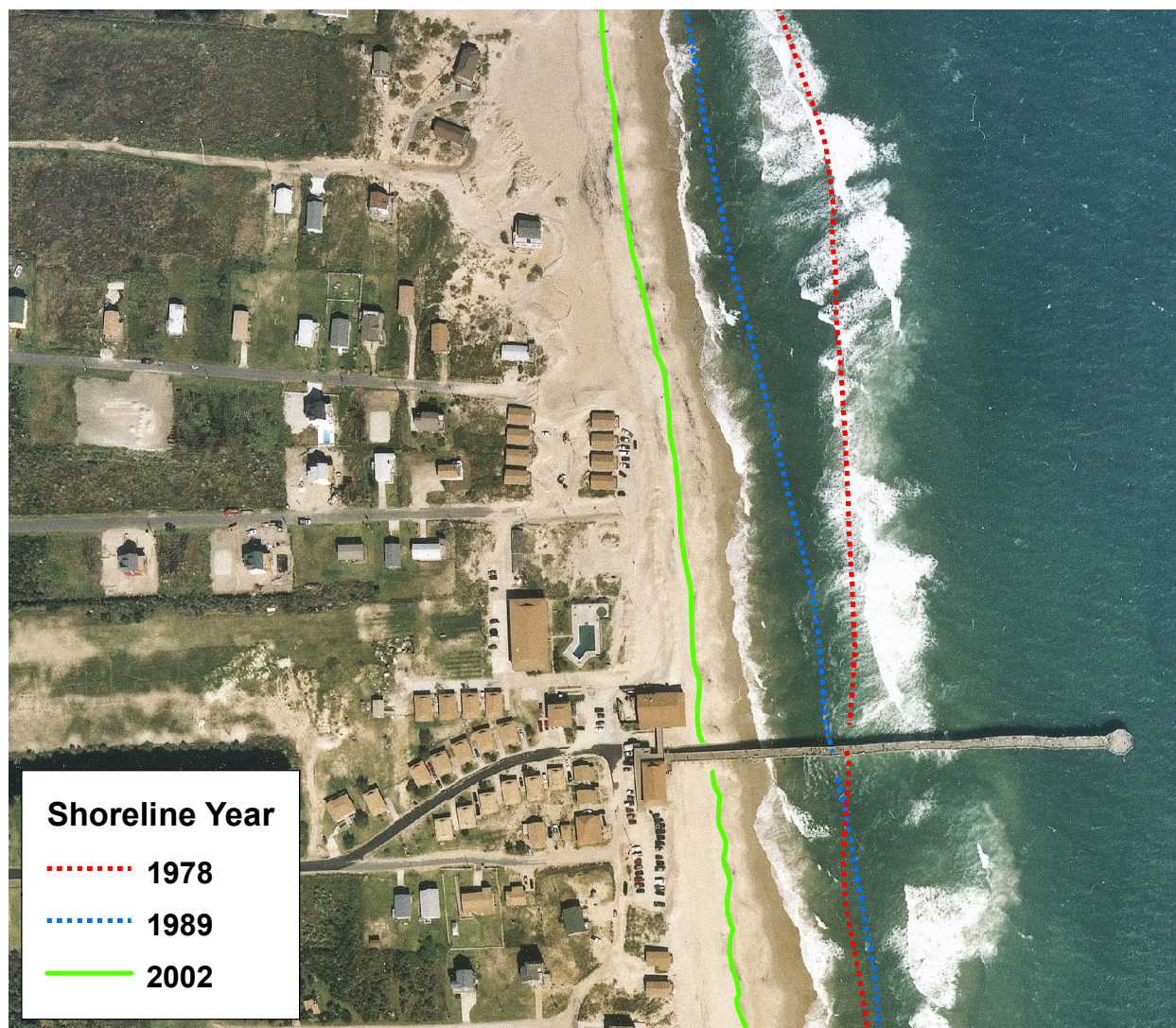![USGS logo] **USGS**
science for a changing world

Quantification of Shoreline Change Along Hatteras Island, North Carolina—Oregon Inlet to Cape Hatteras, 1978–2002, and Associated Vector Shoreline Data

By Cheryl J. Hapke and Rachel E. Henderson

Shoreline Year

··········	**1978**
··········	**1989**
————	**2002**

Open-File Report 2015–1002

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

ii

Acknowledgments

Contents

Figures

Tables

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
Length		
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
Flow rate		
meter per year (m/yr)	3.281	foot per year (ft/yr)

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Quantification of Shoreline Change Along Hatteras Island, North Carolina—Oregon Inlet to Cape Hatteras, 1978–2002, and Associated Vector Shoreline Data

By Cheryl J. Hapke and Rachel E. Henderson

Abstract

Shoreline change spanning twenty-four years was assessed along the coastline of Cape Hatteras National Seashore, at Hatteras Island, North Carolina. The shorelines used in the analysis were generated from georeferenced historical aerial imagery and are used to develop shoreline change rates for Hatteras Island, from Oregon Inlet to Cape Hatteras. A total of 14 dates of aerial photographs ranging from 1978 through 2002 were obtained from the U.S. Army Corp of Engineers Field Research Facility in Duck, North Carolina, and scanned to generate digital imagery. The digital imagery was georeferenced and high water line shorelines (interpreted from the wet/dry line) were digitized from each date to produce a time series of shorelines for the study area. Rates of shoreline change were calculated for three periods: the full span of the time series, 1978 through 2002, and two approximately decadal subsets, 1978–89 and 1989–2002.

