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COASTAL VULNERABILITY ASSESSMENT OF ASSATEAGUE ISLAND NATIONAL SEASHORE (ASIS) TO SEA-LEVEL RISE

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For Additional Information:
See the National Park Unit Coastal Vulnerability study at http://woodshole.er.usgs.gov/project-pages/nps-cvi/,
the National Coastal Vulnerability study at http://woodshole.er.usgs.gov/project-pages/cvi/,
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To visit Assateague Island National Seashore, go to http://www.nps.gov/asis/index.htm.

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ABSTRACT

A coastal vulnerability index (CVI) was used to map relative vulnerability of the coast to future sea-level rise within Assateague Island National Seashore (ASIS) in Maryland and Virginia. The CVI ranks the following in terms of their physical contribution to sea-level rise-related coastal change: geomorphology, regional coastal slope, rate of relative sea-level rise, shoreline change rates, mean tidal range and mean wave height. Rankings for each variable were combined and an index value calculated for 1-minute grid cells covering the park. The CVI highlights those regions where the physical effects of sea-level rise might be the greatest. This approach combines the coastal system's susceptibility to change with its natural ability to adapt to changing environmental conditions, yielding a quantitative, although relative, measure of the park's natural vulnerability to the effects of sea-level rise. The CVI provides an objective technique for evaluation and long-term planning by scientists and park managers. Assateague Island consists of stable and washover dominated portions of barrier beach backed by wetland and marsh. The areas within Assateague that are likely to be most vulnerable to sea-level rise are those with the highest occurrence of overwash and the highest rates of shoreline change.

INTRODUCTION

The National Park Service (NPS) is responsible for managing nearly 12,000 km (7,500 miles) of shoreline along oceans and lakes. In 2001, the U.S. Geological Survey (USGS), in partnership with the NPS Geologic Resources Division, began conducting hazard assessments of future sea-level change by creating maps to assist NPS in managing its valuable coastal resources. This report presents the results of a vulnerability assessment for Assateague Island National Seashore (ASIS), highlighting areas that are likely to be most affected by future sea-level rise.

Global sea level has risen approximately 18 centimeters (7.1 inches) in the past century (Douglas, 1997). Climate models predict an additional rise of 48 cm (18.9 in.) by 2100 (IPCC, 2002), which is more than double the rate of rise for the 20th century. Potential coastal impacts of sea-level rise include shoreline erosion, saltwater intrusion into groundwater aquifers, inundation of wetlands and estuaries, and threats to cultural and historic resources as well as infrastructure. Predicted accelerated global sea-level rise has generated a need in coastal geology to determine the response of a coastline to sea-level rise. However, an accurate and quantitative approach to predicting coastal change is difficult to establish. Even the kinds of data necessary to make shoreline response predictions are the subject of scientific debate. A number of predictive approaches have been proposed (National Research Council, 1990), including: 1) extrapolation of historical data (e.g., coastal erosion rates), 2) static inundation modeling, 3) application of a simple geometric model (e.g., the Bruun Rule), 4) application of a sediment dynamics/budget model, or 5) Monte Carlo (probabilistic) simulation based on parameterized physical forcing variables. However, each of these approaches has inadequacies or can be invalid for certain applications (National Research Council, 1990). Additionally, shoreline response to sea-level change is further complicated by human modification of the natural coast such as beach nourishment projects, and engineered structures such as seawalls, revetments, groins, and jetties. Understanding how a natural or modified coast will respond to sea-level change is essential to preserving vulnerable coastal resources.

The primary challenge in predicting shoreline response to sea-level rise is quantifying the important variables that contribute to coastal evolution in a given area. To address the multi-faceted task of predicting sea-level rise impact, the USGS has implemented a methodology to identify areas that may be most vulnerable to future sea-level rise (see Hammar-Klose and Thieler, 2001). This technique uses different ranges of vulnerability (low to very high) to describe a coast's susceptibility to physical change as sea level rises. The vulnerability determined here focuses on six variables which strongly influence coastal evolution:

1) Geomorphology

2) Historical shoreline change rate

3) Regional coastal slope

4) Relative sea-level change

5) Mean significant wave height

6) Mean tidal range

These variables can be divided into two groups: 1) geologic variables and 2) physical process variables. The geologic variables are geomorphology, historic shoreline change rate, and coastal slope; they account for a shoreline's relative resistance to erosion, long-term erosion/accretion trend, and its susceptibility to flooding, respectively. The physical process variables are significant wave height, tidal range, and sea-level change, all of which contribute to the inundation hazards of a particular section of coastline over time scales from hours to centuries. A relatively simple vulnerability ranking system (Table 1) allows the six variables to be incorporated into an equation that produces a coastal vulnerability index (CVI). The CVI can be used by scientists and park managers to evaluate the likelihood that physical change may occur along a shoreline as sea level continues to rise. Additionally, NPS staff will be able to incorporate information provided by this vulnerability assessment technique into general management plans.

