



Inventory of Coastal Engineering Projects in Fort Raleigh National Historic Site

Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2013/704



ON THE COVER

Fort Raleigh National Historic Site, Northern Roanoke Island, Manteo, NC
Photograph by: Kate Dallas

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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 Raleigh National Historic Site (FORA). The report serves as a supplement to a Geographic Information Systems (GIS) database (the GIS data are available online at <http://irma.nps.gov>).

A total of 79 coastal engineering structures were identified in and adjacent to FORA. Thirty-three of these structures were identified within FORA, which together extend over 1 km (0.6 mi) and armor roughly 24% of the shoreline. The remaining 46 coastal structures were found directly adjacent to the park on private or state lands and span over 2 km (1.2 mi). One small dredging project was also found adjacent to FORA in a private marina.

The Waterside Theater revetment has stabilized the shoreline, but also cut off a terrestrial sediment input that has likely contributed to downdrift erosion. Similarly, the Dough Cemetery revetment has impounded a potential sediment source and experienced significant end erosion due to wave reflection or to limited sand mobilization.

Acknowledgments

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We would also like to thank Randy Swilling, the Natural Resource Program Manager at Cape Hatteras National Seashore, for helping us arrange a field visit to the park. Special thanks goes to pilot John Kimmel for taking us on an aerial tour of the park. Thayer Broili, Doug Stover, and Patrick Gamman also provided assistance during our field visit and Laura Pickens helped with acquisition of imagery. Jodi Eshleman generously shared data and references and helped organize the field visit.

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

Seventy-nine coastal engineering structures were identified in, and adjacent to, Fort Raleigh National Historic Site (FORA) (Table 1). Of the total 79 coastal structures, 33 are located inside the park and extend over 1 km (0.6 mi). Within the park, coastal structures armor roughly 24% of the 3.8-kilometer long (2.4 mi) shoreline.

Forty-six structures are on private or state property adjacent to the park and span over 2 km (1.2 mi) (Table 1). Roughly 43% of the shoreline contained within the greater extent of FORA, which spans from the Prince House to nearly 1 km (0.6 mi) south of the Highway 64 Bridge (Figure 3) and includes park, private, and state lands, is armored with coastal structures (Figure 1). A summary of all of the structures within and adjacent to FORA is presented in Appendix B.

Limited dredging (maximum of 7,650 m³/yr [10,000 yd³/yr]) occurs annually in the Heritage Point marina adjacent to FORA. No beach nourishment projects were found in or adjacent to FORA.

Table 1. Coastal structures in and adjacent to Fort Raleigh National Historic Site (note that some of these structures overlap).

¹ Structures	Within FORA	Length (m) within FORA	Adjacent to FORA	Length (m) adjacent to FORA	TOTAL within FORA and adjacent to FORA	TOTAL length (m) within FORA and adjacent to FORA
Breakwater	1	255	0	0	1	255
Bulkhead	0	0	4	480	4	480
Groin	28	346	28	255	56	601
Jetty	0	0	2	260	2	260
Pier	1	35	8	370	9	405
Revetment	3	434	4	643	7	1,077
TOTAL	33	1,070	46	2,008	79	3,078

¹See the Glossary in Appendix A for structure definitions.

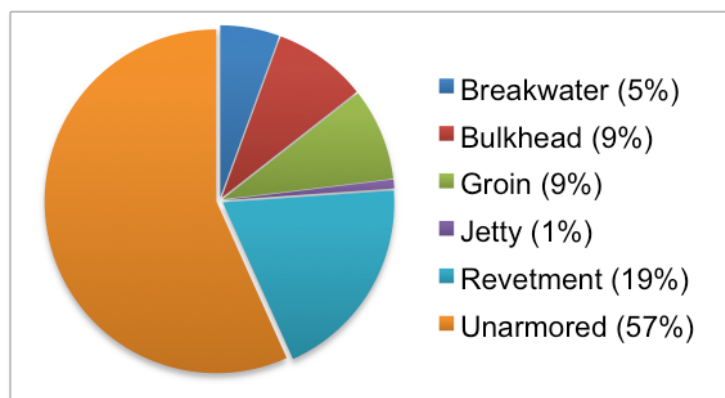


Figure 1. Percentage of shoreline armored by structure type and unarmored in, and adjacent to, Fort Raleigh National Historic Site.