Introduction

There are numerous studies of shoreline change in the Cape Hatteras, North Carolina, region (fig. 1) including those of Everts and others (1983), Dolan and others (1991), Fenster and Dolan (1993), and the North Carolina Division of Coastal Management (2004). This report presents a new dataset that provides a temporally robust collection of historical shorelines for this part of the North Carolina coast. Many earlier shoreline compilations and assessments for this area consist of shoreline datasets that combine various shoreline proxies and sources including maps, photos, field data, and lidar. This report uses a single method (high water line [HWL] interpretation from imagery) to derive the shorelines. Shoreline change rates quantified from 1978 to 2002 provide a baseline to compare with more recent shoreline change observations and to provide data for models developed to predict change to coastal hazards including storms and sea-level rise.

The U.S. Geological Survey (USGS) National Assessment of Coastal Change Hazards (NACCH) project focuses on quantifying coastal change hazards along open-ocean coasts in the United States and its territories. Two of the primary tasks of the project are to quantify long-term (years to centuries) coastal change using a consistent and systematic approach on a national scale, and to examine the drivers of change on a variety of temporal and spatial scales. In regions of interest and in support of other USGS research investigations, more focused analyses of long-term change are also conducted. In North Carolina, the USGS, in collaboration with the U.S. Army Corp of Engineers (USACE), the State of North Carolina, and a number of academic institutions, has engaged in various research projects along the North Carolina coast with an overall goal of increasing the understanding of this dynamic and complex coastal resource. Efforts include the following: mapping the regional sedimentary framework of the northern North Carolina coast to better understand coastal processes, erosion, and shoreline change (*North Carolina Regional Coastal Erosion Study*); improving the capabilities of coastal change
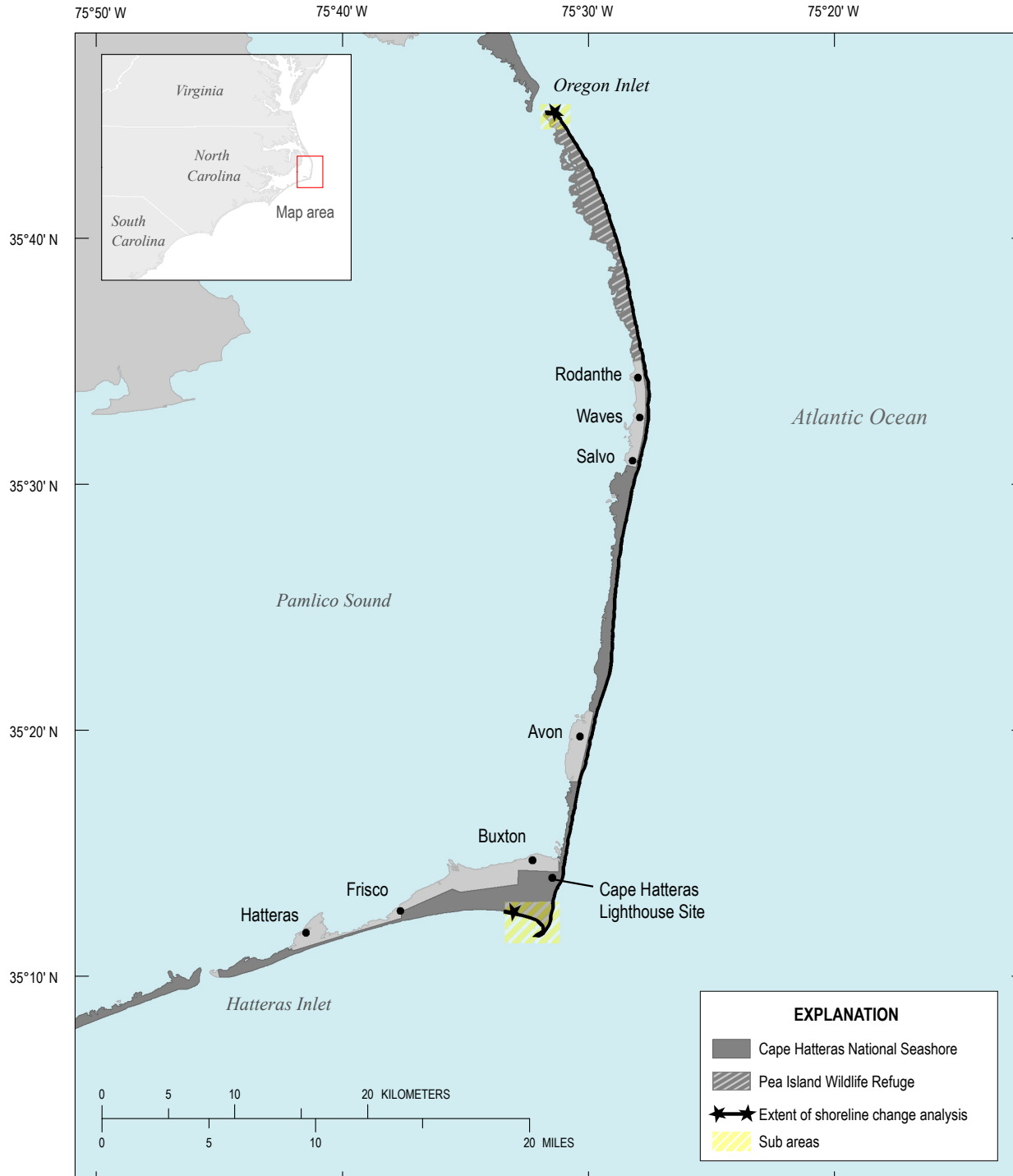
Figure 1. Map of study area. Approximate locations of Cape Hatteras National Seashore and Pea Island Wildlife Refuge digitized from the NPS Cape Hatteras National Seashore map.

models to predict large-scale shoreline change on open-ocean sandy coasts using high-resolution observations of geological framework and shoreline change (*North Carolina Coastal Change*); and investigating the interactions among shoreline, nearshore, and offshore sediment-transport processes driving coastal change in the Carolinas (*Carolina Coastal Change Process*).