DATA RANKING

Table 1 shows the six variables described in the Introduction and includes both quantitative and qualitative information. Actual variable values are assigned a vulnerability ranking based on value ranges, whereas the non-numerical geomorphology variable is ranked qualitatively according to the relative resistance of a given landform to erosion. Shorelines with erosion/accretion rates between -1.0 and +1.0 m/yr are ranked as moderately vulnerable. Increasingly higher erosion or accretion rates are ranked as correspondingly higher or lower vulnerability. Regional coastal slopes range from very high risk (< 0.3 percent) to very low risk (> 1.2 percent). The rate of relative sea-level change is ranked using the modern rate of eustatic rise (1.8 mm/yr) as very low vulnerability. Since this is a global or "background" rate common to all shorelines, the sea-level rise ranking reflects primarily local to regional isostatic or tectonic adjustment. Mean wave height rankings range from very low (<0.55 m) to very high (>1.25 m). Tidal range is ranked such that microtidal (<1 m) coasts are very high vulnerability and macrotidal (>6 m) coasts are very low vulnerability.

ASSATEAGUE ISLAND NATIONAL SEASHORE

Assateague Island lies along the Atlantic coast of Maryland and Virginia (Figure 1). It is an undeveloped barrier island that consists of large stretches of dunes interrupted by low-lying areas that overwash during storms. Assateague Island is separated from Fenwick Island in Maryland by Ocean City Inlet, and is separated from Wallops Island and Chincoteague Island in Virginia by Chincoteague inlet.

The formation of Ocean City inlet during a hurricane in 1933 had a significant impact on the evolution of northern Assateague Island. Following the formation of Ocean City Inlet, the Army Corps of Engineers (USACE) built jetties to stabilize the inlet. Assateague Island began to experience accelerated rates of shoreline retreat as the jetties interrupted the longshore transport of sediment from north to south. In the 70 years since the opening of Ocean City Inlet, Assateague Island has retreated landward nearly 1 km. In an effort to mitigate this structure-induced shoreline change and habitat loss, NPS, the USACE, and the Minerals Management Service have implemented a restoration plan. The restoration plan will involve the placement of sand on Assateague beaches from an offshore borrow site.

METHODOLOGY

In order to develop a database for a park-wide assessment of coastal vulnerability, data for each of the six variables mentioned above were gathered from state and federal agencies (Table 2). The database is based on that used by Thieler and Hammar-Klose (1999) and loosely follows an earlier database developed by Gornitz and White (1992). A comparable assessment of the sensitivity of the Canadian coast to sea-level rise is presented by Shaw and others (1998).

The database was constructed using a 1:70,000 shoreline for Assateague Island that was produced from the medium resolution digital vector U.S. shoreline provided by the Strategic Environmental Assessments (SEA) Division of NOAA's Office of Ocean

Resources Conservation and Assessment (http://spo.nos.noaa.gov/projects/shoreline/shoreline.html). Data for each of the six variables (geomorphology, shoreline change, coastal slope, relative sea-level rise, significant wave height, and tidal range) were added to the shoreline attribute table using a 1-minute (approximately 1.5 km) grid (Figure 2). Data were then assigned a relative vulnerability value from 1-5 (1 is very low vulnerability; 5 is very high vulnerability) based on the potential magnitude of its contribution to physical changes on the coast as sea level rises (Table 1).

GEOLOGIC VARIABLES

The **geomorphology** variable expresses the relative erodibility of different landform types (Table 1). These data were derived from 1-meter resolution digital orthophotos of Assateague Island (Table 2). In addition, field visits were made within the park to ground-truth the geomorphologic classification. The geomorphology of Assateague Island varies from high vulnerability stable barrier island with dunes to very high vulnerability washover-dominated barrier shoreline (Figures 3 A-D).

Shoreline erosion and accretion rates for Assateague were calculated from existing shoreline data provided by USGS in Virginia and the Maryland Geological Survey in Maryland (Table 2). Shoreline rates of change (m/yr) were calculated at 20 m intervals (transects) along the coast using Digital Shoreline Analysis System (DSAS) software (http://woodshole.er.usgs.gov/project-pages/dsas/) to derive the rate of shoreline change over time. The rates for each transect within a 1-minute grid cell were averaged to determine the shoreline change value used here, with positive numbers indication accretion and negative numbers indicating erosion. Shoreline change rates on Assateague Island range from greater than 2 m/yr of accretion (very low vulnerability) to greater than 2 m/yr of erosion (very high vulnerability) (Figure 4 A-C).

The determination of **regional coastal slope** identifies the relative vulnerability of inundation and the potential rapidity of shoreline retreat because low-sloping coastal regions should retreat faster than steeper regions (Pilkey and Davis, 1987). The regional slope of the coastal zone was calculated from a grid of topographic and bathymetric elevations extending landward and seaward of the shoreline. Elevation data were obtained from the National Geophysical Data Center (NGDC) as gridded topographic and bathymetric elevations at 0.1 meter vertical resolution for 3 arc-second (~90 m) grid cells. These data were resampled to 1-minute resolution (Figure 2). Regional coastal slopes for Assateague Island fall within the high vulnerability category.