Background

FORA occupies 1.4 km² (355 ac) (NPS 2011) on the northern end of Roanoke Island in the northeast region of North Carolina (Figure 2). Roanoke Island is situated between the coastal mainland of North Carolina and Bodie Island, a barrier island in the Outer Banks barrier island chain (Figure 2). FORA was established on April 5, 1941 to preserve the probable location of the first English colony in the United States and the history of the Native Americans, European Americans, and African Americans who have lived on Roanoke Island (NPS 2007a).



Figure 2. Regional map of Fort Raleigh National Historic Site (shown in yellow). Area in pink box is enlarged in Figure 3 (images from ESRI Bing Maps basemap layer 2012).

FORA's legislative boundary encloses 2 km² (513 ac) divided between FORA (1.4 km² [355] ac), the State of North Carolina (0.07 km² [18 ac]), and private groups (0.6 km² [140 ac]) (NPS 2011). FORA is a partner with the Roanoke Island Historical Association (RIHA), which

produces the outdoor play *The Lost Colony* at the Waterside Theater (Figure 3). To the west of the theater is the Elizabethan Gardens (Figure 3), which is owned by the RIHA and leased to The Garden Club of North Carolina. Heritage Point is a private residential area that is surrounded by parkland on the northwest tip of Roanoke Island (Figure 3).



Figure 3. Map of Fort Raleigh National Historic Site and places mentioned in the report. Yellow shading shows the park property (image from ESRI Bing Maps basemap layer 2012).

Setting

Sea-level fluctuations during the Quaternary Period (last 2.6 million years) have produced an extremely complex sediment record in northeastern North Carolina (Riggs et al. 1992). Parham et al. (2007) demonstrated the occurrence of nine transgressive sequences in the late Quaternary in Croatan Sound based on drill-hole and seismic data. The result is a complicated, cross-cutting series of riverine, estuarine, and marginal marine deposits in the greater FORA region (Riggs et al. 2000).

Croatan and Roanoke Sound are drowned tributaries that flowed northward to the paleo-Roanoke River (now Albermarle Sound) (Figure 2) and Roanoke Island is a remnant of the divide that separated these two tributaries (Riggs et al. 1992). In the Roanoke Island region, a thick sequence of Quaternary sediments (about 75 m [245 ft]) rest unconformably on the Pliocene Yorktown Formation (Brown et al. 1972, Mallinson et al. 2005). The upper 4 to 6 m (13 to 20 ft) of Quaternary sediments on Roanoke Island are late Pleistocene aged estuarine and barrier-island facies (Riggs et al. 1992). On top of the late Pleistocene sediments in the FORA region are several meters of Holocene aged estuarine sand deposits and sand dunes that thin southward (NPS 2007b).

Depending on the prevailing wind and wave direction, littoral drift can be to the east or west (Eshleman and York 2011). Strong winds from the northwest will drive sediment from west to east along northern Roanoke Island, while winds from the northeast will cause sediment transport from east to west. The dominant net sediment transport direction is most likely to the east, as evidenced by an eastward migrating sand spit (Crab Claw Spit) located southeast of the park (Dolan and Lins 1985, Riggs and Ames 2003). Eroding banks are the primary source of beach sand to the littoral system, with major periods of erosion occurring during high-energy storms (Riggs and Ames 2003).

FORA is at the juncture of Albermarle, Roanoke, and Croatan Sounds and faces a large fetch of open water to the north (Figure 2), making it exposed to storm waves and surges from both nor'easters and hurricanes (Dolan and Lins 1985). The sounds around FORA have low amplitude astronomical tides because only four inlets exist along the 300-kilometer (190 mi) long Outer Banks barrier island chain, limiting the influence of oceanic processes (Riggs and Ames 2003). Instead, the intensity and duration of the wind primarily determines the currents and water levels (Riggs and Ames 2003).

Normal wind tides (surge) are small (<0.3 m [<1 ft]), with storm tide amplitudes reaching up to 0.9–1.2 m (3–5 ft) and occasionally up to 3 m (10 ft) or more during hurricanes (Riggs and Ames 2003). Storms can also generate waves that can exceed 1.5 m (5 ft) (Dolan and Lins 1985).

The longest record of sea level data in the area is at the Duck, North Carolina tide gauge, located approximately 28 km (17 mi) northeast of FORA on the Atlantic coast. The Duck gauge shows a 4.59 ± 0.94 mm/yr (0.18 ± 0.04 in/yr) rise in sea level from 1978 to 2011 (NOAA 2012). More information on sea level trends for the State of North Carolina can be found in Zervas (2004) and NCCRC (2010).

