastal structures armor 19%, or 1,613 m (5,292 ft), of the approximately 8.4-kilometer (5.2 mi) long river and ocean shoreline. Five additional structures, including one bulkhead, three revetments, and two seawalls, with a total length of 2,642 m (8,668 ft), were mapped in the adjacent community of Summer Haven. A summary of all of the structures within and adjacent to FOMA is presented in Appendix B.

Three dredging projects in the waters around FOMA (Matanzas River, Matanzas Inlet, and Intracoastal Waterway) have removed a minimum of 3,299,000 m^3 (4,314,930 yd^3) of sediment from 1932 to 2007 (minimum value because volume information was not found for all dredging projects) (see Appendix C for detailed data). Four fill projects were identified on Rattlesnake Island from 1932–1977, but only one project had volume data, which included placement of 147,890 m^3 (193,432 yd^3) in 1936 (see Appendix C). Beach nourishment activities north of the park have placed nearly 6,000,000 m^3 (7,847,700 yd^3) of sand since 1963.

Table 1. Coastal structures in Fort Matanzas National Monument.

[1]Structures	Total	Length (m)
Bulkhead	1	55
Dike	2	676
Groin	8	163
Pier	2	105
Revetment	3	996
Seawall	1	23
TOTAL	**17**	**2,018**

[1] See Glossary in Appendix A for coastal structure definitions.

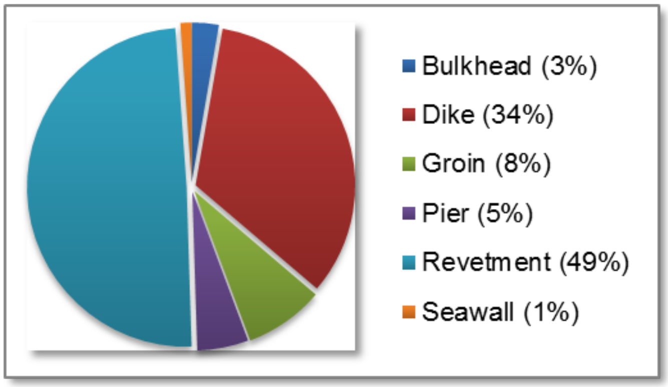

Figure 1. Total length of each structure type in FOMA (does not include structures adjacent to the park).

Background

Fort Matanzas National Monument is located on the eastern coast of Florida at the mouth of the Matanzas River, roughly 22 km (14 mi) south of the city of St. Augustine, Florida (Figure 2). The monument was established on October 15, 1924 to preserve the fort and its associated cultural landscapes and archeological resources (NPS 2012). FOMA consists of 1.3 km^2 (313 ac) on Rattlesnake and Anastasia Islands and includes a virtually undisturbed barrier island system containing beaches, salt marsh, and coastal oak forest. The Matanzas River passes between Anastasia and Rattlesnake Islands and the Intracoastal Waterway (ICW) is located west of Rattlesnake Island (Figure 3). Matanzas Inlet is one of the last “natural” inlets (i.e. with no dredged channel or armored shoreline) on the east coast of Florida and is unsuitable for navigation, except by small craft (Mehta and Jones 1977).

Figure 2. Regional map of the Fort Matanzas area (images from ESRI Bing Maps basemap layer 2012).

Setting

The entire state of Florida lies on the Floridian Plateau, a physiographic province that has been alternately covered by ocean and exposed as dry land (Graham 2009). The park is composed of Pleistocene (1.8 million years ago to 10,000 years ago) Anastasia Formation and Holocene (10,000 years ago to present) sands (Scott et al. 2001). The Anastasia Formation formed in beach and shallow-water nearshore environments and includes coquina, a sedimentary rock composed of sandy grains and mollusk shells (Graham 2009).

The barrier island morphology in northeastern Florida is influenced by both waves and tides (Graham 2009). Tides in the region are semi-diurnal (two highs and two lows every day), with mixed tides during neap period (Taylor Eng. 2009). The St. Augustine Beach, Florida tide gauge, located 16 km (10 mi) north of FOMA (Figure 2), indicates a mean tidal range of 1.4 m (4.52 ft) (NOAA 2012).

Figure 3. Map of Fort Matanzas National Monument and places mentioned in the report. Orange line is park boundary (image from ESRI Bing Maps basemap layer 2012).

The mean significant offshore wave height for the area in 18 m (59 ft) water depth is 1.1–1.2 m (3.5–4.0 ft) (FDEP 2000). Waves are predominantly out of the northeast and net littoral transport is from north to south on the order of 152,910 to 229,370 m^3/yr (200,000 to 300,000 yd^3/yr) (USACE 2007). Water level data from the tide gauge in Mayport, Florida, located approximately 80 km (50 mi) north of FOMA, shows a 2.4 ± 0.31 mm/yr (0.09 ± 0.01 in/yr) rise in sea level from 1928 to 2006 (NOAA 2012).

The FOMA coastline experiences hurricanes, tropical storms, and nor'easter storms. The nor'easter storms, with few exceptions, are the most damaging (Mehta and Jones 1977). Shoreline change studies have shown that the southern tip of Anastasia Island has grown southward, while erosion has occurred south of the inlet at Summer Haven (Figure 3) (FDEP 2000).

