Coastal Adaptation Science and Planning at Cape Hatteras National Seashore, NC

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Introduction

Among protected areas of the Southeast United States, few areas rival the public's affection for natural scenic beauty and recreation as its national seashores. These protected and public lands contain a wealth of natural and cultural resources yet are emblematic of growing threats of climate change, rising sea level, creeping coastal development, and mass tourism.

National seashore managers are responsible for maintaining diverse assets that support visitors and natural resources in the public trust across large swaths of the Southeast. In addition to provisioning tourism and recreational assets such as parking lots, visitor centers, restrooms and roads, park managers and staff are also stewards of natural resources that are dynamically responding to sea level, storms, and climate change. For Cape Hatteras National Seashore of North Carolina's Outer Banks, these natural resources include wildlife (resident and migratory as well as threatened and endangered species), critical habitats, and cultural and historical resources such as shipwrecks, historic properties, and national monuments such as the Bodie Island, Cape Hatteras, and Ocracoke Lighthouses.

Coastal erosion has increased the vulnerability of properties to storm damage and left others uninhabitable. Projections of sea level rise, changing storminess, and accompanying climate change effects may drive responses of beaches and dunes to rates far exceeding historical records. The US National Park Service (NPS) has undertaken system-wide risk assessments and planning for seashores and other NPS units exposed to SLR (Caffrey and Beavers 2008, 2013). The NPS has found utility in these projects to address specific threats, such as tidal flooding, coastal erosion, and storm surges.

To advance the use of coastal science and geospatial analysis in national seashore management, this poster presents an assessment of coastal risks from dynamic barrier island shoreline changes, storm surges, and future sea level rise at Cape Hatteras National Seashore on the Outer Banks of North Carolina. A multi-hazard approach allows for short- and long-term potential adaptations. The study focuses on long-term shoreline change analysis, potential storm surges with future SLR, and developing geospatial datasets for exposure assessments for infrastructure, cultural and natural resources. Relevant data, rates of change, and near-term projections of conditions from years to decades are also presented. Results could provide the NPS with potential mitigation options, identify the most critical vulnerabilities and uncertainties, and inform seashore capital project planning.

Study Area

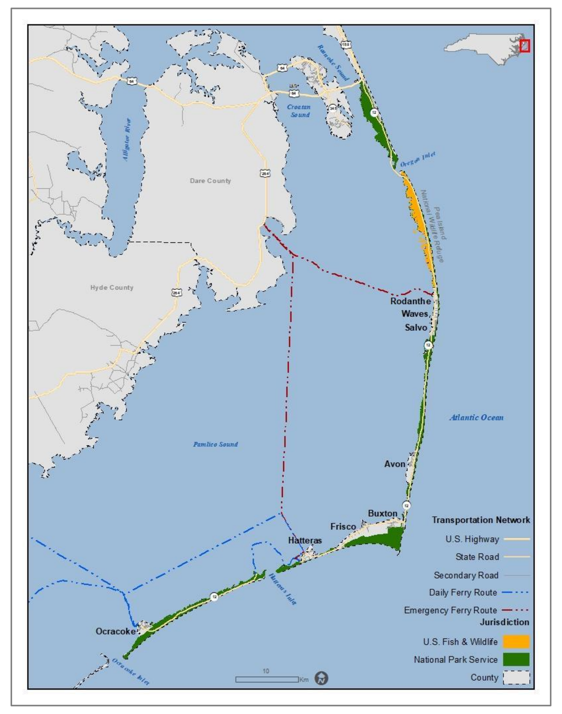

Figure 1. Study area location, Cape Hatteras National Seashore, North Carolina.

The Cape Hatteras National Seashore (Seashore) was established in 1937 to preserve cultural and natural resources of national significance. The Seashore shares boundaries with counties and towns and coordinates management with federal and state agencies including the U.S. Fish and Wildlife Service (USFWS), which oversees the management of the Pea Island National Wildlife Refuge (PINWR), and the NC Division of Transportation (NCDOT) (Figure 1).

The establishment of these jurisdictions has influenced where coastal development has occurred as well as the regulations that have guided resource management, conservation, visitor use, recreation, and tourism throughout the region. Although the type and level of management vary among the jurisdictions, all of the coastal development that currently exists either within or adjacent to the Seashore is potentially subject to impacts from multiple coastal hazards. Therefore, it is important to implement effective hazard mitigation planning in order to reduce both the short- and long-term risks that coastal hazards pose to the park's cultural resources.

