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Historical Coastal Change Hazards for the Conterminous United States and Hawaii: Initial Progress Under the USGS National Coastal Assessment

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Introduction

As coastal population continues to increase in the United States, the conflict between accelerating oceanfront development and the inherent geological instability of the shore, especially with respect to sea-level rise and storms, has become a dilemma of increasing magnitude (Figure 1). The last national compilation of historical shoreline change for the U.S. Geological Survey was prepared more than 20 years ago. Since then, methods of obtaining, analyzing, displaying, and storing shoreline data have substantially improved, and more than 20 years of coastal change has occurred. Furthermore, coastal scientists have not agreed on standard methods for analyzing and reporting the data, nor have they identified rigorous mathematical tests that are widely accepted for quantifying the results. Consequently, there are critical needs for a nationwide compilation of reliable shoreline data including the most recent shoreline position, and a standardization of methods for obtaining and comparing shoreline positions and mathematically analyzing the trends. Our primary objectives are:

Figure 1. Destruction of homes due to Hurricane Dennis, north of Oregon Inlet, NC.

- to develop and implement improved methods of assessing and monitoring shoreline movement,
- to obtain a better understanding of the processes controlling shoreline movement,
- to improve quantitative methods for predicting shoreline changes and coastal inundation within reasonable temporal and spatial limits,
- to enter into strategic partnerships to facilitate data dissemination.

Progress under the first objective listed above is the subject of this report.

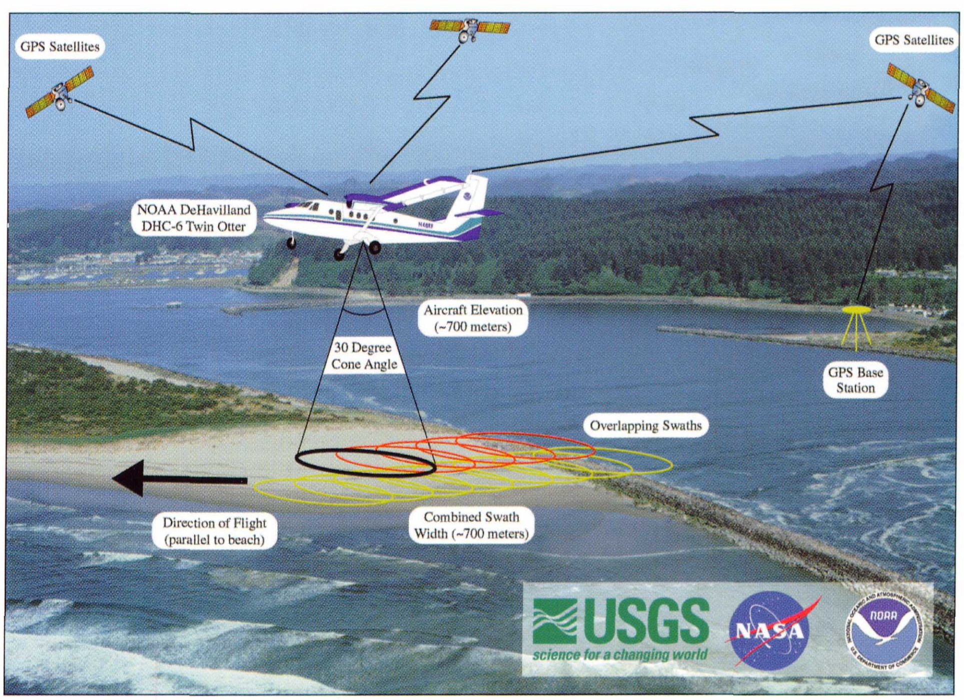

Figure 2. Lidar data is collected using NASA's Airborne Topographic Mapper (ATM) mounted on a Twin Otter aircraft.

Shorelines Derived from Historical Data

University researchers and government agencies have been quantifying rates of shoreline movement and studying coastal change for decades. The most commonly used sources of historical shoreline position include National Ocean Service (NOS) Topographic Sheets (T-sheets) and aerial photographs. Extraction of shoreline position from these data sources involves georeferencing and removing distortions from the maps/aerial photographs followed by digitizing of shoreline position.