Rattlesnake Island

The shoreline of Rattlesnake Island has changed significantly due to the dredging of the Matanzas Relocation Cut and the ICW. The Matanzas Relocation Cut was finished in January 1932 and routed the ICW to the west of Rattlesnake Island. The U.S. Army Corps of Engineers

(USACE) performed the dredging and removed 400,290 m^3 (523,555 yd^3) at a cost of $50,252.57 (Mehta and Jones 1977). More than 382,280 m^3 (500,000 yd^3) of the dredged material was placed on the southern end of Rattlesnake Island and nearby marsh, transforming the original small island into the 0.8 km^2 (200 ac) island seen today (See Impacts section for more details) (Powers 1984).

To separate the Matanzas River from the new ICW, the USACE built a sheet pile dike on the southwest shore of Rattlesnake Island in the latter part of 1936 at a cost of $1,721.11 (Figure 4 & #17 Figure 5) (Freeland 1940, Mehta and Jones 1977). Original reports record the dike's length at 640 meters (2,100 ft). We report a length of 533 m (1,749 ft) based on field observations and examination of aerial imagery. The dike may extend further to the southeast, but it is not currently visible due to a revetment.

Figure 4. The top of the 1936 steel sheet pile dike buried in fill along the southwest shore of Rattlesnake Island (#17 Figure 5). View is to the southeast (image by Kate Dallas).

The dike was built to 3 m (10 ft) above mean low water and included placement of 147,890 m^3 (193,428 yd^3) of fill along the dike dredged from the ICW at a cost of $24,544,86 (Mehta and Jones 1977). In addition, 8,200 m^3 (10,729 yd^3) of revetment was also installed along both sides of the dike (USACE 1976). This revetment has been buried over time and is not currently visible. Minor flanking around the north end of the dike in subsequent years was repaired through placement of sand during ICW maintenance dredging (USACE 1976).

In 1964 Hurricane Dora breached the northern end of the dike, causing a decline in the percentage of tidal flow moving through the north arm of the river (Figure 6) (Mehta and Jones 1977). The USACE closed the breach in 1977, which had widened to 97 m (319 ft), with construction of a steel sheet pile dike (#15 Figure 5) at a contract cost of $873,419 and revetment on both sides of the breach (#14, 16 Figure 5 & Figure 7) (Mehta and Jones 1977). The project also included dredging of a relief channel in the north arm of the Matanzas River to increase flow. The dredged material was used to fill the breach and as beach nourishment on 975 m (3,200 ft) of ocean beach south of Matanzas Inlet (USACE 1976). The cost of the entire project in 1976 was approximately $1,980,000 (USACE 1976).

Figure 5. Structure map for the FOMA area. Yellow shading shows park property. Area in pink box is shown in Figure 9 (image from ESRI Bing Maps basemap layer 2012).

Figure 6. View looking south in January 1974 towards the dike breach on southern Rattlesnake Island. The Matanzas River and Matanzas Inlet are to the left and the Intracoastal Waterway is to the right (from NPS 1980).

Figure 7. Revetment placed in 1977 to close the dike breach on Rattlesnake Island (#14 Figure 5). View is upriver (northwest) (image by Kate Dallas).

Fort Matanzas

Fort Matanzas was completed in 1742 to maintain control of the Matanzas Inlet and is the only example of a Spanish fortified watchtower in the continental United States (NPS 2012). The fort's shoreline has been stabilized with a variety of structures (Figures 8 & 9). In 1916 the War Department built a concrete retaining wall around the north, east and south sides of the fort (Mehta and Jones 1977). Erosion concerns were addressed again in 1924 with construction of an oyster shell revetment, and in 1927 with a concrete revetment. Kidd (2004) reports that both structures were eventually washed away.

In October through December of 1936 a steel sheet pile bulkhead with a concrete cap was installed to confine the soils around the fort's foundation and protect the fort against the erosive impacts of the Matanzas River (Figure 8 & #5 Figure 9) (NPS 1980, USACE 1987). The area behind the bulkhead was backfilled and revetment was placed in front (NPS 1980). In 1948–1949 parts of the bulkhead were cleaned and treated and the void between the bulkhead and fort was filled following storms in 1944 and 1947 (NPS 1980). Additional steel sheet pilings were placed approximately 0.3 m (1 ft) in front of the bulkhead by the NPS in 2007 (NPS 2006b).

Figure 8. Groins, revetment, bulkhead, and ferry dock at Fort Matanzas in 2011 (#1–7 Figure 9). Left image looks downriver (southeast), while right image looks upriver (northwest) (images by Kate Dallas).