Study Area *(continued...)*

For the Outer Banks, access to Hatteras and Ocracoke Island by tourists and residents is largely provided by NC Highway 12 (N.C. 12). Transportation along this highway has been interrupted on many occasions by hurricanes (Isabel (2003), Irene (2011), Sandy (2012), Dorian (2019)) and nor'easters. The management of this transportation corridor is complicated by diverse stakeholder interests, including federal, state, and local residents. Re-opening of the historic 1933 "New Inlet" on Pea Island, NC, led the NC Department of Transportation (NCDOT) to construct an overpass given its susceptibility to recurrent overwash and repeated dune breaching. The NCDOT also developed a plan for the "Jug Handle" bridge, which now bypasses the southern overwash-prone segment of Pea Island National Wildlife Refuge (PINWR) via causeway into the village of Rodanthe. This bridge opened just months ahead of large swells from offshore Hurricane Earl in September 2023 that would have closed N.C. 12 due to major overwash at the section of highway the bridge now bypasses.

The long-term viability of the N.C. 12 transportation corridor has attracted intense scrutiny, planning, and public controversy over the past several decades. N.C. 12 has seven areas that are vulnerable to periodic disruptions owing to ocean overwash and continued coastal erosion threatens the structural integrity. Potential inlet-opening, such as the 2003 Isabel Inlet "breach" between Frisco and Hatteras villages has profound implications for vehicular access, commerce and recreation. Some of widely held vulnerable areas include: a) the "Canal Zone" at the northern tip of Hatteras Island near Oregon Inlet; b) Pea Island National Wildlife Refuge (PINWR) Visitor Center; c) Rodanthe 'S' Curves along N.C.12 and Mirlo Beach; d) south of the village of Avon; e) the "Haulover" site just north of Buxton; f) Sandy Bay between Frisco and Hatteras Villages; and g) northern Ocracoke Island (near the South Dock ferry terminal).

Methods

Calculating Oceanfront Shoreline Change Rates

The Digital Shoreline Analysis System (DSAS), developed by the US Geological Survey (USGS), is a freely available software application that works within ESRI's desktop Geographic Information System (ArcGIS) software (Himmelstoss et al., 2018a). Historical oceanfront shoreline positions representing the high water line (HWL) between 1998 and 2022 were compiled and imported into a geodatabase for use with DSAS v5.1. The historical shoreline position data were either delineated from aerial imagery via wet-dry interpretation and heads-up digitizing at 1:1,000 scale by NCDCM staff (NCDCM 2019), delineated from field surveys of wet-dry interpretation collected with survey-grade global navigation satellite system (GNSS) units and later post-processed by NPS staff (Baron 2018), or delineated from high resolution satellite imagery at a 1:2,400 scale by NPS staff for the purpose of providing coverage along PINWR to supplement NPS field mapping efforts.

Forecasting 10- and 20-Year Shoreline Position

Long and Plant (2012) developed a methodology for forecasting shoreline evolution using an extended Kalman filter framework (Kalman, 1960). The latest DSAS software version 5.1 includes an experimental shoreline forecasting model able to generate 10- and 20-year future shoreline horizons and uncertainty bands in addition to being able to calculate the following statistics: SCE, NSM, EPR, LRR, and WLR. The LRR is the shoreline statistic that must be generated in order to initialize the Kalman filter model (Himmelstoss et al., 2018b).

Modeling Storm Surge Inundation

Storm surge analysis was conducted to assess the current and future exposure of assets to flooding. The approach relied heavily on the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) operational surge model and digital elevation models (DEMs). Allen et al. (2017) used the coastal inundation mapping methodology developed by NOAA (2015) to evaluate the vulnerability of historic structures located within the Seashore to storm surge and sea level rise. Allen et al. (2017) generated a DEM of the study area from Quality Level 2 bare earth LiDAR that was collected for the North Carolina Floodplain Mapping Program in 2014. The vulnerability of historic structures standing within the Seashore to storm surge was then evaluated by subtracting the first floor elevation (FFE) from the value representing the depth of inundation at the location of the structure for each scenario to determine if the water level exceeded the FFE. The FFEs for the park structures were obtained in 2022 by NPS staff using survey-grade GNSS units.