Shoreline change occurs along the park shoreline due to storm waves, tides, and currents. Rates of erosion are directly related to shoreline type and fetch, with areas of high banks and high fetch eroding dramatically more than areas with low banks and low fetch (Riggs and Ames 2003). Dolan and Bosserman (1972) report that northern Roanoke Island has eroded severely, with as much as 280 m (928 ft) of shoreline recession from 1851 to 1970. Numerous shoreline stabilization efforts have occurred over time, fixing the location of the shoreline while also simultaneously decreasing the amount of sediment available for littoral transport (Riggs and Ames 2003).

Erosion currently threatens culturally significant sites and related infrastructure at FORA and planning is underway to develop emergency stabilization actions (Eshleman and York 2011). Shoreline erosion has already caused the Prince House and Beehive buildings (Figure 3) to be condemned and has required the exhibits at a day-use area next to the Highway 64 Bridge to be moved (NPS 2011).

Waterside Theater Area

The Waterside Theater was constructed by the Works Progress Administration in 1937 and is the home of *The Lost Colony* theater production, managed by the RIHA. In response to rapid erosion, RIHA built two 15 m (50 ft) groins behind the stage and dressing rooms in 1941 and replaced them 5 years later with 9 m (30 ft) groins (Binkley and Davis 2003). Tee groins were

also reported in front of the theater in 1980 by the U.S. Army Corps of Engineers (USACE 1980) and observed to be ineffective in controlling shoreline erosion. No groins currently exist behind the theater and the history of the 1940s era RIHA groins and those observed by the USACE in 1980 is unknown.

Binkley and Davis (2003) also note that beginning in 1949 the park constructed four groins of salvaged material from a local bridge demolition project along the northern Roanoke Sound shoreline, but the location and fate of these groins is unknown. In 1980 the NPS built a 242-meter (794 ft) long granite revetment in front of the theatre to stabilize the shoreline (#64 Figures 4, 5 & 6) (Binkley and Davis 2003).



Figure 4. Structure map for FORA. Yellow shading shows the park property. Area in pink box is enlarged in Figure 5 (image from ESRI Bing Maps basemap layer 2012).

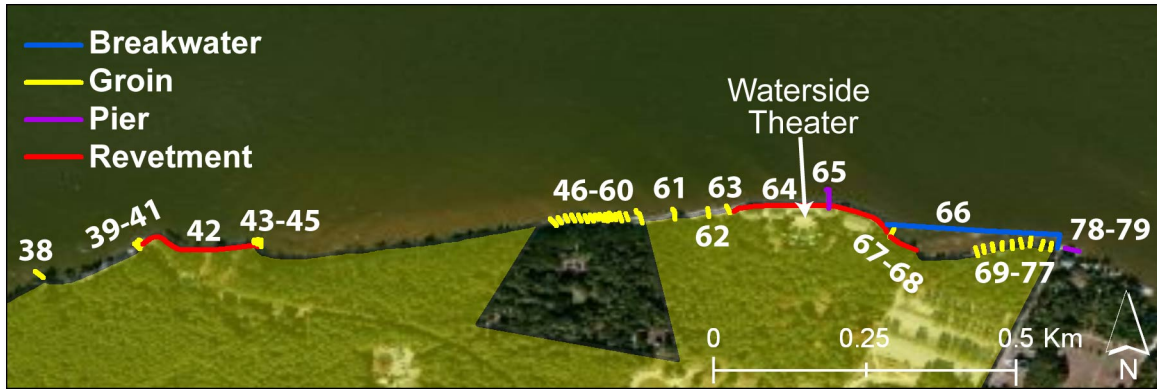


Figure 5. Structure map for the northern shoreline of FORA. Yellow shading shows the park property (image from ESRI Bing Maps basemap layer 2012).



Figure 6. Revetment (#64 Figure 5) fronting the Waterside Theater. View is to the west (image by Kate Dallas).