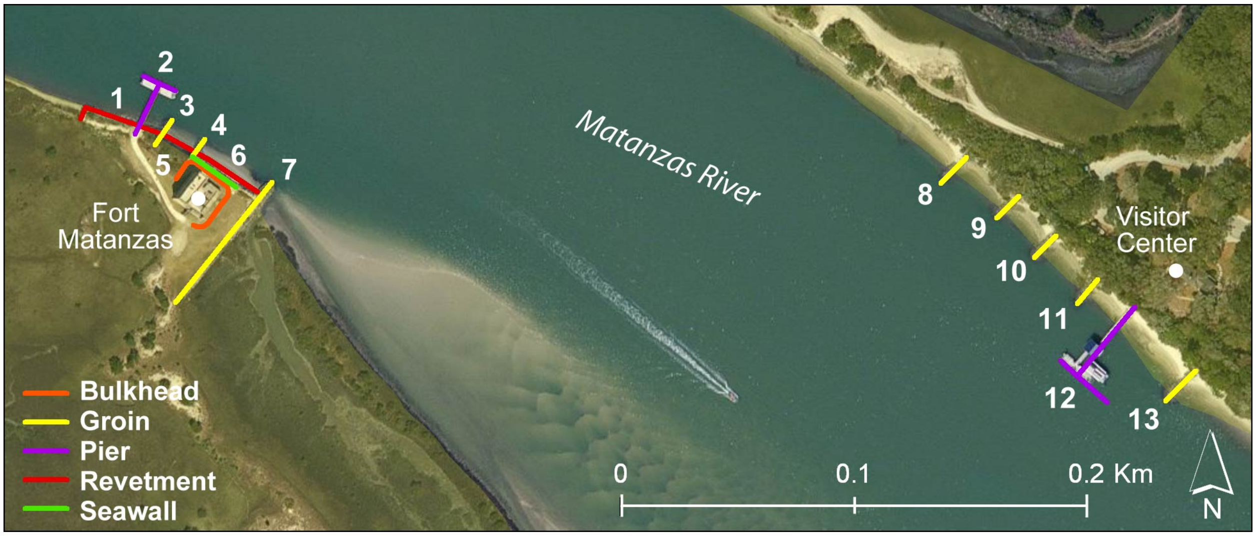

Figure 9. Structure map for the area around Fort Matanzas and the Visitor Center. Yellow shading shows park property (image from ESRI Bing Maps basemap layer 2012).

In 1940 a coquina seawall was constructed along the northeast side of the fort (#6 Figure 9) and two groins were built (#3, 4 Figure 9) on the shoreline (NPS 1980). The seawall is not currently visible because a coquina revetment covers it. The groin at the southeast corner of the fort was built in 1948–1949 (#7 Figure 9) (NPS 1980) and lengthened and reinforced with timber sheet piling and coquina rock in 1966 (Kidd 2004). Further engineering work in 1966 included filling between the fort and southeast groin with dredged material, and placement of extra coquina on the seawall (NPS 1980, USACE 1987).

The original ferry dock on Rattlesnake Island was built in 1935 (Kurt Foote, Natural Resource Management Specialist FOMA, email, 27 August 2012) and rebuilt in 1956, 1978–1979 (NPS 1980), and in 2007 when the NPS replaced it with the current concrete floating dock (Figure 8 and #2 Figure 9) (NPS 2006b). In 2007 the NPS also upgraded and stabilized the coquina seawall and groins, placed additional revetment (#1 Figure 9), and repaired the steel bulkhead (NPS 2006b).

Anastasia Island

FOMA includes 0.6 km^2 (138 ac) on the southern end of Anastasia Island (Figure 3). Most of the ocean and Matanzas River shoreline along the island is undeveloped, with only a few coastal structures near the Visitor Center (Figure 9).

In 1934–1935 eleven rock groins were constructed near the present day Visitor Center to stabilize the shoreline (Mehta and Jones 1977). The Youth Conservation Corps repaired the groins in 1976 (NPS 1980). Only five groins were visible during our site visit in 2012 (#8–11, 13 Figure 9 and Figure 10), all of which were repaired by the NPS in 2007 (NPS 2006b). The ferry dock on Anastasia Island was originally built in 1935 (Kurt Foote, Natural Resource Management Specialist FOMA, email, 27 August 2012) and replaced in 2000 by the NPS with a floating concrete dock (#12 Figure 9) (NPS 2006b).

Figure 10. Rock groins along Anastasia Island's Matanzas River shoreline (#9–11 Figure 9). View is upriver (northwest) (image by Kate Dallas).

Matanzas Inlet & Intracoastal Waterway Dredging

Dredging activities in 1930 removed 44,840 m^3 (58,644 yd^3) from the south and north sides of the Matanzas Inlet (Mehta and Jones 1977). In 1976, dredging occurred in the inlet channel and a shoal was removed between the bridge and Rattlesnake Island (NPS 1981).

The ICW in the region around FOMA was dredged to 4 m (12 ft) deep and 38 m (125 ft) wide from 1945–1951, with unknown volumes of sediment removed (Mehta and Jones 1977). Taylor Eng. (2009) reports that from 1958 to 2007, 2,531,735 m^3 (3,311,385 yd^3) of sediment was dredged from the ICW near the Matanzas Inlet, with an average of 51,668 m^3/yr (67,579 yd^3/yr). Starting in 1999, dredged material has been placed on the ocean beaches of Summer Haven (see next section). Prior to 1999, dredged material was placed onto spoil islands outside of FOMA (Kurt Foote, FOMA, email, 27 August 2012).

Summer Haven

Immediately south of Matanzas Inlet is the community of Summer Haven (Figure 3). Numerous coastal structures have been placed along the Summer Haven ocean and river shoreline to combat erosion. A regional sediment budget analysis for Northeast Florida by the USACE in 2007 reported that from 1972 to 2003 the Summer Haven ocean shoreline experienced -35,170 m^3/yr (-46,000 yd^3/yr) of sand loss (USACE 2007).