Methods *(continued...)*

Evaluating the Effects of Sea Level Rise

Risk assessment of park structural assets to sea level rise was initially investigated by Allen et al. (2017) and included simulated storm surge heights that would occur under relative sea level rise scenarios of 20, 40, 70, 100, and 140 cm. This approach helped to identify areas within the seashore that are less vulnerable for the purpose of considering the possibility of relocating historic structures to safer locations. Relative sea level rise (RSLR) was chosen so as to account not only for steric elevation of the coastal ocean and sounds, but also to factor the vertical land motion or subsidence in the region. These rates were estimated from the long-term available tide gauge records between the US Army Corps of Engineers' Field Research Station at Duck, NC, and newer gauges at Oregon Inlet and Beaufort, NC (NCCRC 2016). For the period of study from the present to future ~50-year period, we chose to adopt a morphostatic landform state, without extreme, low-probability events such as barrier island collapse or major, multiple new inlet opening events.

Results

Seven distinct hotspots are discernable in the map of shoreline change rates (Figure 2), with moderate to high rates of change in Table 1 (negative values indicate landward movement, or recessional and erosional change in the shoreline position).

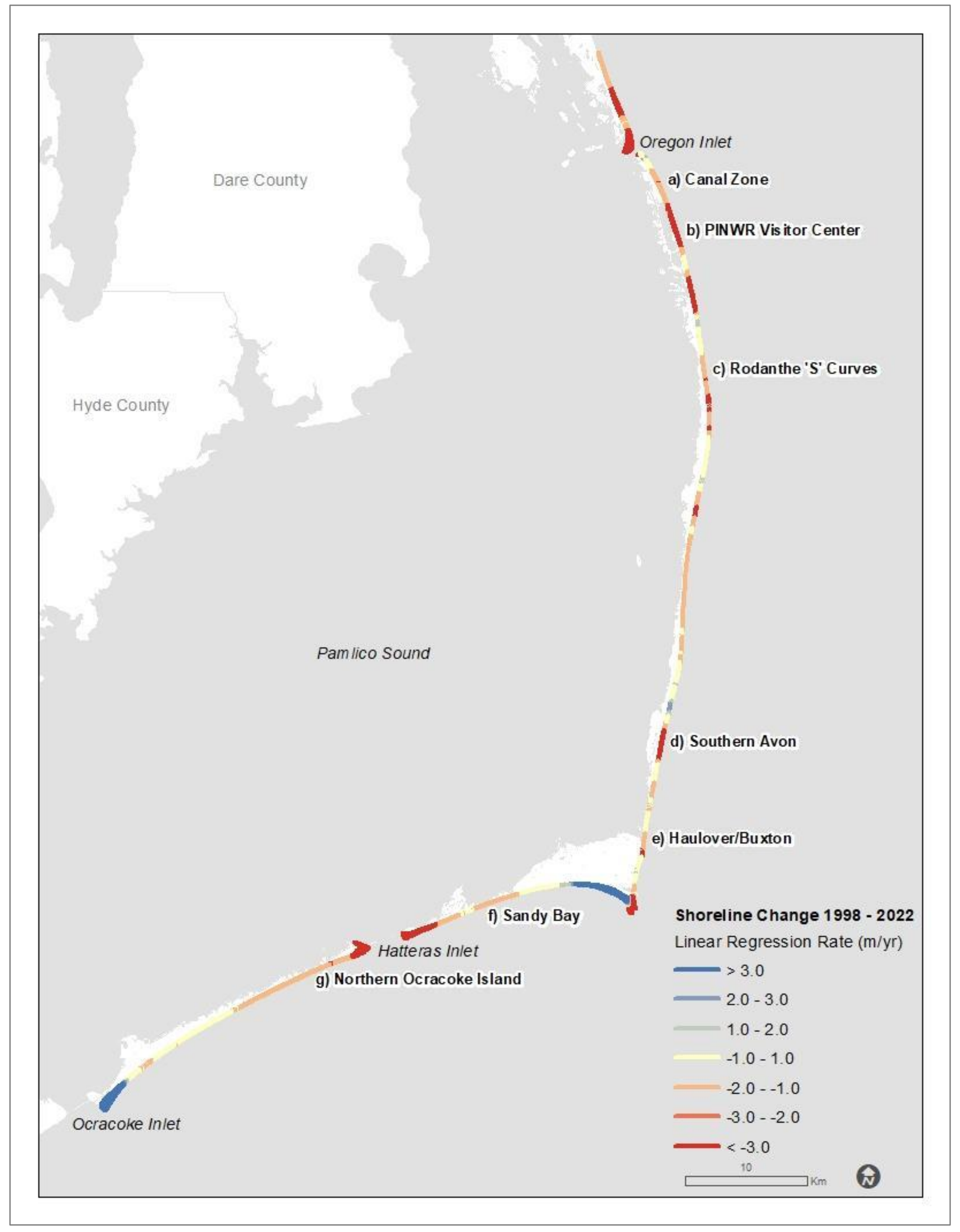

Figure 2. Oceanfront shoreline change rates along the Cape Hatteras National Seashore between 1998 - 2022 with references to the N.C. 12 erosion hotspots.