To the west of the theater are 18 wooden groins, which were built in the early 1950s (#46–63 Figures 5 & 7) (Dolan and Bosserman 1972). The groin field has been successful at trapping sand, with about 9 m (30 ft) of shoreline progradation observed between 1950 and 1970 (Dolan and Bosserman 1972). A breakwater was also built concurrently with the groins in the early 1950s (Dolan and Bosserman 1972), but no longer remains and details of its history are unknown. Eshleman and York (2011) report that park maintenance staff noted a sill offshore from the theater, which may be the same structure referred to as a breakwater by Dolan and Bosserman (1972).



Figure 7. Wooden groins to the west of the Waterside Theater (#60–63 Figure 5). View is to the east (image by Kate Dallas).

East of the theater is a submerged breakwater, rock revetment, ten wooden groins, and a small wooden bulkhead and pier in front of a private residence (#66–79 Figure 5). Eshleman and York (2011) reported that the original breakwater was built with sand bags in the 1960s, while Klingelhofer (2008) documents that a concrete breakwater was installed in the 1950s. The 42-meter (138 ft) long rock revetment was constructed in the 1970s (Klingelhofer 2008). It is unknown when the wooden groins were built, but historic Google Earth images show that all of the groins were built before 2002 (#67–77 Figure 5 & Figure 8).



Figure 8. Wooden groins (#74–77 Figure 5) and submerged breakwater (#66 Figure 5) to the east of the theater. View is to the northwest (image by Kate Dallas).

Dough Cemetery

The area around Dough Cemetery has experienced the highest rates of erosion in FORA because this stretch of shoreline has the greatest fetch (32–56 km [20–35 mi]), making it highly exposed to storm waves (Riggs and Ames 2003). Erosion rates in this area were as high as -7 m/yr (-23 ft/yr) from 1969–1975 (Riggs and Ames 2003).

In response to rapid erosion, the NPS installed a 168 meter-long (551 ft) granite block revetment in 1980 (#42 Figure 5 & Figure 9) (Binkley and Davis 2003). Three wooden groins exist on both the eastern and western end of the revetment, but nothing could be found on their history (#39–41, 43–45 Figure 5). Severe erosion is now occurring at the eastern end of the revetment, which could threaten the cemetery. FORA staff are communicating with the descendents of the Dough family regarding the possibility of relocating the cemetery (Eshleman and York 2011).



Figure 9. Revetment fronting the Dough Cemetery (#42 Figure 5). View is to the west (image by Kate Dallas).

To the west of Dough Cemetery is a concrete septic tank and metal pipes exposed on the beach (Figure 10). This debris is the only remaining feature from the 1938 Civilian Conservation Corps Camp Wirth Site and acts as a groin, trapping sediment (#38 Figure 5) (Eshleman and York 2011).



Figure 10. Debris from the 1938 Civilian Conservation Corps Camp Wirth Site (#38 Figure 5) (image by Kate Dallas).

Heritage Point Community

The Heritage Point Community is a private residential area and marina on the northwest tip of Roanoke Island (Figure 11). The area was developed in the 1990s and includes a highly altered shoreline consisting of bulkheads, revetments, piers, groins, and jetties (#14–37 Figure 4). The two rock jetties (#21–22 Figure 4) were built in 1991 and were extended in 1998 (Terry McGuiness, Heritage Point Home Owners Association President, phone, 10-24-12). Historic images from Google Earth provide a rough timeline for the installation of the other coastal structures.



Figure 11. Heritage Point residential area and marina. View is to the northwest (image by Kate Dallas).

The timber pier to the north of the marina (#24 Figure 4) was built in 1993 and the adjacent timber bulkhead and eight timber groins (#23, 26–34 Figure 4) were installed sometime from 1993–1998. The southern bulkhead (#17 Figure 4) was built in 1998, followed by construction of the pier and revetment on the southern edge of the community (#14–15 Figure 4) and the northern revetment (#25 Figure 4) sometime between 2002 and 2005. Lastly, four timber piers were added in the mid 2000s (#18, 30, 35, 37 Figure 4). The NPS Administrative History (Binkley and Davis 2003) reports that the development of the Heritage Point area caused erosion on the adjacent parkland.

The Heritage Point marina is dredged annually with a maximum of 7,650 m³ (10,000 yd³) removed per year. The dredge spoil is deposited on land and used in local construction projects (Terry McGuiness, Heritage Point Home Owners Association President, phone, 10-24-12).

South of the Heritage Point Community are three rock groins (#11–13 Figure 4) of unknown age and a short rock revetment just outside the park at the base of the Highway 64 bridge footings (#10 Figure 4). Eshleman and York (2011) report the revetment was likely installed in 2009.