The first bridge built across the inlet was completed in 1925–1926, and replaced in 1956 (Mehta and Jones 1977). Dean and O'Brien (1987) proposed that the concrete bridge abutment at the southern end of the bridge in Summer Haven prevents southward migration of the inlet and erosion in the area is due to large volumes of sand stored in the flood tidal shoal.

In 1957–1958, a 126-meter (415 ft) long concrete sheet pile seawall was built along the ocean shoreline in Summer Haven to protect the highway (#22 Figure 5) (Mehta and Jones 1977). The seawall was severely damaged during a nor'easter in November 1962 and by Hurricane Dora in 1964 (Mehta and Jones 1977).

Roughly 550 m (1,800 ft) of granite revetment was installed in 1963 (#20 Figure 5) (FDEP 2000). The revetment was extended in 1964 after Hurricane Dora and has been repaired many times (Mehta and Jones 1977, FDEP 2000). In 1976, 975 m (3,200 ft) of beach south of the bridge was nourished with an unknown volume of sand (NPS 1981). A 150-meter (490 ft) long seawall of unknown age also exists near the northern end of the revetment (#21 Figure 5).

The shoreline west of the bridge along the Matanzas River is armored with a bulkhead and rock revetment for approximately 880 m (2,890 ft) (#18–19 Figure 5). Roughly 325 m (1,070 ft) of the revetment, extending west from the bridge, was installed in 1964 (NPS 1981). The histories of the bulkhead and the remaining section of revetment are unknown.

During large storm events, Summer Haven has experienced wash-over of the beach. A nor'easter in March 1989 overwashed the dune immediately south of the revetment (#20 Figure 5) and established a short-lived inlet connecting to the Matanzas River (Taylor Eng. 1989). Since 1991 over 1,300,000 m^3 (1,700,336 yd^3) of sediment dredged from the ICW has been placed along Summer Haven's ocean beaches (Table 2) (David Roach, Executive Director Florida Inland Navigation District, email, 13 Sept 2012).

Table 2. Dredged sediment placed on the Summer Haven ocean shoreline (outside of FOMA).

Year	Volume (m^3)
1991	146,414
1994	150,900
1999	169,731
2001	584,884
2001	9,175
2007	144,501
2011	191,139
TOTAL	**1,396,744**

Northern Anastasia Island

The beaches of Anastasia State Park and the city of St. Augustine Beach, located approximately 16 km (10 mi) north of FOMA on northern Anastasia Island (Figure 2), have experienced significant erosion. Shoreline change rates for the years 1972–1995 range from -0.3 to -7.3 m/yr (-1.0 to -24.0 ft/yr) (FDEP 2000). These beaches are south of Augustine Inlet and are strongly influenced by the Augustine Inlet system (FDEP 2000).

Between 1940 and 1986, 1,049,730 m^3 (1,373,000 yd^3) of sediment was dredged from the St. Augustine Inlet and placed primarily offshore (FDEP 2008), causing a net loss of sand to the nearshore system. Since 1996, when 197,260 m^3 (258,000 yd^3) was placed at St. Augustine Beach, dredged material from the inlet has been placed on downdrift beaches (Table 3) (WCU 2012). Although outside of the park boundary, beach nourishment projects on northern Anastasia Island may affect beaches within the park as sand moves down coast through littoral transport (USACE 2007).

Valverde (1999) reports 38,228 m^3 (50,000 yd^3) was placed on area beaches as early as 1963, but the source of the material is unknown. Maintenance dredging of nearby channels placed an unknown volume of additional sediment at Anastasia State Park and St. Augustine Beach in 1999 (FDEP 2008).

The beaches of St. Augustine Beach were nourished again from 2000 to 2005 with sand dredged from St. Augustine Inlet's ebb shoal (FDEP 2008, WCU 2012). The nourishment was authorized under the federal St. Johns County Shore Protection Project and included placement of 3,211,130 m^3 (4,200,000 yd^3) along 6.1 km (3.8 mi) of beach from April 2002 to January 2003. Following Hurricanes Frances and Jeanne in 2004, an additional 2,140,750 m^3 (2,800,000 yd^3) was dredged from the ebb shoal and placed along 4.7 km (2.9 mi) of beach in St. Augustine Beach in September 2005 (FDEP 2008).

To date, nearly 6,000,000 m^3 (7,847,700 yd^3) of material has been placed on the beaches of northern Anastasia Island (Table 3). Future renourishment of 1,242,400 m^3 (1,625,000 yd^3) at five-year intervals is projected over the next 50 years (USACE 2007).

Table 3. Beach nourishment projects along northern Anastasia Island (outside of FOMA).

Location	Year	Volume (m^3)	Length (m)	Project-Year Cost	Source
Anastasia State Park / St. Augustine Beach	1963	38,228		$95,000	Valverde (1999)
Anastasia State Park / St. Augustine Beach	1996	197,255		$2,523,240	WCU (2012)
Anastasia State Park / St. Augustine Beach	1998	215,604	975	$1,410,000	WCU (2012)
Anastasia State Park / St. Augustine Beach	1999				FDEP (2008)
St. Augustine Beach	2000	152,911	915	$950,000	WCU (2012)
Anastasia State Park / St. Augustine Beach	2002–2003	3,211,130	6,115		FDEP (2008)
St. Augustine Beach	2005	2,140,754	4,670	$13,000,000	FDEP (2008)
TOTAL		**5,955,882**			

Impacts

The physical landscape of FOMA has been shaped by both natural processes and engineering projects focused primarily on navigation issues. While the formation of the ICW dramatically altered the region, the Matanzas Inlet itself remains one of the last undeveloped inlets on the east coast of Florida (USACE 2007).