Numerous proxies for shoreline position are used by different investigators to document coastal change including the mean high water line (MHWL), wet-dry line, vegetation line, dune toe, dune crest, cliff top and cliff toe. The USGS National Assessment will make use of existing historical shoreline databases, and numerous contributors have already provided the USGS with digital shoreline data sets. Currently, we have performed a quality assessment of existing shoreline data for the Gulf Coast of the United States and have filled the majority of remaining data gaps using scans of historical T-sheets provided by the NOAA Vectorization Project.

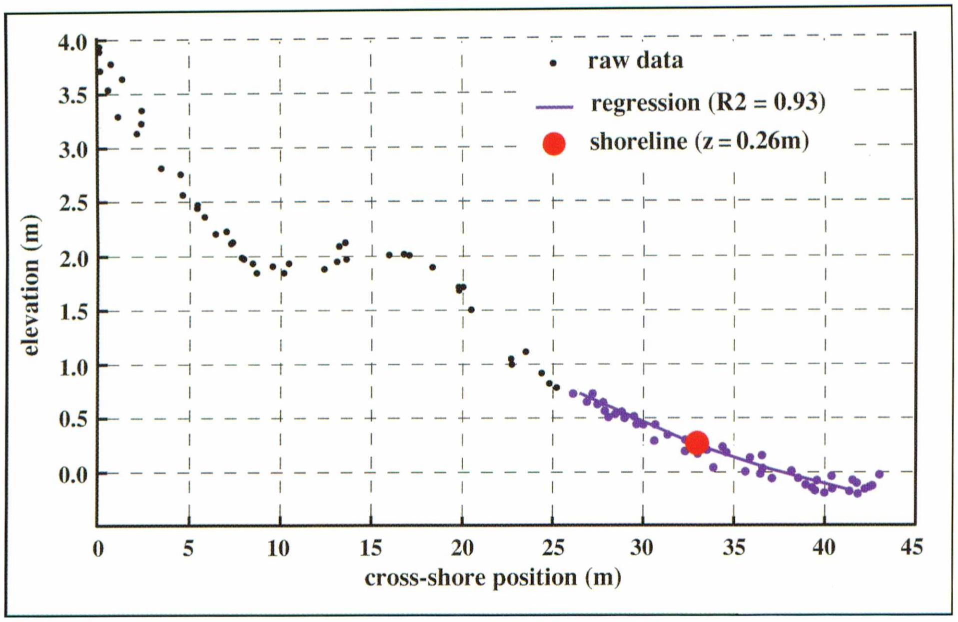

Figure 3. Shoreline position can be determined from lidar data using the profile extraction method developed by Stockdon et al. (in press).

Shorelines Derived From Lidar

The most recent shoreline used in the National Assessment will be derived from lidar (light detection and ranging) data. The USGS, in collaboration with NASA and NOAA, has been using the NASA Airborne Topographic Mapper (ATM), mounted on a Twin Otter aircraft, to map coastal areas since 1996 (Krabill et al., 2000; Sallenger et al., 1999) (Figure 2). The ATM surveys ground elevation using a blue-green laser and a rotating mirror that creates an elliptical ground scan pattern. Upon correction for aircraft pitch, roll, and heading using the global positioning system, beach elevations of ~15 cm root mean square accuracy are generated (Krabill et al., in press; Sallenger