South of the Highway 64 Bridge are eight groins and a wooden bulkhead adjacent to park property (#1–9 Figure 4). Google Earth images show the groins were built in the 1990s and the bulkhead was installed sometime between 2002 and 2008.

Impacts

From 1851 to 1970 the FORA shoreline eroded at an average rate of -1.2 to -1.5 m/yr (-4 to -5 ft/yr) (Riggs and Ames 2003). If this erosional trend reflects the general trend since Colonial time, the northwestern shoreline of Roanoke Island would have receded an average of over 500 m (1,640 ft) since 1585 (Figure 12). The location of the modern FORA shoreline is a result of long-term erosion due to wind, waves, and currents combined with impacts related to shoreline stabilization structures. Most of the shoreline stabilization structures have been constructed since the 1970s and are actively contributing to landform modification (Riggs and Ames 2003).

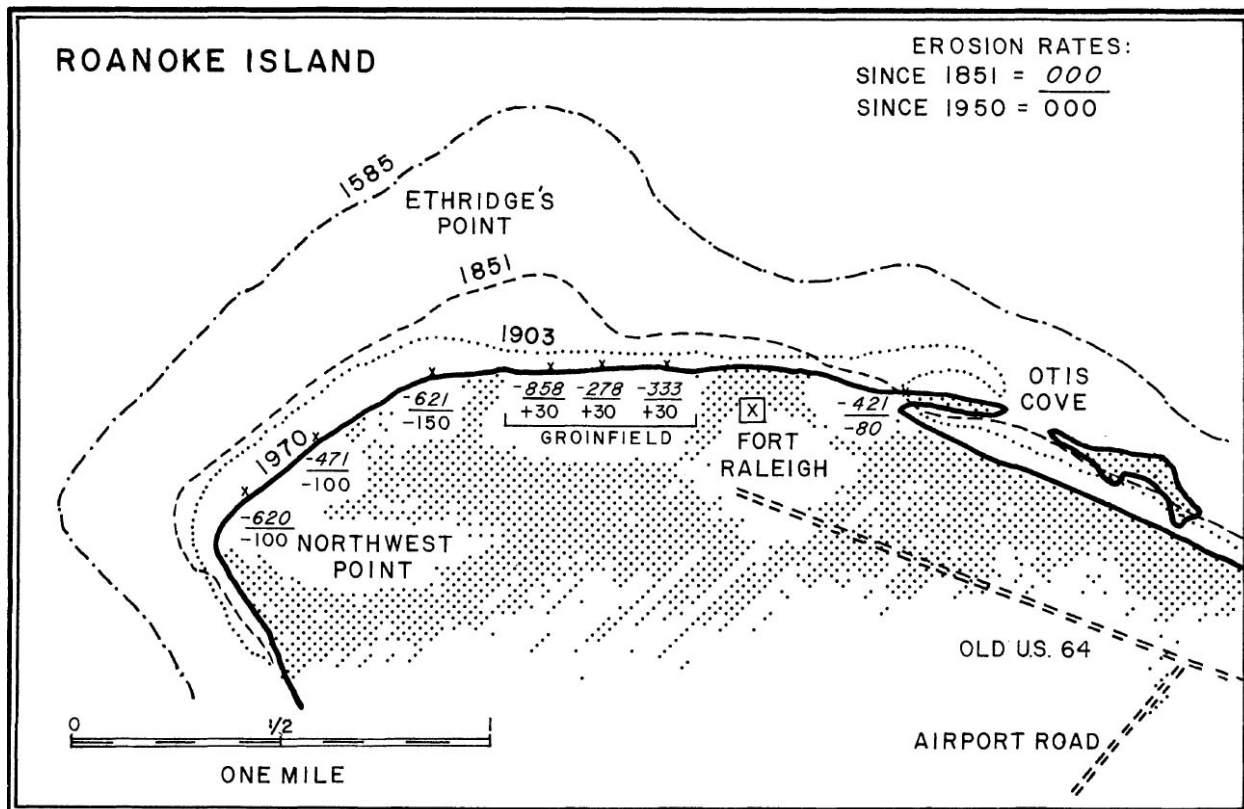


Figure 12. Estimated historic shorelines for northern Roanoke Island (1585, 1851, 1903 and 1970) and erosion rates (ft/yr) for 1851–1970 and 1950–1970 (from Dolan and Bosserman 1972).