Location		Net Shoreline Movement (m)			End Point Rate (m/yr)			Linear Regression Rate (m/yr)		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
NC12 Hot Spot	Canal Zone	-28.34	-49.60	10.85	-1.20	-2.10	0.46	-2.45	-3.22	-1.50
	Pea Island Visitor Center	-86.73	-106.15	-56.33	-3.67	-4.50	-2.39	-4.27	-4.75	-3.88
	Rodanthe 'S' Curves	-60.46	-90.41	-23.76	-2.56	-3.82	-1.18	-2.26	-3.1	-1.29
	Southern Avon	-92.74	-113.88	-65.79	-3.92	-4.81	-2.78	-4.51	-5.2	-3.34
	Haulover/Buxton	-34.01	-76.16	-2.35	-1.44	-3.22	-0.1	-1.44	-2.86	-0.32
	Sandy Bay	-36.89	-54.07	-24.45	-1.56	-2.28	-1.03	-1.73	-2.24	-1.07
	Northern Ocracoke Island	-42.47	-61.54	-18.58	-1.8	-2.61	-0.79	-1.79	-2.27	-1.21
Cape Hatteras National Seashore		-22.65	-1134.61	550.24	-0.96	-47.93	23.32	-1.25	-38.12	18.80

Table 1. Shoreline change statistics calculated from oceanfront shoreline positions along Cape Hatteras National Seashore between 1998 - 2022 summarized for each N.C. 12 erosion hotspot and the total length of the Seashore.

Results of the DSAS future shoreline predictions (Figure 3) portray expected landward forecast locations. The proximity of the future shoreline to N.C. 12 is extremely close along northern sections of the Pea Island National Wildlife Refuge, Rodanthe 'S' Curves, the Haulover site north of Buxton, Sandy Bay, and stretches along northern Ocracoke Island.