Data and Methods

Historical aerial photographic film or contact prints, if film was not available, were acquired from the USACE air photo library located at the Field Research Facility in Duck, N.C., not shown on map (table 1). The photographs were scanned at approximately 1,200 dots per inch using a Zeiss/Intergraph PS 2000 photogrammetric scanner.

Georeferencing of Aerial Imagery

The historical digital imagery was georeferenced to 2007 North Carolina State orthophotography (1:4,800, 1-ft pixel, color, North American Datum 1983 (NAD83), North Carolina [feet U.S.]) using Earth Resources Data Analysis System (ERDAS) Imagine [v. 9.3]. Eight to 10 control points were established for each image by visually identifying coincident points between the historical imagery and the 2007 orthophotography. Additional points were added as necessary to achieve acceptable root mean square (RMS) error (less than 1 meter [m]). The images were georeferenced using a second-order polynomial transformation with a nearest-neighbor resample method, and quality assessments were conducted. The average RMS value for each year is reported as the georeferencing uncertainty for that dataset (table 1).

Shorelines

Shorelines were digitized from the georeferenced aerial images in Esri ArcMap (v. 9.3) using the wet/dry line as a high water line (HWL) shoreline proxy (fig. 2). The HWL is defined as the line of wetted sand that is most often present seaward of the berm crest indicating the landward limit of the last high-tide swash incursion.

The HWL is the intersection of a water level on the beach, and because of this, variations in either the morphology of the beach or the water level can result in substantial horizontal displacements of the HWL shoreline. Errors associated with the displacement of the HWL because of wave, tide, or wind effects can amount to tens of meters (Thieler and Danforth, 1994; Pajak and Leatherman, 2002). To minimize errors associated with the use of the HWL as a shoreline indicator, meteorological data (waves, tides, and wind) were gathered on the date and time of the aerial photography; post-storm photography was avoided and a bias uncertainty was applied to account for expected variations in HWL position.

Shorelines were quality-assessed and edited to remove any overlap between adjacent shorelines. No edge matching between adjacent shorelines was attempted. Shorelines from all years were merged to produce a single shoreline file for the region while maintaining the identity, date, and uncertainty information of each shoreline. The merged shoreline file was projected from NAD 83, State Plane North Carolina, feet to NAD 83, Universal Transverse Mercator (UTM) zone 18N.

The positional errors for shorelines used in this study are determined following the methodology of Morton and Miller (2005), Hapke and others (2006), and Hapke and others (2011). The terms included are those associated with the georeferencing process (pixel size, georeferencing RMS and control-point uncertainty) and digitizing error. The digitizing error is the maximum considered in past studies (Anders and Byrnes, 1991; Crowell and others, 1991; Moore, 2000). The shoreline position uncertainty is estimated using a square root of the sum of the squares of the terms (table 2). The addition of a term for HWL uncertainty was included to cover unknown meteorological effects on the position of the HWL shoreline on the beach. Shoreline position uncertainty is added to the attribute table of each shoreline file, for use with shoreline change uncertainty calculations.
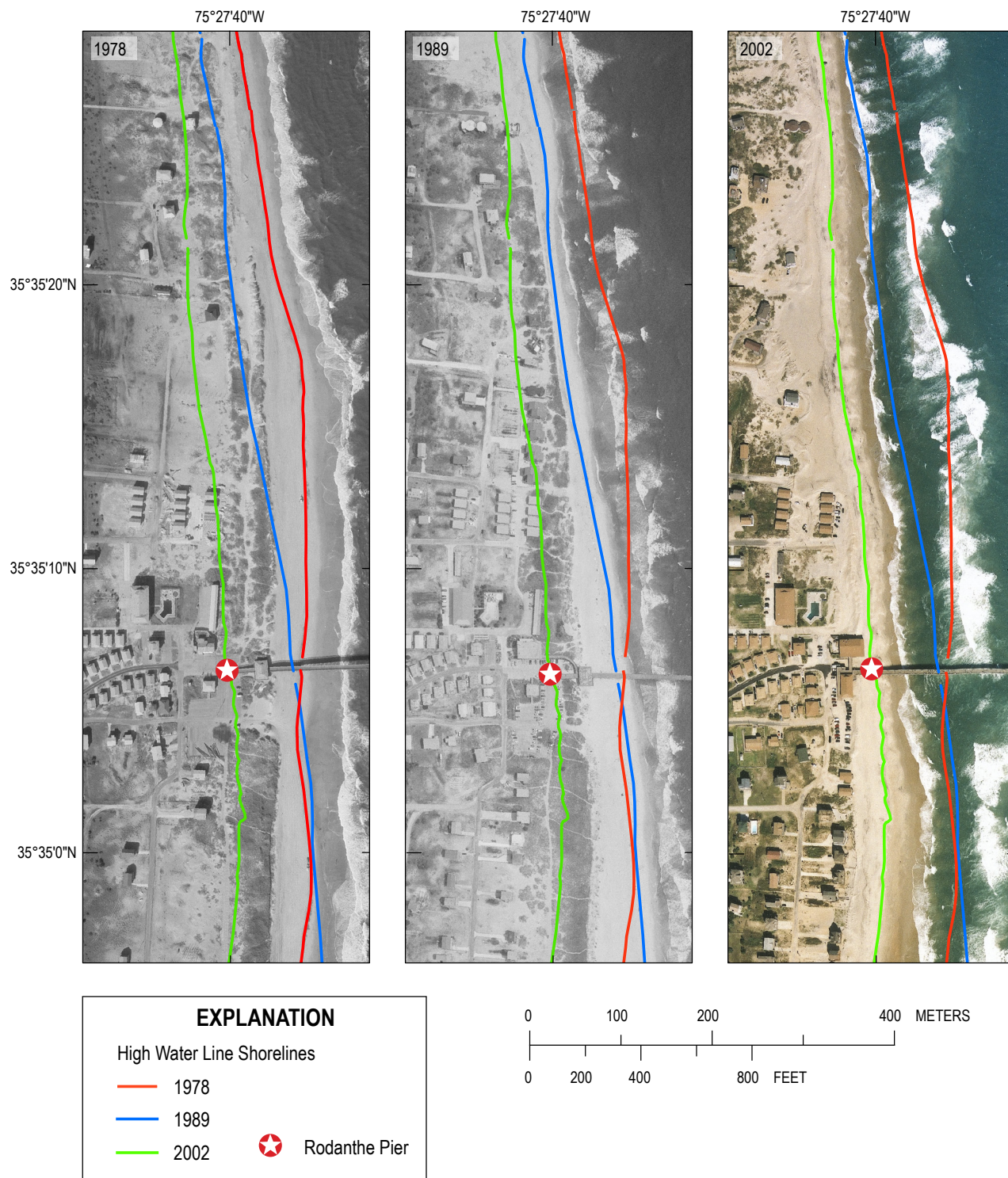
Figure 2. Example of high water line (HWL) shorelines and imagery for 3 of the 14 dates included in the shoreline database and the shoreline change analysis. The area shown in the imagery is the village of Rodanthe, North Carolina.