Waterside Theater & Adjacent Property

The shoreline at the Waterside Theater has been stabilized since the 1940s with various types of structures including groins and rock revetments. The shoreline in this area is exposed to moderate wave energy, with fetch distances of 6.4–8.1 km (4–5 mi) (Riggs and Ames 2003). The historic (1851–1970) shoreline erosion rate for this section is approximately -0.9 to -1.2 m/yr (-3 to -4 ft/yr) (Riggs and Ames 2003).

Revetments in front of the theater (#64 & 68 Figure 13) have fixed the location of the shoreline, preventing an estimated 30 m (100 ft) of shoreline loss since 1980. These structures have also likely cut off an important sediment supply to downdrift areas. Erosion at the eastern end of the

shorter revetment (structure #68) has become quite pronounced within the last few decades (Figure 14).



Figure 13. Shoreline in the vicinity of the Waterside Theater. View is to the south (image from Bing Maps 2012).



Figure 14. The shoreline east of the Waterside Theater includes a wooden groin field, submerged breakwater and revetment. View is to the southwest (image from Eshleman and York 2011).

Klingelhofer (2008) found that the shoreline in the Prince House vicinity (east of revetment #68) has experienced erosion on the order of -1.25 m/yr (-4.1 ft/yr) over the last 25 years. Even with the construction of a groin field and submerged breakwater, erosion is still occurring, likely due to deflected currents and limited sediment supply (Klingelhofer 2008). Eshleman and York (2011) report that erosion in front of the Prince House and Waterside Theater parking area is a major concern for park maintenance staff. An additional impact of continued erosion includes decreased habitat for local species such as the mound-lily yucca and the Carolina water snake, both of which are native to the area and considered to be threatened (Eshleman and York 2011).

Dough Cemetery Revetment

The Dough Cemetery revetment (#42 Figures 5, 9 & 15), built in 1980, extends 168 m (551 ft) along the bluffs of the northern boundary of the park. The cemetery's shoreline is exposed to high wave energy, with fetch distances of up to 56 km (35 mi) (Riggs and Ames 2003). The long-term (1851–1970) shoreline change rate in this area is approximately -2.4 to -2.7 m/yr (-8 to

-9 ft/yr), with rates as high as -7 m/yr (-23 ft/yr) observed from 1969–1975 (Riggs and Ames 2003).



Figure 15. Rock revetment and groins in front of the Dough Cemetery (#42 Figure 5). View is to the south (images from Eshleman and York 2011).

Since construction of the revetment in 1980, the backshore has been held in place preventing an estimated 80 m (260 ft) of additional shoreline erosion. The armoring of the shoreline has likely limited sediment supply to downdrift beaches and caused accelerated erosion to the east of the revetment (Figure 15).

Between 1975 and 1998 erosion rates along the eastern end of the revetment were roughly double the erosion rates of the shoreline further to the east (-1 m/yr [-3.3 ft/yr] versus -0.6 m/yr [-2.0 ft/yr]) (Riggs and Ames 2003). Erosion at the eastern end of the revetment appears to be an end effect, where the ends of structures experience erosion extending alongshore in a curved indentation due to reflection of waves or due to a groin effect of the structure limiting sand mobilization (McDougal et al. 1987, Kraus and McDougal 1996, Comfort and Single 1997).

The greater the length of the hard shore protection structure, typically the greater the volume of sand impoundment (due to loss of sediment supply and groin effect) and the greater the expected downdrift erosion (Tait and Griggs 1991, McDougal et al. 1987). McDougal et al. (1987) used field and laboratory evidence to develop simple relationships for the expected erosion adjacent to a vertical seawall. They found that the inland extent of structure-induced erosion is 10% of the length of the structure and the expected alongshore extent of structure-induced erosion is 70% the length of the structure.

Applying these simple empirical relationships to the Dough Cemetery revetment, which is 168-meters (551 ft) long and causes impacts similar to those of a vertical seawall, results in inland erosion of about 17 m (56 ft) and an alongshore extent of erosion of 118 m (387 ft). These simple estimates are relatively close to the observed erosion east of the revetment.

Since the entire region has a long history of retreat, erosion will likely continue along the eastern end and downstream of the revetment in the foreseeable future, further impacting the cemetery. However, end effects specifically attributable to the structure may be slowing according to the simple empirical relationships applied above (McDougal et al. 1987).