PHYSICAL PROCESS VARIABLES

The **relative sea-level change** variable is derived from the increase or decrease in annual mean water elevation over time as measured at tide gauge stations along the coast. The rate of sea-level rise in Lewes in DE is 3.16 +/- 0.16 mm/yr and 3.59 +/- 0.27 mm/yr in Kiptopeke, VA, based on 81 and 49 years of data, respectively (Zervas, 2001). This variable inherently includes both eustatic sea-level rise as well as regional sea-level rise due to isostatic and tectonic adjustments of the land surface. Relative sea-level change data are a historical record, and thus only portray the recent sea-level trend (<150 years). Relative sea-level rise for Assateague Island falls within high vulnerability based on extrapolation from water elevation data at Lewes, DE and Kiptopeke, VA.

Mean significant wave height is used here as a proxy for wave energy which drives the coastal sediment budget. Wave energy is directly related to the square of wave height:

$$E = 1/8\ \rho g H^2$$

where E is energy density, H is wave height, ρ is water density and g is acceleration due to gravity. Thus, the ability to mobilize and transport coastal sediments is a function of wave height squared. In this report, we use hindcast nearshore mean significant wave height data for the period 1976-95 obtained from the USACE Wave Information Study (WIS) (see references in Hubertz and others, 1996). The model wave heights were compared to historical measured wave height data obtained from the NOAA National Data Buoy Center to ensure that model values were representative of the study area. For Assateague Island, mean significant wave heights are between 1.2 and 1.3 m, which represents high and very high vulnerability, respectively.

Tidal range is linked to both permanent and episodic inundation hazards. Tide range data were obtained from NOAA/NOS for an ocean tide gauge at the Ocean City Inlet fishing pier. All of Assateague Island is classified as high vulnerability (1-2 m) with respect to tidal range.

COASTAL VULNERABILITY INDEX

The CVI presented here is the same as that used in Thieler and Hammar-Klose (1999) and is similar to that used in Gornitz and others (1994), as well as to the sensitivity index employed by Shaw and others (1998). The CVI allows the six variables to be related in a quantifiable manner that expresses the relative vulnerability of the coast to physical changes due to future sea-level rise. This method yields numerical data that cannot be equated directly with particular physical effects. It does, however, highlight areas where the various effects of sea-level rise may be the greatest. Once each section of coastline is assigned a vulnerability value for each specific data variable, the CVI is calculated as the square root of the product of the ranked variables divided by the total number of variables;

$$\mathrm{CVI} = \sqrt{\frac{(a*b*c*d*e*f)}{6}}$$

where, a = geomorphology, b = shoreline erosion/accretion rate, c = coastal slope, d =relative sea-level rise rate, e = mean wave height, and f = mean tide range. Calculated CVI values are divided into quartile ranges to highlight different vulnerabilities within the park. The CVI ranges (low – very high) reported here apply specifically to Assateague Island National Seashore, and are not comparable to CVI ranges in other parks where the CVI has been employed (i.e. very high vulnerability along ASIS does not mean the same thing as very high vulnerability along the Olympic National Park coast). To compare vulnerability between coastal parks, the national-scale studies should be used (Thieler and Hammar-Klose, 1999, 2000a, and 2000b). We feel this approach best describes and highlights the vulnerability specific to each park.

RESULTS

The calculated CVI values for Assateague Island range from 14.61 to 32.66. The mean CVI value is 24.9; the mode and the median are 25.3. The standard deviation is 4.91. The 25th, 50th, and 75th percentiles are 20.5, 25.5 and 29.0, respectively.

Figure 5 shows a map of the CVI divided into ranges (low – very high) for Assateague Island National Seashore. CVI values were divided into low, moderate, high, and very high-vulnerability categories based on the quartile ranges and visual inspection of the data. CVI values below 20.5 are assigned to the low vulnerability category. Values from 20.5 to 25.5 are considered moderate vulnerability. High-vulnerability values lie between 25.6 and 29.0. CVI values above 29.0 are classified as very high vulnerability. Figure 6 shows a histogram of the percentage of ASIS shoreline in each vulnerability category. Nearly 60 km (37 miles) of shoreline is evaluated along the national seashore. Of this total, 30 percent of the mapped shoreline is classified as being at very high vulnerability due to future sea-level rise. Thirty percent is classified as high vulnerability, twenty-one percent as moderate vulnerability, and eighteen percent as low vulnerability.

DISCUSSION

The data within the coastal vulnerability index (CVI) show variability at different spatial scales (Figure 5). However, the ranked values for the physical process variables vary little over the extent of the shoreline. The value of the relative sea-level rise variable is constant at high vulnerability for the entire study area. The significant wave height vulnerability is very high to high, and the tidal range is high vulnerability.

The geologic variables show the most variability and thus have the most influence on the CVI value (Figure 5). Geomorphology in the park includes high vulnerability barrier island shoreline with dune ridges separated by very high vulnerability washover-dominated low areas. Vulnerability assessment based on historical shoreline change trends varies from very low to very high (Figure 4 A-C). Regional coastal slope is in the high vulnerability range for the extent of Assateague Island.

The most influential variables in the CVI are geomorphology, shoreline change, and significant wave height; therefore they may be considered the dominant factors controlling how Assateague Island will evolve as sea level rises. Geomorphology and significant wave height only vary between high and very high vulnerability, whereas shoreline change ranges from very low to very high.

Because of the importance of habitat and the dynamic nature of Assateague, concern about erosion, storm surge breaching of the barriers, future sea level rise, and mainland flooding, planning is underway by Federal and State agencies to address these issues. Alternatives such as large-scale nourishment of the beach and dunes along Assateague Island are being considered. Implementation of beach nourishment could alter the CVI results presented here.