Rattlesnake Island

The Matanzas Relocation Cut is a component of the broader ICW project, which extends from Massachusetts to Florida via inlets, rivers, bays and sounds for both recreational and commercial passage (USACE 1948). Prior to relocation of the ICW, the Matanzas River flanked both sides of Rattlesnake Island and the inland waterway route was exposed to Matanzas Inlet (Figure 11). After dredging of the Matanzas Relocation Cut, Rattlesnake Island was artificially elongated and attached to the Atlantic coast at Summer Haven (Figure 11). During this phase of the ICW project more than 382,280 m^3 (500,000 yd^3) of sand was placed on the island and nearby marsh (Powers 1984), directly impacting terrestrial and aquatic habitat.

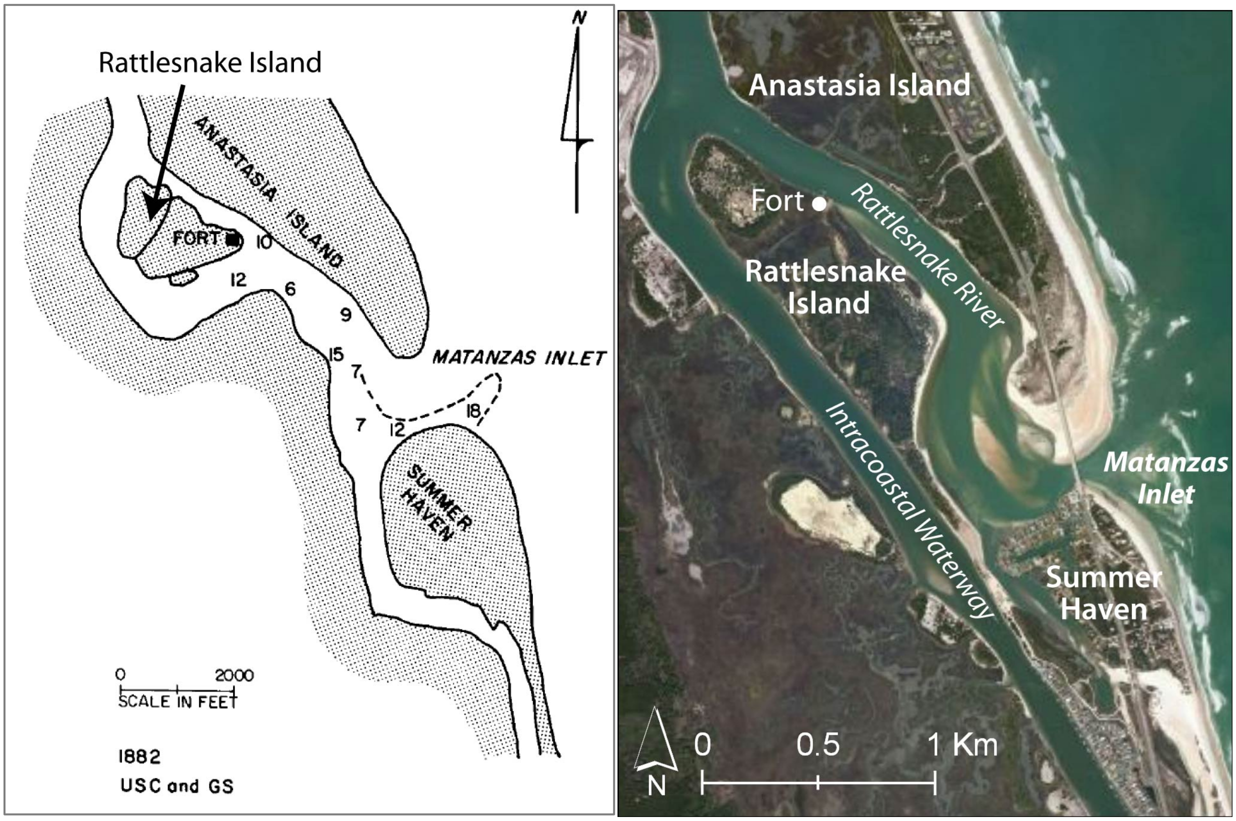

Figure 11. 1882 map (left) and 2011 image (right) of the Matanzas Inlet area (map adapted from Mehta and Jones 1977, image from ESRI Bing Maps basemap layer 2012).

The changes to the Matanzas Inlet system impacted the natural flow of sediment within the inlet and the surrounding region. The creation of the ICW led to a reduction in current velocity at the junction of the Matanzas River and the ICW north of Rattlesnake Island, which caused the development of a shoal (Frazel 2009). The USACE currently dredges 133,800 m^3 (175,000 yd^3)

from this location every 2.7 years to maintain ICW navigational depths (Figure 12) (Kabling and Odroniec 2010). The dredging and filling activities associated with the ICW have also altered water depths and fetch distances, which have impacted waves and currents and indirectly contributed to local erosion (Price 2005).