Calculation of Shoreline Change Rates

Rates of shoreline change were generated in ArcMap (v. 9.3) using the Digital Shoreline Analysis System (DSAS; v. 4.2), which is a freely available ArcGIS tool developed by the USGS (Thieler and others, 2009). Baselines were manually drawn seaward of, and parallel to, the general trend of the shorelines. DSAS was used to generate transect lines orthogonal to the baselines at 50-m intervals and extending to intersect all the shorelines. Measurements made from the intersection of the transect lines and the shorelines are used to calculate shoreline change rates using a variety of statistical approaches.

For this report, long-term rates of shoreline change were calculated at each transect using a linear regression applied to all shoreline positions from the earliest (1978) to the most recent (2002). Linear-regression rates of change were also determined for two subsets of the time series, 1978–89 and 1989–2002. In all, 14 shorelines/dates were used to compute the rate of change (table 1). Linear-regression fitting is the most commonly applied statistical technique for expressing shoreline movement and estimating rates of change (Crowell and Leatherman, 1999).

Table 1. Dates and details of aerial imagery.

[m, meters; RMS, root mean square; B&W, black and white; imagery acquired from U.S. Army Corps of Engineers air photo library located at the Field Research Facility in Duck, NC]

Year	Date	Media	Scale	Pixel size (m)	Georeferenced RMS (m)	Base map uncertainty (m)
1978	02 Dec	Film–B&W	1:12,000	0.29	0.005	1.2
1979	20 Sep	Film–B&W	1:12,000	0.29	0.006	1.2
1984	07, 19 Sep	Film–B&W	1:12,000	0.29	0.008	1.2
1985	23 Aug	Film–B&W	1:12,000	0.29	0.004	1.2
1987	10 Jul	Film–B&W	1:12,000	0.28	0.004	1.2
1989	30 Jul	Film–B&W	1:12,000	0.28	0.007	1.2
1991	19 Oct	Film–B&W	1:12,000	0.29	0.003	1.2
1992	02 Oct	Film–B&W	1:12,000	0.29	0.004	1.2
1993	02 Sep	Film–B&W	1:12,000	0.29	0.004	1.2
1995	18 Oct	Film–B&W	1:12,000	0.24	0.005	1.2
1996	14 Oct	Print–B&W	1:12,000	0.30	0.002	1.2
1997	12 Oct	Film–Color	1:12,000	0.29	0.004	1.2
1998	02 Oct	Print–Color	1:12,000	0.30	0.002	1.2
2002	18 Oct	Print–Color	1:12,000	0.30	0.002	1.2
			Average	**0.30**	**0.004**	**1.2**

Shoreline Change Uncertainty

The uncertainty associated with rates of shoreline change determined at each individual transect is a function of the total uncertainty of the shoreline positions used in the regression calculation at that location. Along with linear-regression rates (LRRs), DSAS automatically generates user-defined

confidence intervals for each transect. The confidence interval was calculated by multiplying the standard deviation of the slope by the two-tailed test statistic at the 95 confidence percentage (Thieler and others, 2009; Zar, 1999). This uncertainty is shown as the shaded area around the shoreline change curves of figures 3–5.