CONCLUSIONS

The coastal vulnerability index (CVI) provides insight into the relative potential of coastal change due to future sea-level rise. The maps and data presented here can be viewed in at least two ways:

1) as an example of where physical changes are most likely to occur as sea-level rises; and

2) as a planning tool for the Assateague Island National Seashore.

As ranked in this study, geomorphology, shoreline change, and significant wave height are the most important variables in determining the CVI for Assateague Island. Wave height, tide range, coastal slope, and sea-level rise do not contribute to the spatial variability in the coastal vulnerability index.

Assateague preserves a dynamic natural environment, which must be understood in order to be managed properly. The CVI is one way that a park can assess objectively the natural factors that contribute to the evolution of the coastal zone, and thus how the park may evolve in the future.

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Figure 1. Location of Assateague Island National Seashore in Maryland and Virginia.

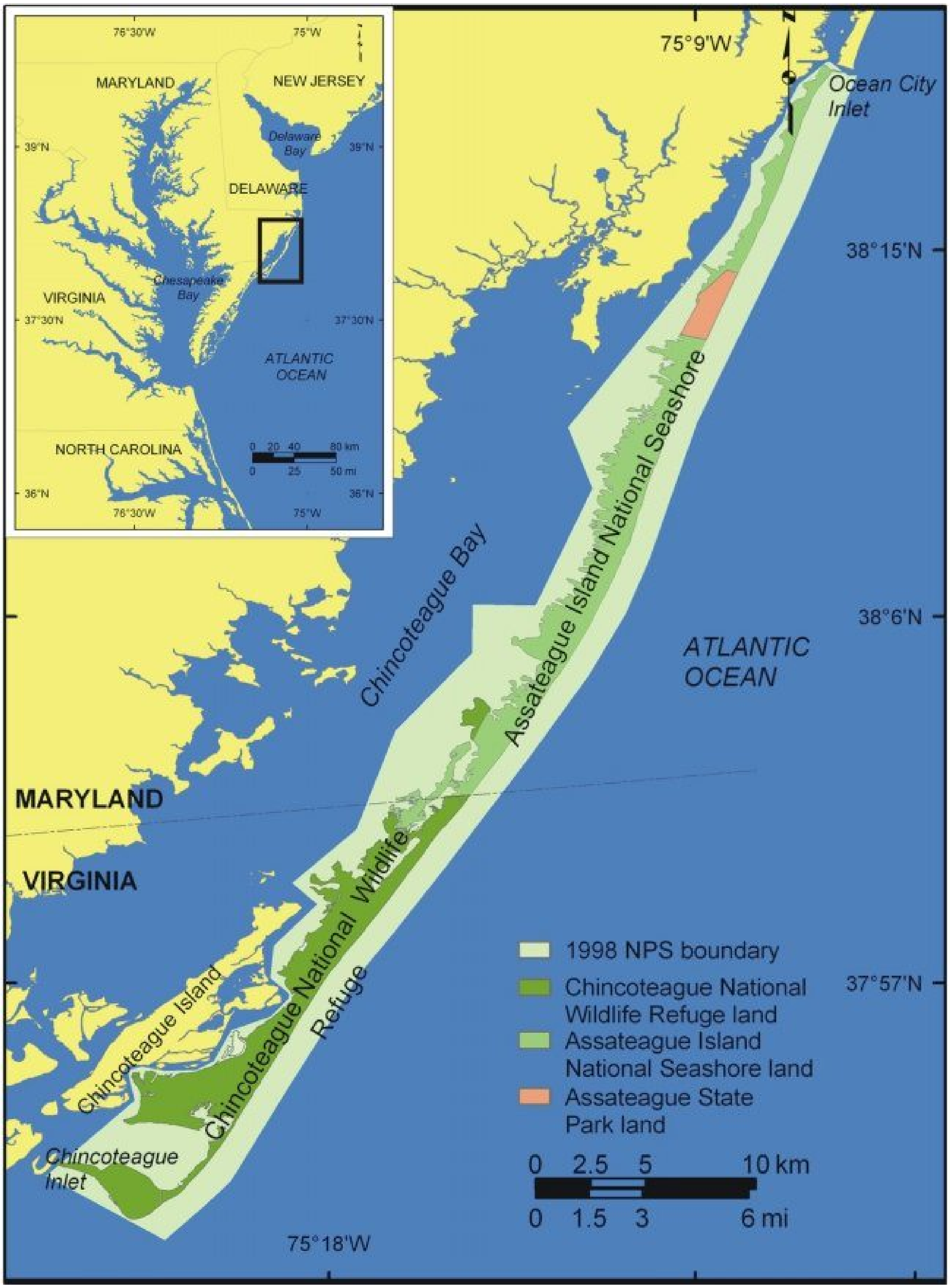

Figure 2. Shoreline grid for Assateague Island National Seashore.