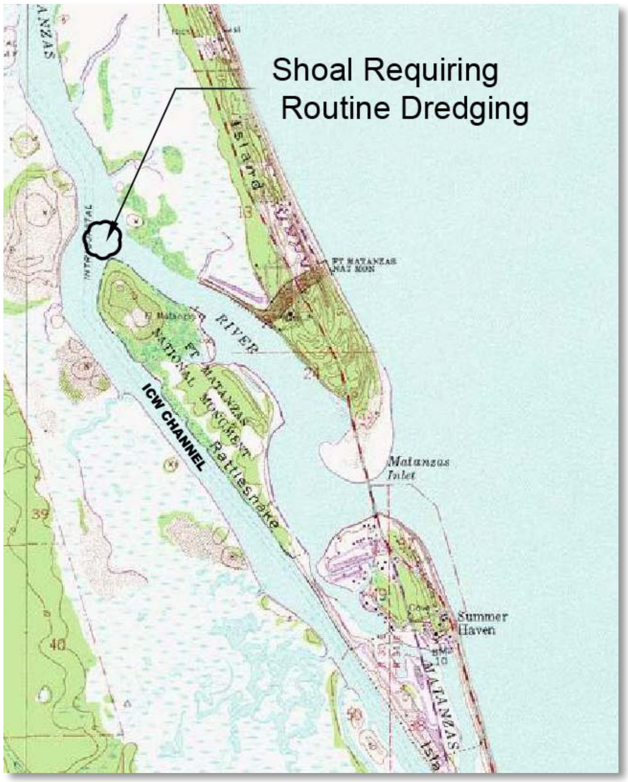

Figure 12. Map of shoal located north of Rattlesnake Island (image from Topoquest 2009).

The original 640-meter (2,100 ft) long dike along southern Rattlesnake Island was breached in 1964 during Hurricane Dora. The impact of this breach, which was not repaired until 1977, was substantial. By 1976 maximum average flow velocity had reached 1.5 m/s (4.8 ft/s) through the 95-meter (310 ft) wide breach and shoaling of 1,530 m^3/month (2,000 yd^3/month) was measured in the ICW channel (USACE 1976).

From 1964–1976 the inlet's tidal prism was predominantly directed through the breach, as opposed to the typical northern Matanzas River route, and was reduced by 80% (Mehta and Jones 1977). The ICW was adversely affected due to cross-channel currents and shoaling, while the Matanzas River suffered from reduced flows resulting in siltation and degradation of local oyster habitat (USACE 1976). Mehta and Jones (1977) report that the erosion/accretion rates along Rattlesnake Island and the western shore of Anastasia Island are related to the dominant tidal flow direction and inlet orientation, with less erosion (or higher rates of accretion) observed during the breakthrough period (1964–1977).

The Matanzas River system is complex, due to changing channel characteristics, natural inlet morphology, differential flow patterns, and tidal conditions. The continued presence of a hardened shoreline separating the river from the ICW will continue to impact natural sediment transport pathways.

Fort Matanzas Structures

Since the initial construction of Fort Matanzas in 1740, the military outpost has incorporated a wide range of coastal engineering approaches for protection against erosion due to waves and currents. The area around Fort Matanzas currently includes a seawall, revetment, bulkhead, pier, and three groins (#1–7 & Figures 8, 9 and 13). These structures are not only a testimony to the rich history of how the fort has been protected from erosion (Kidd 2004), but they also help elucidate the local sediment dynamics within the region.

Figure 13. Oblique aerial image of Fort Matanzas on the Matanzas River. View is to the north (image from Bing Maps 2012).

Impacts to natural sediment transport processes from the collection of structures near the fort likely began prior to the Matanzas Relocation Cut. Historic surveys suggest that the original Rattlesnake Island likely tended to migrate northwest (Mehta and Jones 1977) (Figure 14). The presence of tidally dominated upriver flows and limited sediment deposition from upriver sources, further support this notion (Gallivan and Davis 1981, Price 2005). The original shoreline stabilization measures (pre-1935) held the fort in place while minor erosion likely occurred in the surrounding areas. The erosive nature of the area remained unchanged following the ICW project with additional layers of fortification (seawall, revetment, bulkhead and groins) subsequently constructed.