Results *(continued...)*

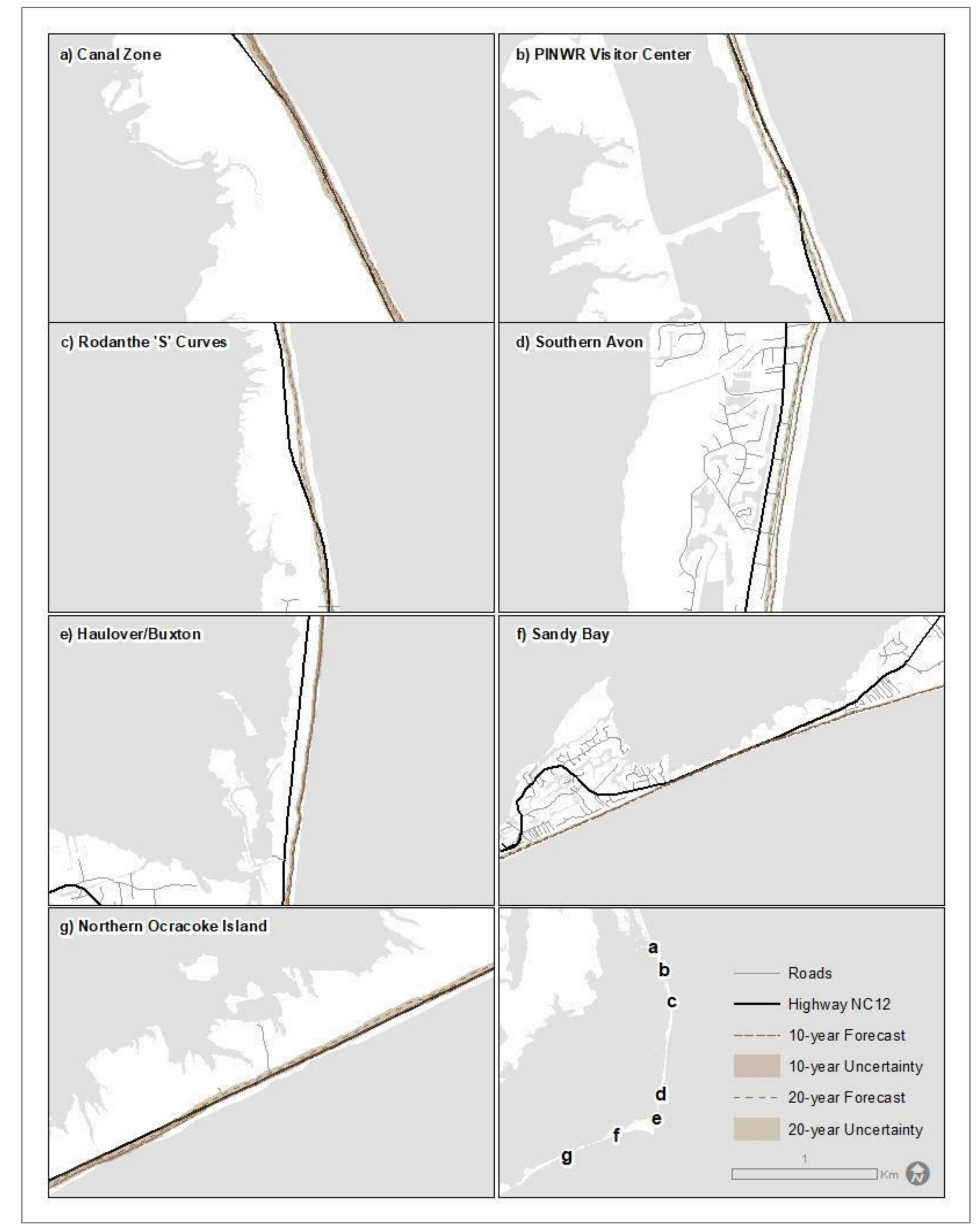

Figure 3. The 10- and 20-year shoreline position prediction with uncertainty bands based on the linear regression rates calculated from oceanfront shoreline positions along the Cape Hatteras National Seashore between 1998 - 2022 displayed at each of the seven highway N.C. 12 hotspots.

The results of the storm surge inundation analysis emphasize the need for attention to identify strategies to mitigate, adapt, or relocate assets due to their current flooding exposure. The results were evaluated for the cultural and historic structures located at the Bodie Island and Ocracoke Light Stations, and indicate that even storm surge generated from a category 1 scenario occurring at high tide poses a concerning level of flood exposure with minimal free board (< 0.5 m) and slight (0-0.5 m) to moderate (0.5-1.0 m) inundation modeled for the structures at each light station. The results display that depth of inundation increases with an increase in category as expected (Table 3).

Structure	FFE (m)	Inundation (m)				
		Category 1	Category 2	Category 3	Category 4	Category 5
Bodie Island Light Station						
BI HS Bodie Island Lighthouse	1.862	0.249	-0.754	-1.442	-1.884	-2.390
BI HS Bodie Island Light Station Oil House	1.862	0.250	-0.753	-1.441	-1.883	-2.388
BI HS Keepers Quarters (Visitor Center)	1.794	0.186	-0.814	-1.502	-1.942	-2.447
BI HS LH Store House	1.186	-0.423	-1.425	-2.109	-2.547	-3.050
BI BD LH Comfort Station	1.697	0.086	-0.918	-1.597	-2.032	-2.532
Ocracoke Light Station						
OI HS Ocracoke Lighthouse	1.962	0.667	0.144	-0.185	-0.574	-1.277
OI HS Oil House	1.329	0.033	-0.490	-0.820	-1.207	-1.911
OI HS Keepers Quarters	1.478	0.181	-0.339	-0.671	-1.068	-1.770
OI BD Quarters Generator Shed	1.498	0.203	-0.320	-0.649	-1.040	-1.743
OI HS Tool House	1.197	-0.099	-0.621	-0.952	-1.344	-2.047
OI HS Privy	0.676	-0.621	-1.143	-1.474	-1.864	-2.568

Table 3. Present vulnerability of storm surge for CAHA sites and structures. Data are presented for each feature: First Floor Elevation (FFE), and the difference between FFE and SLOSH inundation for each surge category (c1-c5) is given. Positive values indicate no flooding (white). Negative values indicate slight inundation risk (blue) indicates surge reaching 0-0.5 m above FFE; moderate inundation risk (yellow) is flooding of 0.5-1.0 m, and severe inundation risk (orange) is >1.0 m of flooding. Features listed by district denoted by two letters in the first column: Bodie Island (BI), Ocracoke Island (OI), LH = Lighthouse; HS = Historic; BD = Non-Historic Building.

Conclusion

Evaluating the accessibility of the entire Cape Hatteras National Seashore provides a baseline for coastal hazard decision making for historical and cultural resources such as the Bodie Island and Ocracoke Light Stations as well as other NPS maintained assets that support natural resource management and visitor use. Accessibility of the Seashore is fundamental to the National Park Service's mission as well as the economic prosperity and cultural heritage of the surrounding communities.