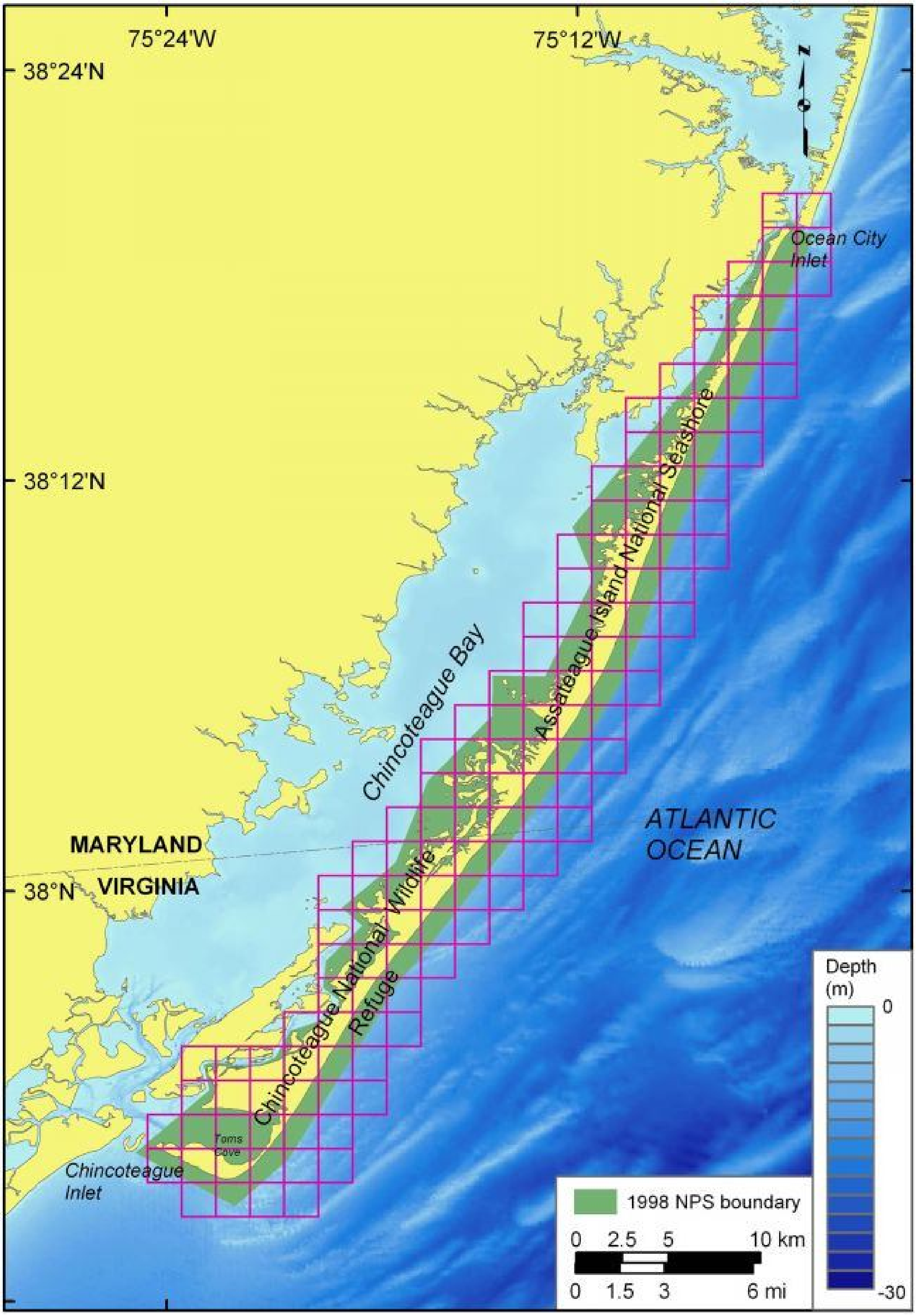

Figure 3. A) Northern Assateague Island showing an area that is low and overwashed (5 - very high vulnerability). B, C, and D) show dunes along Assateague Island. Areas with a mature dune ridge were categorized as 4 - high vulnerability (photos courtesy of Rebecca Beavers and Melanie Ransmeier).