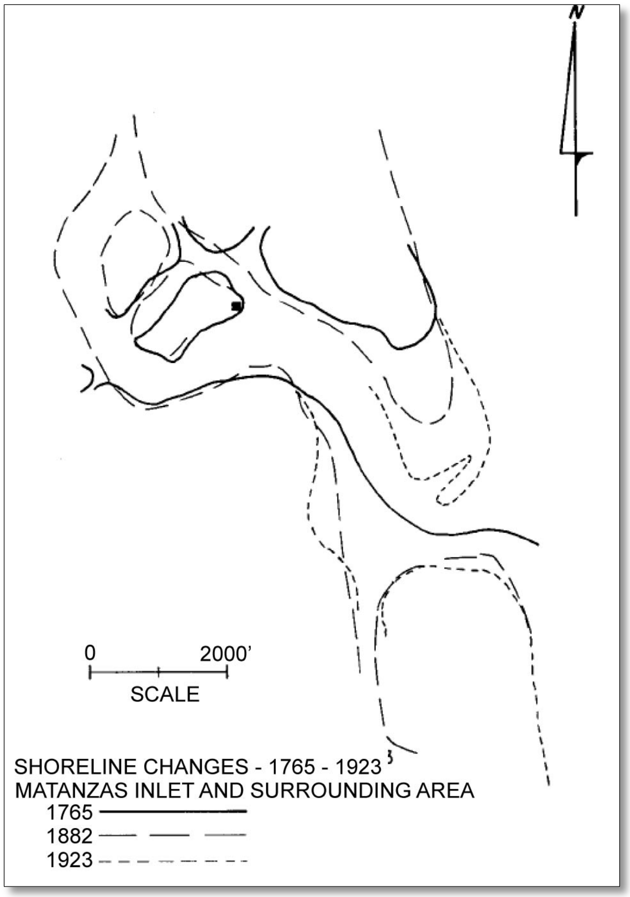

Figure 14. Historic shoreline change in the Matanzas Inlet area (from Mehta and Jones 1977).

Summer Haven Area

In the immediate vicinity of the Matanzas Inlet the net direction of longshore sediment transport is to the south (Mehta and Jones 1977). This, coupled with the Matanzas Inlet being a sediment sink, leads to a sediment deficit along the northern extent of Summer Haven (USACE 2007) with approximately 3.9 km (2.4 mi) of critically eroding shoreline (FDEP 2008). Dean and O'Brien (1987) hypothesized that this erosion is due to large volumes of sand stored in the Matanzas Inlet flood tidal shoal.

Coastal structures (#20–22 Figure 5), dune manipulation, and beach nourishment projects have been completed south of the inlet along the ocean shoreline to combat erosion and protect roadway, commercial, and residential infrastructure. Together structures along the inlet and nearby ocean waterfront harden nearly 1,600 m (5,250 ft) of shoreline, limiting the available sediment supply and possibly increasing downdrift erosion. In response to ongoing erosion, an erosion control study has been initiated by the community of Summer Haven to examine shoreline stabilization alternatives in a region extending 3.2 km (2 mi) south of the inlet (SJCG 2007). Proposed alternatives include additional seawalls, revetments and/or groins coupled with beach nourishment (SJCG 2007).

Discussion and Recommendations for Further Study

The engineering projects and coastal structures within Fort Matanzas National Monument play a substantial role in dictating flow and sediment transport patterns. The coastal structures built for the Matanzas Relocation Cut resulted in shoaling at the northern end of Rattlesnake Island, necessitating frequent dredging. Changes to the local hydrodynamics have led to the construction of shoreline protection structures along Fort Matanzas, Anastasia Island, and Summer Haven.

FOMA consists primarily of low-lying tidal flats and marsh areas that are at risk to increased erosion and potential flooding due to sea level rise. Fort Matanzas is only 1.5 m (5 ft) above the local high tide level (Graham 2009). Dorr et al. (2012) modeled the effect of sea level rise on the land area of FOMA and found a 0.6 m (2 ft) rise in mean sea level would inundate 0.2 km^2 (59 ac), or 19% of the park. Similarly, they found a 1.2 m (4 ft) rise in mean sea level would result in 0.5 km^2 (124 ac), or 40% of the park, being inundated.

At present, the coquina seawall and portions of Rattlesnake Island are flooded several times annually due to high tides in the spring and fall (NPS 2006b). Future increases in sea level, possibly combined with changes to storm frequency and magnitude, will undoubtedly result in increased erosion and flooding (Graham 2009).

Sediment transport processes and coastal change rates within FOMA have been fairly well documented (e.g., Mehta and Jones 1977, Gallivan 1979, Taylor Eng. 1991, Taylor Eng. 2009, and USACE 2007). Future work should continue to focus on alternatives that mitigate the ongoing maintenance dredging as well as potential impacts to hydrodynamics and sediment transport resulting from proposed inlet modifications. Additional research could also focus on FOMA’s vulnerability to sea level rise and alternatives to protect Fort Matanzas from erosion.

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Appendix A. Glossary

Accretion: The accumulation of sediment on a beach, deposited by natural fluid flow processes.

Beach Nourishment: The introduction of sediment along a shoreline to increase or protect the size of a beach (includes dune and berm construction and nearshore disposal of sediment for the purpose of shoreline stabilization).

Breakwater: Shore-parallel structures that reduce the amount of wave energy reaching a harbor or stretch of shoreline located behind the structure. Breakwaters are similar to natural bars, reefs or nearshore islands and are designed to dissipate wave energy. The reduction in wave energy results in gradients in littoral drift, causing sediment deposition in the sheltered area behind the breakwater. Some longshore sediment transport may continue along the coast behind the breakwater. Structures can be detached, attached or utilized as a headland control feature depending on design and functionality characteristics.

Bulkhead: Vertical structures or partitions, usually running parallel to the shoreline, for the purpose of retaining upland soils while providing protection from wave action and erosion. Bulkheads are either cantilevered or anchored sheet piles or gravity structures such as rock-filled timber cribs and gabions, concrete blocks or armorstone units.

Dike: Earthen structures (dams) that keep elevated water levels from flooding interior lowlands. The protected area is often below sea level. In open coast areas, dikes that separate low-lying areas from open water are often constructed with a revetment or similar armor layer on the open waterside to protect the dike from wave action and erosion.

Dredging: The mechanical removal of sediment, often used to increase or maintain the depth of a navigable waterway.

Erosion: The wearing away of land and the removal of beach or dune sediments by wave action, tidal currents, wave currents, or drainage.