Figure 3. Shoreline change rates for 1978–2002. Rates of change are linear regression with the 95-percent confidence interval highlighted. Changes at Oregon Inlet and Cape Hatteras Point (boxed area on map) are not presented in this figure. Average shoreline change rates for these sections are presented in table 3.
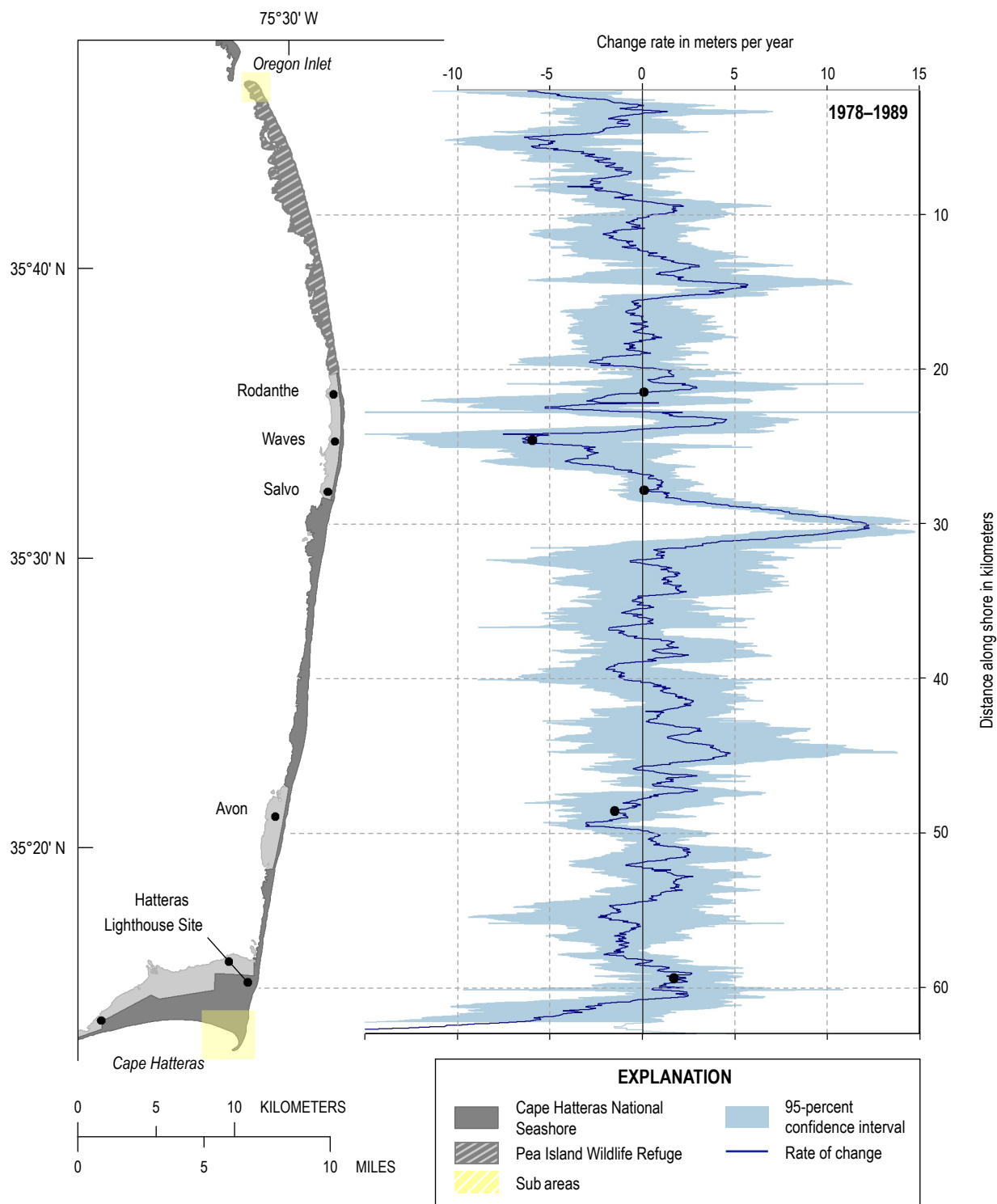
Figure 4. Shoreline change rates for 1978–89. Rates of change are linear regression with the 95-percent confidence interval highlighted. Changes at Oregon Inlet and Cape Hatteras Point (boxed area on map) are not presented in this figure. Average shoreline change rates for these sections are presented in table 4.
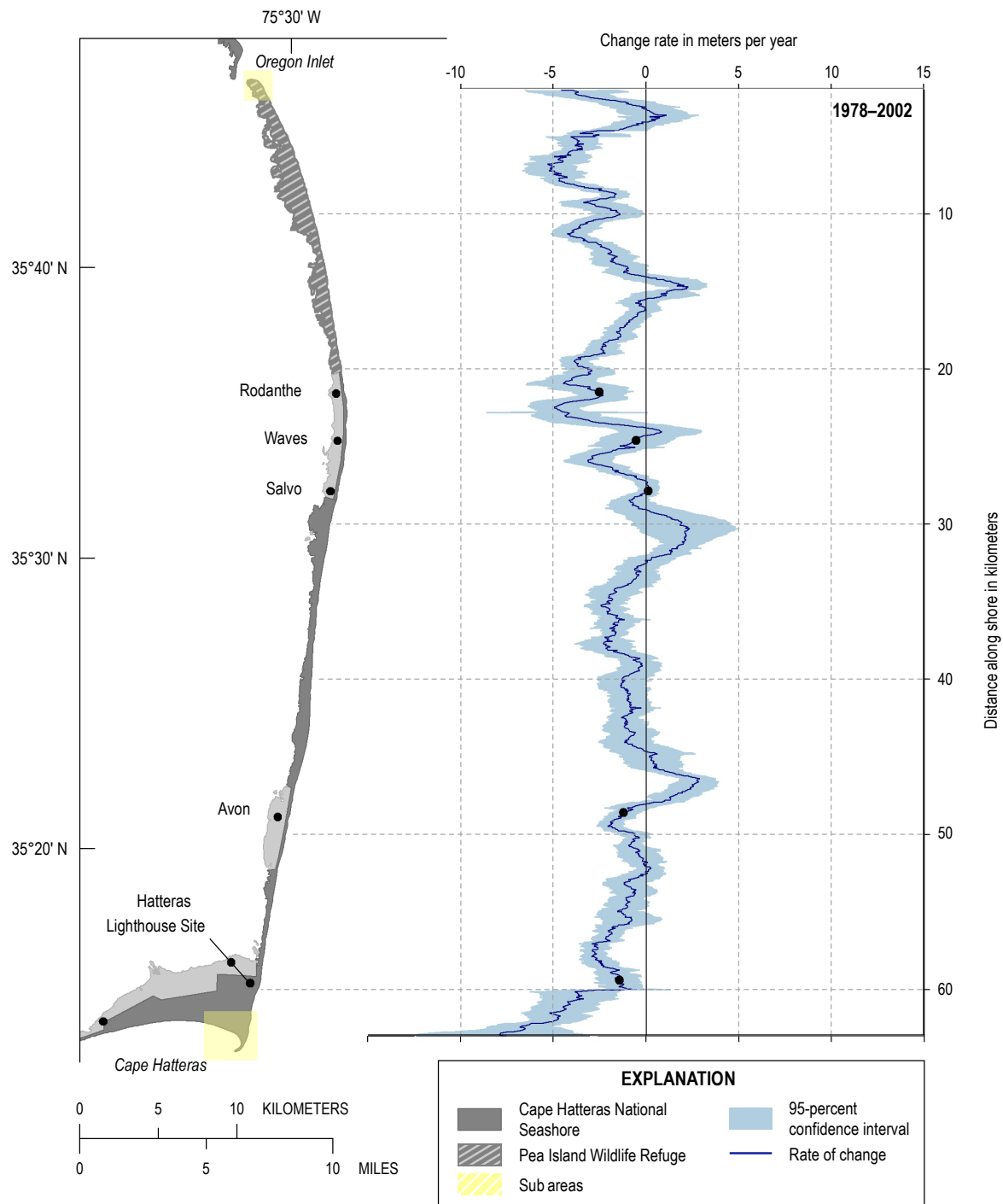
Figure 5. Shoreline change rates for 1989–2002. Rates of change are linear regression with the 95-percent confidence interval highlighted. Changes at Oregon Inlet and Cape Hatteras (boxed area on map) are not presented in this figure. Average shoreline change rates for these sections are presented in table 5.