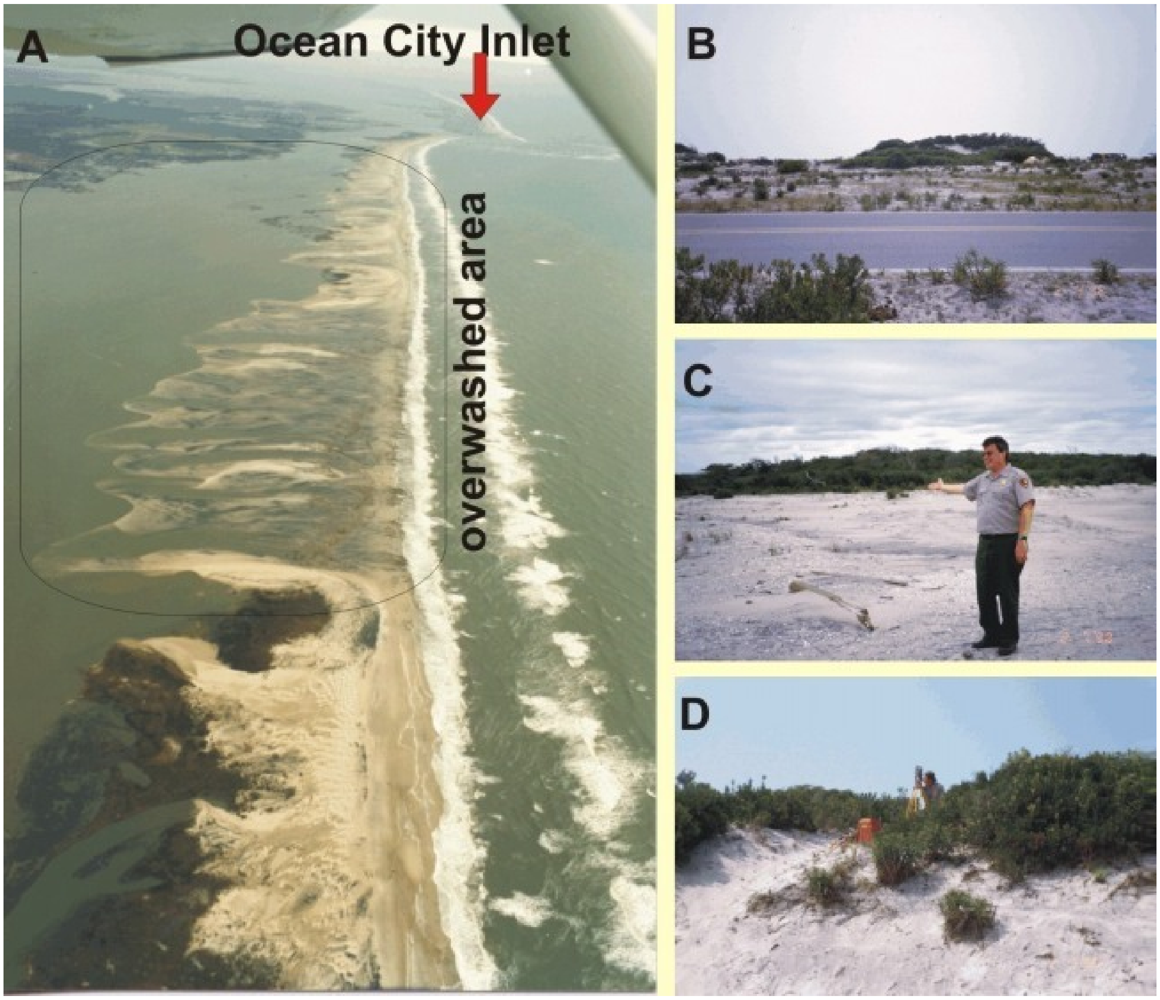

Figure 4. Historic Shoreline positions for A) northern, B) south-central, C) and southern Assateague Island.