Groin: Structures that extend perpendicular or at nearly right angles from the shore and are relatively short when compared to navigation jetties at tidal inlets. Often constructed in groups called groin fields, their primary purpose is to trap and retain sand. Groins can be constructed from a wide range of materials including armorstone, pre-cast concrete units or blocks, rock-filled timber cribs and gabions, steel sheet pile, timber sheet pile, or grout filled bags and tubes.

Headland Control: The concept of systematically placing structures (typically breakwaters) to create artificial headlands in an effort to promote equilibrium beach formation. Bays are sculptured between these headlands, such that diffraction and refraction cause waves to develop perpendicular to the coast. This is intended to result in a stable shoreline even if sediment is still passing through a system of headlands. This concept is often employed as a regional approach to shore protection.

Jetty: Structures that extend perpendicular or at nearly right angles from the shore commonly used to limit the volume of sediment deposited in inlet channels and prevent inlet migration.

Levee: Flood protection structure that holds back water during flood stage, typically built along a river to protect against flooding.

Pier: A platform extending over water from a shore that is supported by piles or pillars, used to secure, protect, and provide access to ships or boats.

Revetment: A cover or facing of material placed directly on an existing slope, embankment or dike to protect the area from waves and strong currents. Revetments are designed to armor and protect the land behind them and are commonly constructed using armorstone (high wave energy environments) or riprap stone (lower wave energy environments) in combination with smaller stone and geotextile fabrics. Other construction materials include gabions, poured concrete (usually in stepped fashion), pre-cast concrete blocks, and grout filled bags. Structures can be partially detached from the shore (spur) depending on design considerations.

Seawall: Vertical structures used to protect backshore areas from heavy wave action, and in lower wave energy environments, to separate land from water. They can be constructed using a range of materials including poured concrete, steel sheet pile, concrete blocks, gabions, sandbags, or timber cribs.

Sill: Combination of elements from offshore breakwaters and rock revetments, typically built relatively close to shore, continuous and low-lying. Sills are generally built in lower wave energy regimes with the intent of reducing the wave climate and establishing marsh ecosystems or beaches.

Appendix B. Coastal Structure Data

ID	Location	Structure	Material	Year Built	Year Maint.	Length (m)	In FOMA	[2]Source
1	Fort Matanzas	Revetment	Rock	1936	2007	88	Yes	1
2	Fort Matanzas	Pier	Concrete	1935	1956, 1978–79, 2007	39	Yes	1,2
3	Fort Matanzas	Groin	Rock	1940	2007	13	Yes	1,3
4	Fort Matanzas	Groin	Rock	1940	2007	9	Yes	1,3
5	Fort Matanzas	Bulkhead	Steel and cement	1936	2007	55	Yes	1, 2,4
6	Fort Matanzas	Seawall	Rock	1940	1966	23	Yes	3,4
7	Fort Matanzas	Groin	Wood and rock	1948–49	1966, 2007	66	Yes	2,3
8	Visitor Center	Groin	Rock	1934–1935	2007	16	Yes	1,5
9	Visitor Center	Groin	Rock	1934–1935	2007	14	Yes	1,5
10	Visitor Center	Groin	Rock	1934–1935	2007	13	Yes	1,5
11	Visitor Center	Groin	Rock	1934–1935	2007	14	Yes	1,5
12	Visitor Center	Pier	Concrete	1935	2000	66	Yes	1
13	Visitor Center	Groin	Rock	1934–1935	2007	18	Yes	1,5
14	S. Rattlesnake Island	Revetment	Rock	1977		781	Yes	6
15	S. Rattlesnake Island	Dike	Steel	1977		[1]143	Yes	5,6
16	S. Rattlesnake Island	Revetment	Rock	1977		127	Yes	6
17	S. Rattlesnake Island	Dike	Steel	1936		[1]533	Yes	7
18	Summer Haven	Revetment	Rock			[1]749	No	
19	Summer Haven	Bulkhead		pre 1995		[1]825	No	8
20	Summer Haven	Revetment	Rock	1963		816	No	9
21	Summer Haven	Seawall				149	No	
22	Summer Haven	Seawall	Concrete	1957–58		104	No	5

[1] Length for these structures is approximate.

[2] Source: 1: EA Engineering (2006), 2: NPS (1980), 3: Kidd (2004), 4: USACE (1987), 5: Mehta and Jones (1977), 6: USACE (1976), 7: Freeland (1940), 8: Google Earth, 9: FDEP (2000).

Appendix C. Dredge and Fill Data

Location	Type	First Year	Last Year	Episodes	Volume (m^3)	In FOMA	[1]Source
Matanzas Inlet	Dredge	1930		1	44,837	No	1
Intracoastal Waterway	Dredge	1932	2007	min. 29	3,151,357	No	1,3
Southern Rattlesnake Island	Fill	1936		1	147,890	Partial	1
Fort Matanzas bulkhead	Fill	1944	1947	2		Yes	2
Fort Matanzas groin	Fill	1966		1		Yes	2
Matanzas River	Dredge	1977		1		No	1
Southern Rattlesnake Island	Fill	1977		1		Partial	4

[1] Source: 1: Mehta and Jones (1977), 2: NPS (1980), 3: Taylor Eng. (2009), 4: USACE (1976).

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