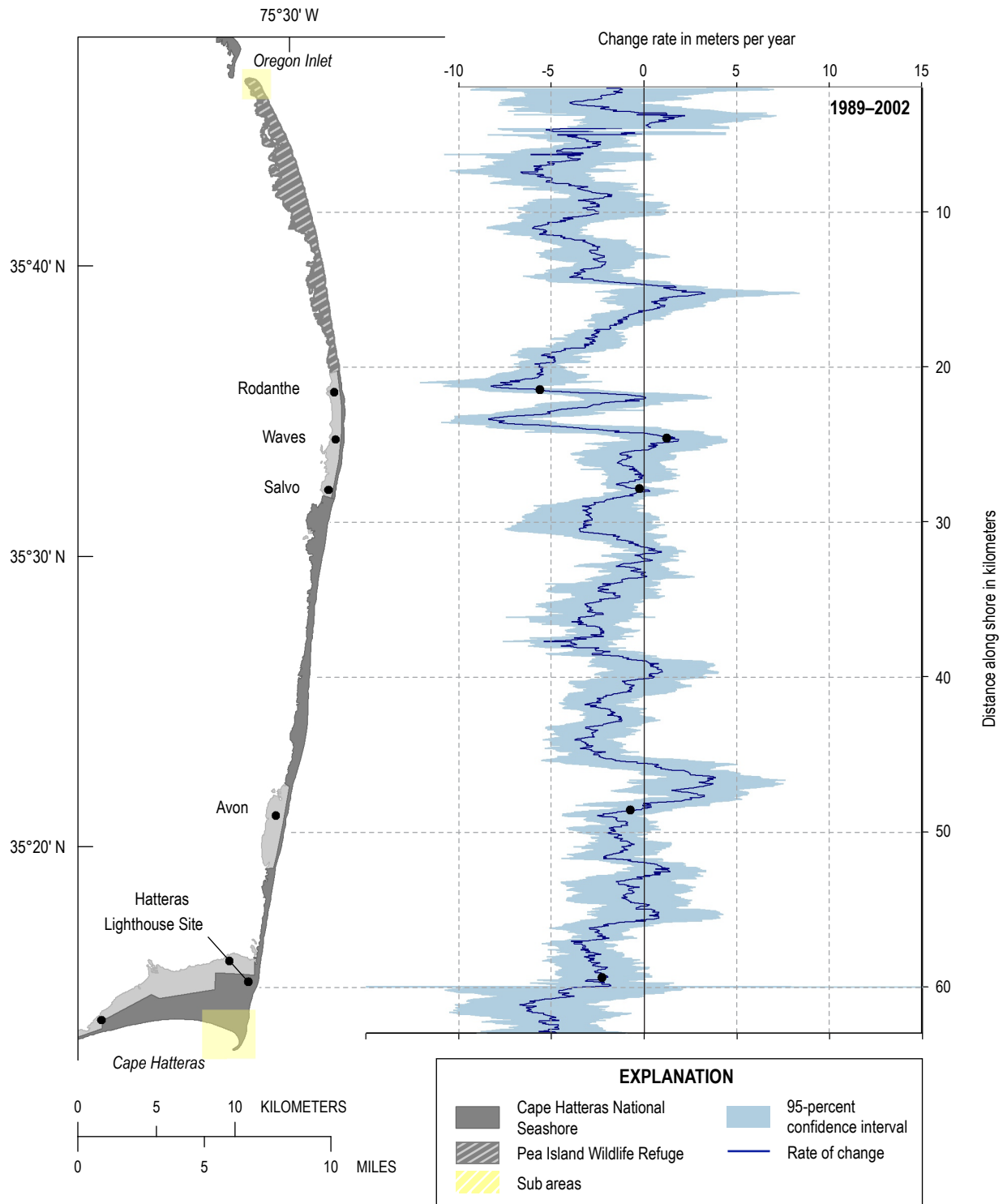
The uncertainties reported for the subarea averaged linear-regression rates (tables 3, 4, and 5) are calculated following the method developed by Hapke and others (2011). This approach uses a spatially lagged autocorrelation (Garrett and Toulany, 1981) to determine the number of independent transects in the area along which rates are being averaged. A quadrature average (Taylor, 1997) of the 95-percent confidence interval is then determined using the reduced number of independent transects. The subarea adjacent to Oregon Inlet (fig. 1) is too small to successfully determine a reduced number of independent transects, and thus it is assumed that there is only one independent sample within this limited area. Therefore, the uncertainty associated with averaged rates for the Oregon Inlet subarea presented in tables 3, 4, and 5 is the average of the 95-percent confidence interval measured at each transect.