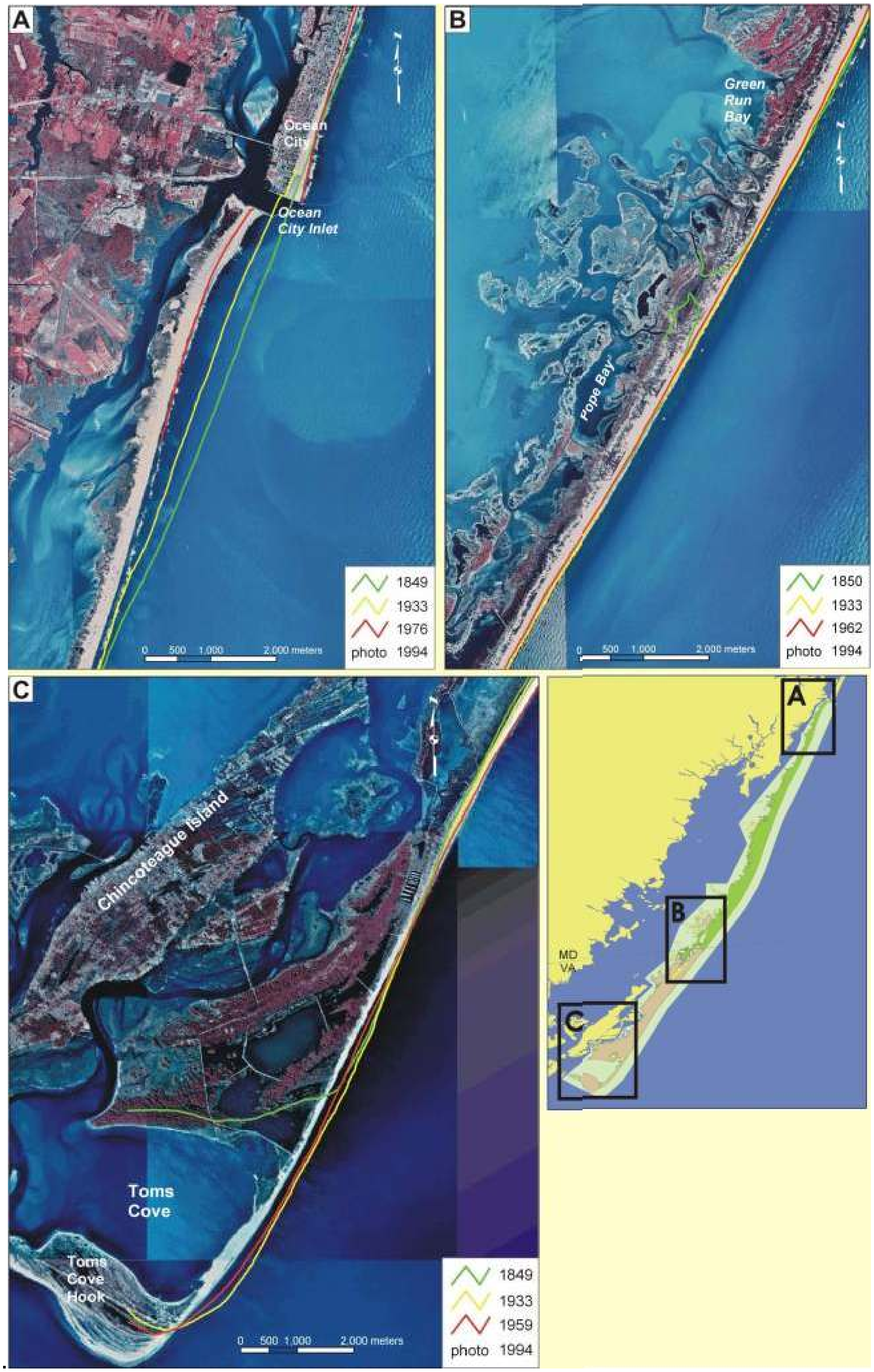

Figure 5. Relative Coastal Vulnerability for Assateague Island National Seashore. The innermost color bar is the relative coastal vulnerability index (CVI). The remaining color bars are separated into the geologic variables (1-3) and physical process variables (4 - 6). The very high vulnerability shoreline is located in low overwashed areas where rates of shoreline erosion are highest. The low vulnerability shoreline is located at the southernmost end of Assateague in Virginia near Chincoteague Inlet where shoreline accretion rates are high.

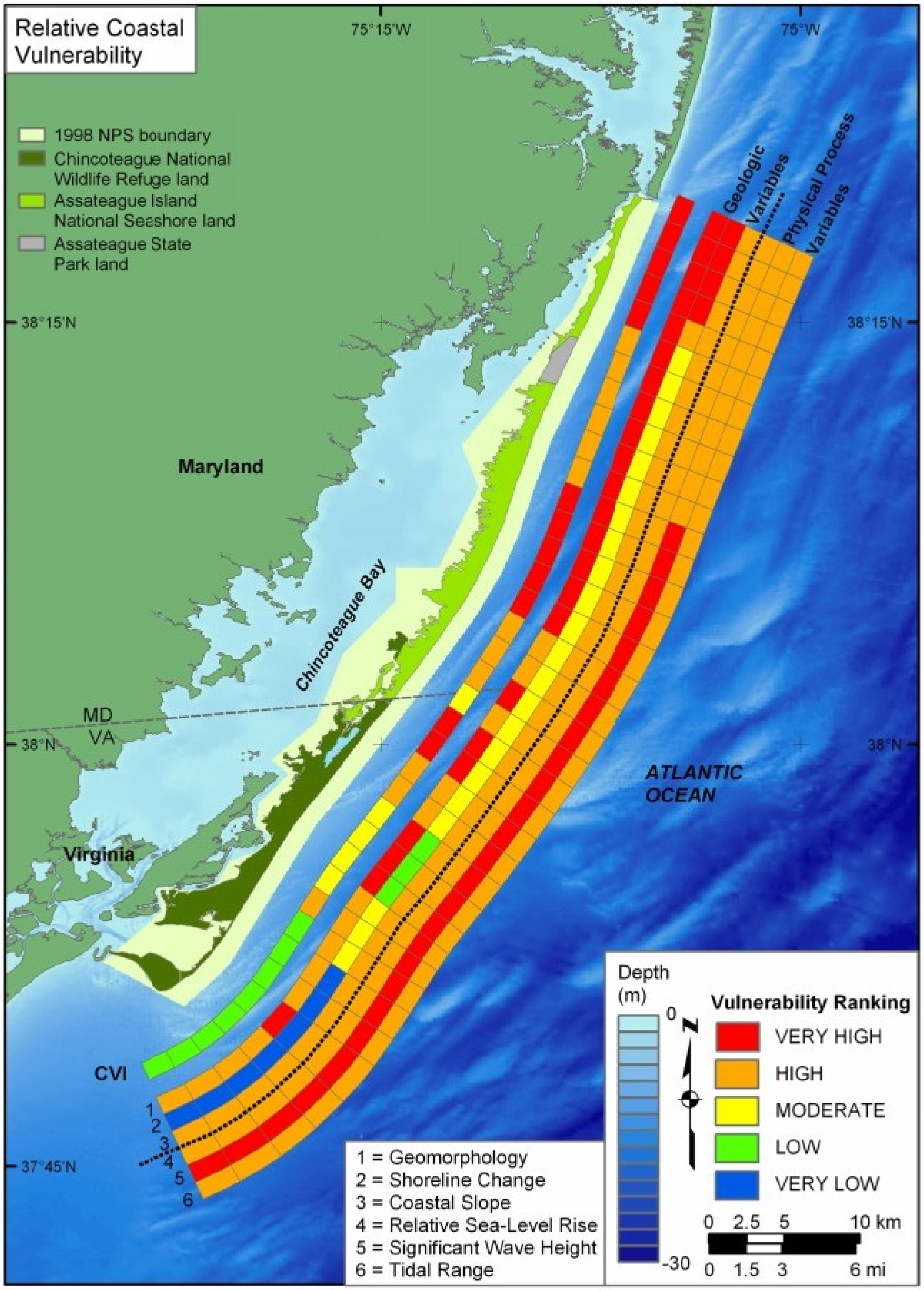

Figure 6. Percentage of ASIS shoreline in each CVI vulnerability category.