Discussion and Recommendations for Further Study

Coastal engineering structures in and adjacent to FORA have altered the natural rates of shoreline erosion and subsequent flow of sediment. The structures have stabilized the backshore that they were intended to protect, but have also simultaneously limited the sediment supply for downdrift shorelines. Since shoreline change rates within FORA have been relatively well documented (e.g. Dolan and Bosserman 1972, Dolan and Lins 1985, and Riggs and Ames 2003), future work should focus on the development of a sediment budget.

Much of the park's shoreline consists of high banks and bluffs that range in elevation from sea level to 6 m (20 ft) (Figure 16) (Riggs and Ames 2003, NPS 2010). Given the relatively high elevation of the park, flooding due to sea level rise is considered a relatively minor threat. However, the secondary effects of rising sea levels coupled with climate change, most notably potential changes in storm frequency and strength (particularly nor'easters and hurricanes), are likely to play a significant role in the continued modification of the landscape. Rising sea levels will increase storm impacts and consequently the rates and amounts of shoreline recession. Therefore, additional research could focus on FORA's vulnerability to changes in sea level and storminess with a focus on the compounded impact as it relates to coastal erosion processes.

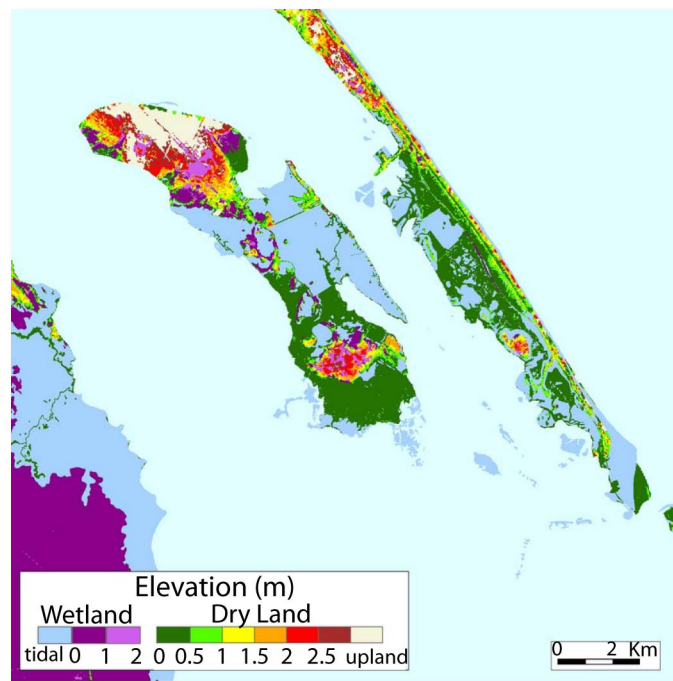


Figure 16. Roanoke Island elevation map (from More Sea Level Rise Maps n.d.).