Table 2. Shoreline positional uncertainty.

[m, meter; RMS, root mean square; georeferenced imagery uncertainty is the quadrature summation of the averaged terms defined in table 1 and the shoreline-positional uncertainty (in bold) is the quadrature summation of the georeferenced, digitizing, and high water line uncertainty terms]

Georeferenced Imagery Uncertainty	1.2 m
Average Pixel Size (0.3 m)	
Average Georeferencing RMS (0.004 m)	
Base map uncertainty (1.2 m)	
Digitizing Uncertainty	1 m
High Water Line Uncertainty	4.2 m
Shoreline-Position Uncertainty	**4.5 m**

Results of Shoreline Change Rate Analysis

Rates of shoreline change for Hatteras Island are presented for three different time periods—the entire time span of the dataset (1978–2002) and the decadal subsets (1978–89 and 1989–2002)—to quantify and examine temporal variations in the shoreline behavior (figs. 3, 4, and 5; tables 3, 4, and 5). The section of coast covered by the database extends from Oregon Inlet to the point at Cape Hatteras (fig. 1). The rates of change in the areas immediately adjacent to Oregon Inlet and Cape Hatteras are substantially greater than the rest of Hatteras Island primarily because of disruptions in the sediment supply associated with the jetty at Oregon Inlet and the dynamic sediment-transport processes related to the Cape and cape shoals. The plots of shoreline change rates (figs. 3, 4, and 5) exclude values for the portions of the coast (highlighted in fig. 1) adjacent to Oregon Inlet and south of the Cape Hatteras Lighthouse Site. In addition, tables 3, 4, and 5 present averaged rates for the entire study area, and for the subdivided portions of the coast to more adequately represent the change rates along the main length of Hatteras Island and the adjacent stretches of coastline.

The average rate of shoreline change for the 24-year time period spanning 1978–2002 along the full length of the study area is -1.4±0.3 meters per year (m/yr; table 3). The rates of change differ considerably along Hatteras Island (fig. 3), but are predominantly negative (erosional), with the exception of several localized zones of accretion in northern and southern Pea Island Wildlife Refuge, south of Salvo, N.C., and north of Avon, N.C.. Rates of change in the subarea of Cape Hatteras are positive (progradational), whereas the area adjacent to Oregon Inlet has high rates of negative change with an average rate of -15.4±9.7 m/yr (table 3) and a maximum erosion rate of -76.6±35.3 m/yr.

Table 3. Shoreline change statistics for Hatteras Island, North Carolina, for the time period 1978–2002.

[Shoreline analysis divided by regions. Value for the entire study are are displayed in bold. m/yr, meters per year; max, maximum; min, minimum; -, negative; ±, plus or minus; +, positive]

Area	No. of Transects	Percent Eroding	Mean (m/yr)	Max (m/yr)	Min (m/yr)
Hatteras Island, North Carolina: 1978–2002					
Hatteras Island	1217	83	-1.5±0.2	+2.9	-7.9
Oregon Inlet	23	100	-15.4±9.7	-4.3	-76.6
Cape Hatteras	64	27	+6.1±3.8	+19.4	-8.1
Oregon Inlet to Cape Hatteras	**1304**	**80**	**-1.4±0.3**	**+19.4**	**-76.6**

Table 4. Shoreline change statistics for Hatteras Island, North Carolina, for the time period 1978–89.

[Shoreline analysis divided by regions. Values for the entire study are displayed in bold. m/yr, meters per year; max, maximum; min, minimum; +, positive; ±, plus or minus; -, negative]

Area	No. of Transects	Percent Eroding	Mean (m/yr)	Max (m/yr)	Min (m/yr)
Hatteras Island, North Carolina: 1978–89					
Hatteras Island	1220	48	+0.14±0.6	+12.3	-18.9
Oregon Inlet	23	100	-28.0±20.3	-6.8	-76.6
Cape Hatteras	48	31	+9.6±17.5	+41.1	-43.9
Oregon Inlet to Cape Hatteras	**1291**	**48**	**-0.01±0.9**	**+41.1**	**-76.6**

Table 5. Shoreline change statistics for Hatteras Island, North Carolina, for the time period 1989–2002.

[Shoreline analysis divided by regions. Value for the entire study are are displayed in bold. m/yr, meters per year; max, maximum; min, minimum; -, negative; ±, plus or minus; +, positive]

Area	No. of Transects	Percent Eroding	Mean (m/yr)	Max (m/yr)	Min (m/yr)
Hatteras Island, North Carolina: 1989–2002					
Hatteras Island	1217	83	-2.1±0.3	+3.8	-8.4
Oregon Inlet	20	30	+10.0±43.3	+84.1	-4.2
Cape Hatteras	58	33	+0.45 ± 8.5	+20.7	-40.4
Oregon Inlet to Cape Hatteras	**1295**	**80**	**-1.8±0.4**	**+84.1**	**-40.4**

In the time period spanning 1978–89, the average rate of change for the study area is not significantly different from a zero rate of change (-0.01±0.9 m/yr; table 4). A large zone of significant positive (progradational) change rates exists immediately south of Salvo, N.C. (fig. 4). The maximum rate of erosion, -76.6±35.3 m/yr was measured in the subarea adjacent to Oregon Inlet, and the maximum rate of progradation, 41.1±23.8 m/yr was located in the Cape Hatteras subarea (table 4).

The rates of change in the more recent time period of the analysis (1989–2002) are predominantly erosional with an average rate for the study area of -1.8±0.4 m/yr (table 5). Along the main portion of Hatteras Island, the highest rates of negative change are located in the vicinity of Rodanthe, N.C. (fig. 5). The rates of change in the Cape Hatteras subarea are highly variable ranging from a maximum of 20.7±34.5 m/yr to a minimum of -40.4±176.7 m/yr (table 5).