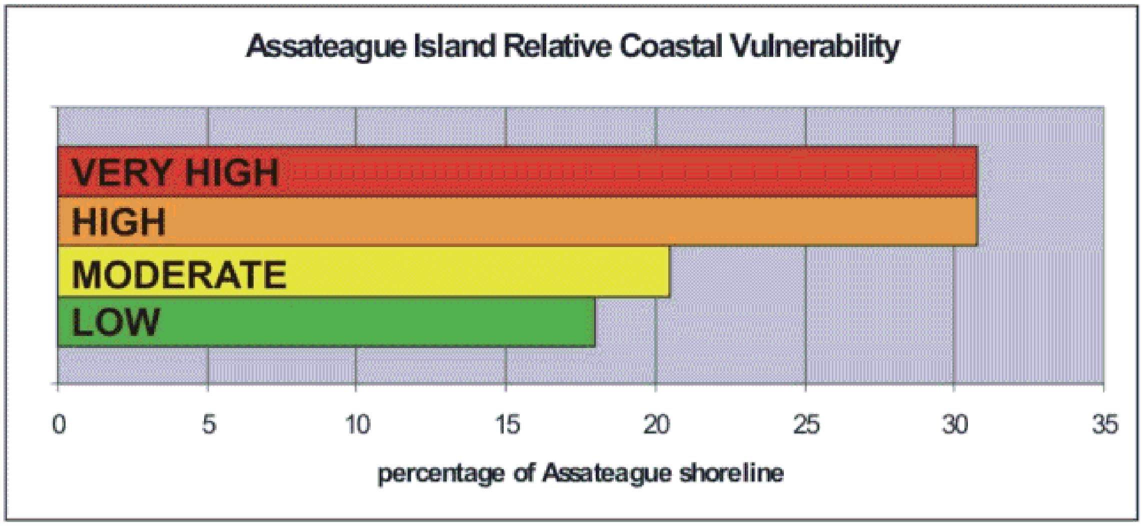

Table 1: Ranges for Vulnerability Ranking of Variables on the Atlantic Coast.

Variables	Very Low 1	Low 2	Moderate 3	High 4	Very High 5
GEOMORPHOLOGY	Rocky cliffed coasts, Fjords	Medium cliffs, Indented coasts	Low cliffs, Glacial drift, Alluvial plains	Cobble Beaches, Estuary, Lagoon	Barrier beaches, Sand beaches, Salt marsh, Mud flats, Deltas, Mangrove, Coral reefs
SHORELINE EROSION/ACCRETION (m/yr)	> 2.0	1.0 - 2.0	-1.0 - 1.0	-2.0 - -1.0	< -2.0
COASTAL SLOPE (%)	> 1.20	1.20 - 0.90	0.90 - 0.60	0.60 - 0.30	< 0.30
RELATIVE SEA-LEVEL CHANGE (mm/yr)	< 1.8	1.8 - 2.5	2.5 - 3.0	3.0 - 3.4	> 3.4
MEAN WAVE HEIGHT (m)	< 0.55	0.55 - 0.85	0.85 - 1.05	1.05 - 1.25	> 1.25
MEAN TIDE RANGE (m)	> 6.0	4.0 - 6.0	2.0 - 4.0	1.0 - 2.0	< 1.0

Table 2: Sources for Variable Data

Variables	Source	URL
GEOMORPHOLOGY	Orthophotos from the Maryland Department of Natural Resources and the GIS Center at Radford University	http://dnrweb.dnr.state.md.us/gis/data/data.asp http://www.radford.edu/~geoserve/doqq/doqq_va_1_01.htm
SHORELINE EROSION/ACCRETION (m/yr)	Historical Shorelines for Maryland coast (1843 -1989) from the Maryland Geological Survey. Virginia coast shoreline data (1849-1994) from the US Geological Survey	http://www.mgs.md.gov/ http://coastal.er.usgs.gov/national_assessment/
COASTAL SLOPE (%)	NGDC Coastal Relief Model Vol 02	http://www.ngdc.noaa.gov/mgg/coastal/coastal.html
RELATIVE SEA-LEVEL CHANGE (mm/yr)	NOAA Technical Report NOS CO-OPS 36 SEA LEVEL VARIATIONS OF THE UNITED STATES 1854-1999 (Zervas, 2001)	http://www.co-ops.nos.noaa.gov/publications/techrpt36doc.pdf
MEAN WAVE HEIGHT (m)	North Atlantic Region WIS Data (Phase II) and NOAA National Data Buoy Center	http://bigfoot.wes.army.mil/ http://www.nbdc.noaa.gov/
MEAN TIDE RANGE (m)	NOAA/NOS CO-OPS Historical Water Level Station Index	http://www.co-ops.nos.noaa.gov/usmap.html