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Appendix A. Glossary

Accretion: The accumulation of sediment on a beach, deposited by natural 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 wind and 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	Length (m)	Source ¹
1	South of Hwy 64 Bridge	Groin		1990s	12	1
2	South of Hwy 64 Bridge	Groin		1990s	11	1
3	South of Hwy 64 Bridge	Bulkhead	Wood	2000s	104	1
4	South of Hwy 64 Bridge	Groin		1990s	7	1
5	South of Hwy 64 Bridge	Groin		1990s	6	1
6	South of Hwy 64 Bridge	Groin		1990s	7	1
7	South of Hwy 64 Bridge	Groin		1990s	6	1
8	South of Hwy 64 Bridge	Groin		1990s	7	1
9	South of Hwy 64 Bridge	Groin		1990s	7	1
10	Highway 64 Bridge	Revetment	Rock	2009	57	2
11	North of Hwy 64 Bridge	Groin	Rock	pre 1993	16	1
12	North of Hwy 64 Bridge	Groin	Rock	pre 1993	15	1
13	North of Hwy 64 Bridge	Groin	Rock	pre 1993	16	1
14	Heritage Point	Revetment	Rock	early 2000s	70	1
15	Heritage Point	Pier		early 2000s	58	1
16	Heritage Point	Revetment	Rock		192	
17	Heritage Point	Bulkhead		1998	214	1
18	Heritage Point	Pier		mid 2000s	40	1
19	Heritage Point	Groin			7	
20	Heritage Point	Pier		2009	7	1
21	Heritage Point	Jetty	Rock	pre 1993	118	1
22	Heritage Point	Jetty	Rock	pre 1993	142	1
23	Heritage Point	Bulkhead	Wood	1990s	150	1
24	Heritage Point	Pier	Wood	1993	126	1
25	Heritage Point	Revetment	Rock	pre 2002	322	1
26	Heritage Point	Groin	Wood	pre 1998	5	1
27	Heritage Point	Groin	Wood	pre 1998	5	1
28	Heritage Point	Groin	Wood	pre 1998	6	1
29	Heritage Point	Groin	Wood	pre 1998	6	1
30	Heritage Point	Pier	Wood	mid 2000s	29	1
31	Heritage Point	Groin		pre 1998	7	1
32	Heritage Point	Groin		pre 1998	5	1
33	Heritage Point	Groin		pre 1998	6	1
34	Heritage Point	Groin		pre 1998	6	1
35	Heritage Point	Pier	Wood	mid 2000s	68	1
36	Heritage Point	Groin			7	
37	Heritage Point	Pier	Wood	mid 2000s	22	1
38	West of Dough Cemetery	Groin	Broken concrete	1930s	15	2
39	Dough Cemetery	Groin	Wood	pre 2002	11	1
40	Dough Cemetery	Groin	Wood	pre 2002	9	1
41	Dough Cemetery	Groin	Wood	pre 2002	6	1
42	Dough Cemetery	Revetment	Rock	1980	168	3
43	Dough Cemetery	Groin	Wood	pre 1993	5	1
44	Dough Cemetery	Groin	Wood	pre 1993	8	1
45	Dough Cemetery	Groin	Wood	pre 1993	11	1
46	West of Waterside Theater	Groin	Wood	1950s	15	4

ID	Location	Structure	Material	Year Built	Length (m)	Source ¹
47	West of Waterside Theater	Groin	Wood	1950s	11	4
48	West of Waterside Theater	Groin	Wood	1950s	10	4
49	West of Waterside Theater	Groin	Wood	1950s	11	4
50	West of Waterside Theater	Groin	Wood	1950s	12	4
51	West of Waterside Theater	Groin	Wood	1950s	11	4
52	West of Waterside Theater	Groin	Wood	1950s	12	4
53	West of Waterside Theater	Groin	Wood	1950s	9	4
54	West of Waterside Theater	Groin	Wood	1950s	12	4
55	West of Waterside Theater	Groin	Wood	1950s	12	4
56	West of Waterside Theater	Groin	Wood	1950s	13	4
57	West of Waterside Theater	Groin	Wood	1950s	9	4
58	West of Waterside Theater	Groin	Wood	1950s	14	4
59	West of Waterside Theater	Groin	Wood	1950s	11	4
60	West of Waterside Theater	Groin	Wood	1950s	24	4
61	West of Waterside Theater	Groin	Wood	1950s	17	4
62	West of Waterside Theater	Groin	Wood	1950s	14	4
63	West of Waterside Theater	Groin	Wood	1950s	12	4
64	Waterside Theater	Revetment	Rock	1980	224	3
65	Waterside Theater	Pier	Wood	pre 1993	35	1
66	East of Waterside Theater	Breakwater	Rock	1950s	255	5
67	East of Waterside Theater	Groin	Wood	pre 1999	15	1
68	East of Waterside Theater	Revetment	Rock	1970s	42	5
69	Prince House	Groin	Wood	pre 2002	14	1
70	Prince House	Groin	Wood	pre 2002	12	1
71	Prince House	Groin	Wood	pre 2002	11	1
72	Prince House	Groin	Wood	pre 2002	12	1
73	Prince House	Groin	Wood	pre 2002	13	1
74	Prince House	Groin	Wood	pre 2002	13	1
75	Prince House	Groin	Wood	pre 2002	15	1
76	Prince House	Groin	Wood	pre 2002	14	1
77	Prince House	Groin	Wood	pre 2002	12	1
78	East of Prince House	Bulkhead	Wood	pre 2002	13	1
79	East of Prince House	Pier	Wood	pre 1993	19	1

¹Source: 1: Google Earth, 2: Eshleman and York 2011, 3: Binkley and Davis 2003, 4: Dolan and Bosserman 1972, 5: Klingelhofer 2008.

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