The temporal subsets of the time series indicate there is a significant difference in shoreline behavior between the two decadal time periods, 1978–89 and 1989–2002 (tables 4 and 5; figs. 4 and 5). Rates of change are highly variable along the coast in both time periods, but the extent of the study area with negative (erosional) shoreline change rates is substantially higher in the more recent time period (1989–2002). This may be attributable to differences in the wave climate (for example, increased storminess in the later time period) or possibly higher water levels associated with increases in rates of sea-level rise.

Summary

A historical shoreline change assessment was conducted for the part of the Cape Hatteras National Seashore extending from Oregon Inlet to Cape Hatteras North Carolina. As part of the study, 14 dates of aerial photographs of the same scale were obtained from the U.S. Army Corp of Engineers Field Research Facility in Duck, North Carolina, scanned to produce digital imagery, and georeferenced using existing orthophotographs for ground control. High water line (HWL) shorelines were interpreted and digitized from the imagery to produce a time series from 1978 through 2002. Linear-regression rates of shoreline change for three time periods, 1978–2002, and two subsets of the time series, 1978–89 and 1989–2002, indicate that shoreline response along this coast is highly variable in time and space.

Rates of change are the most extreme in the vicinity of Oregon Inlet and Cape Hatteras. Along the main east-facing portion of Hatteras Island, rates of shoreline change for the full time series are predominantly negative (erosional) with the exception of several very localized zones of accretion. The temporal subsets of the time series indicate that the more recent time period (1989–2002) is significantly more erosional than the previous one.

The time series produced in this study provides a unique dataset of 14 historical shorelines that were derived using a systematic, consistent methodology and common source. The data provide a baseline to assess temporal and spatial variations in coastal behavior along this stretch of coastline that includes federal lands, private communities, and public infrastructure. The assessments of shoreline change derived during this study may help coastal managers and planners understand change within this dynamic system, and can be used to provide data for models of future change on Hatteras Island.

References Cited

Anders, F.J., and Byrnes, M.R., 1991, Accuracy of shoreline change rates as determined from maps and aerial photographs: Shore and Beach, v. 59, p. 17–26.

Crowell, M., Leatherman, S.P., and Buckley, M.K., 1991, Historical shoreline change—Error analysis and mapping accuracy: Journal of Coastal Research, v. 7, p. 839–852.

Crowell, M., and Leatherman, S.P., eds., 1999, Coastal erosion mapping and management: Journal of Coastal Research, Special Issue, v. 28, 196 p.

Dolan R., Fenster M.S., and Holme, S.J., 1991, Temporal analysis of shoreline recession and accretion: Journal of Coastal Research, v. 7, no. 3, p. 723–744.

Everts, C.H., Battley, J.P., Jr., and Gibson, P.N., 1983, Shoreline movements, report 1, Cape Henry, Virginia to Cape Hatteras, North Carolina, 1849-1980: U.S. Army Corps of Engineers, Coastal Engineering Research Center, Technical Report CERC–83–1, 111 p.

Fenster, M.S., and Dolan, R., 1993, Historical shoreline trends along the Outer Banks, North Carolina: Processes and responses: Journal of Coastal Research, v. 9, no. 1, p. 172–188.

Garrett, C.J.R., and Toulany, B., 1981, Variability of the flow through the Strait of Belle Isle: Journal of Marine Research, v. 39, p. 163–189.

Hapke, C.J., Himmelstoss, E.A., Kratzmann, M., List, J.H., and Thieler, E.R., 2011, National assessment of shoreline change—Historical shoreline change along the New England and Mid-Atlantic Coasts: U.S. Geological Survey Open-File Report 2010–1118, 57 p.

Hapke, C.J., Reid, D., Richmond, B.M., Ruggiero, P., and List, J., 2006, National assessment of shoreline change part 3—Historical shoreline changes and associated coastal land loss along the sandy shorelines of the California coast: U.S. Geological Survey Open-File Report 2006–1219. [Also available at *http://pubs.usgs.gov/of/2006/1219/*.]

Moore, L.J., 2000, Shoreline mapping techniques: Journal of Coastal Research, v. 16, p. 111–124.

Morton, R.A., and Miller, T.L., 2005, National assessment of shoreline change—Part 2, historical shoreline changes and associated coastal land loss along the U.S. Southeast Atlantic coast: U.S. Geological Survey Open File Report 2005–1401, available at *http://pubs.usgs.gov/of/2005/1401/*.

North Carolina Division of Coastal Management, 2004, Long-term average annual erosion study and setback factors (1998 shoreline): Raleigh, N.C., North Carolina Department of Environment and Natural Resources, available at *http://portal.ncdenr.org/web/cm/download-oceanfront-setback-factor-maps-1998-shoreline*.

Pajak, M.J., and Leatherman, S.P., 2002, The high water line as a shoreline indicator: Journal of Coastal Research, v. 18, p. 329–337.

Taylor, J.R., 1997, An introduction to error analysis—The study of uncertainties in physical measurement: Sausalito, Calif., University Science Books, 327 p.

Thieler, E.R., and Danforth, W.W., 1994, Historical shoreline mapping (II)—Application of the Digital Shoreline Mapping and Analysis Systems (DSMS/DSAS) to shoreline change mapping in Puerto Rico: Journal of Coastal Research, v. 10, no. 3, p. 600–620.

Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., and Ergul, A., 2009, Digital Shoreline Analysis System (DSAS) version 4.0—An ArcGIS extension for calculating shoreline change: U.S. Geological Survey Open-File Report 2008–1278, available at *http://pubs.er.usgs.gov/publication/ofr20081278*.

Zar, J.H., 1999, Biostatistical analysis (4th ed.): Upper Saddle River, N.J., Prentice Hall.

≈USGS