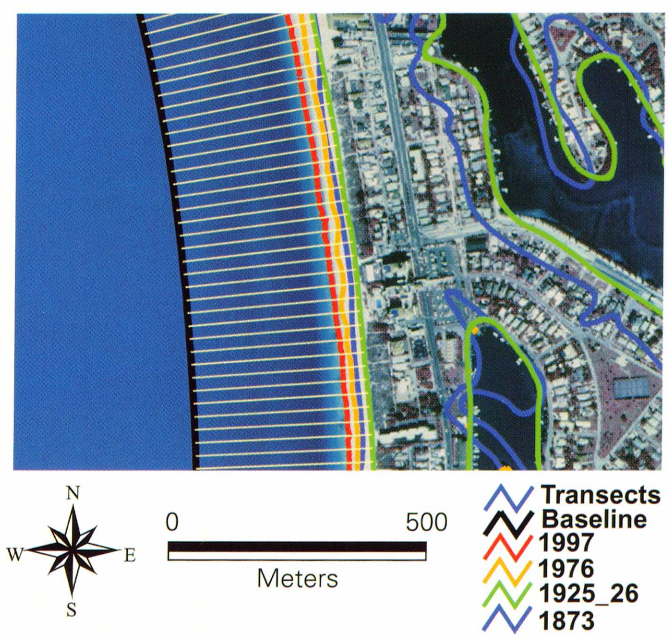

Figure 4. A seaward baseline is drawn from which distances to each shoreline will be measured. A program called "Transect" casts approximately shore-perpendicular transects at a specified interval (25 m, above) along which shoreline change is measured.

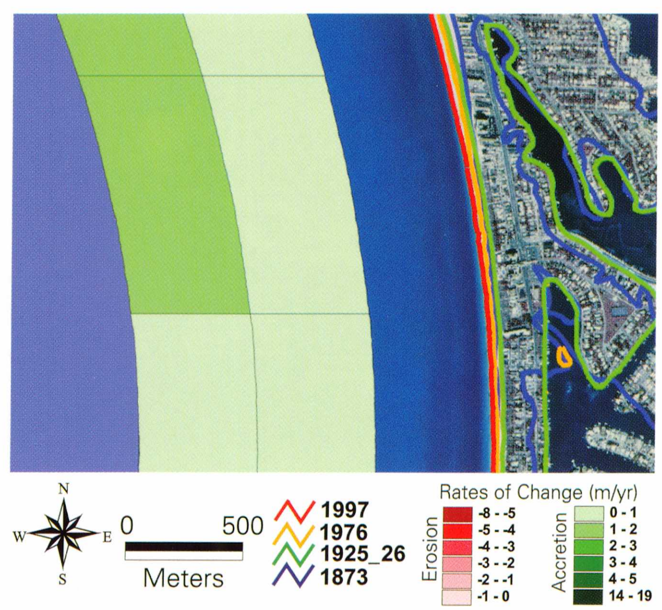

Figure 5. Rates are averaged into alongshore 1-km bins. Long-term rates are represented by the color bar closest to the shoreline while short-term rates are represented by the color bar farthest from the shoreline.

et al., 1999; Sallenger et al., in press). Currently, non-storm influenced, baseline surveys have been completed for approximately 90% of the United States ocean coastline. For comparison with historical data, a modern mean high water (MHW) shoreline will be extracted from the lidar surveys using a method developed by Stockdon et al. (in press). The shoreline extraction method begins with construction of cross-shore profiles from the scattered lidar data at 20-m intervals along the shoreline. Lidar data contaminated by waves and runup are removed from the profile and a linear regression is calculated on the remaining data within a narrow elevation band around mean high water (Figure 3). The horizontal location of the MHW elevation is then determined by the intersection of the MHW elevation with the regression line (filled red circle in Figure 3). Repeating this last procedure for successive profiles generates an alongshore record of shoreline location.

Measuring Rates of Change

To maintain consistency at a national scale, shorelines from four time periods (mid-1800s, 1920s-1930s, 1970s, and post-1995) will be used to evaluate shoreline change. Data for the first three time periods will come primarily from existing databases whereas recent shorelines will be generated by the USGS from lidar data. Using these shorelines, both long-term (mid-1800s - recent) and short-term (1970s - post-1995) rates of change will be generated using the Digital Shoreline Analysis System (DSAS), a series of ArcInfo and C programs, initially developed by Thieler and Danforth (1994).

The process of determining rates of change begins with construction of a baseline seaward of the shorelines. An ArcInfo program then places vertices at a specified interval along the baseline and a C program casts transects perpendicular to the baseline from each of these vertices to the most landward shoreline (Figure 4). A second series of C programs and Arc AMLs calculates the specified long-term and short-term rates of change along these transects by dividing the distance between successive shorelines by the elapsed time between shoreline positions.

After the calculations have been performed, the long-term and short-term rates

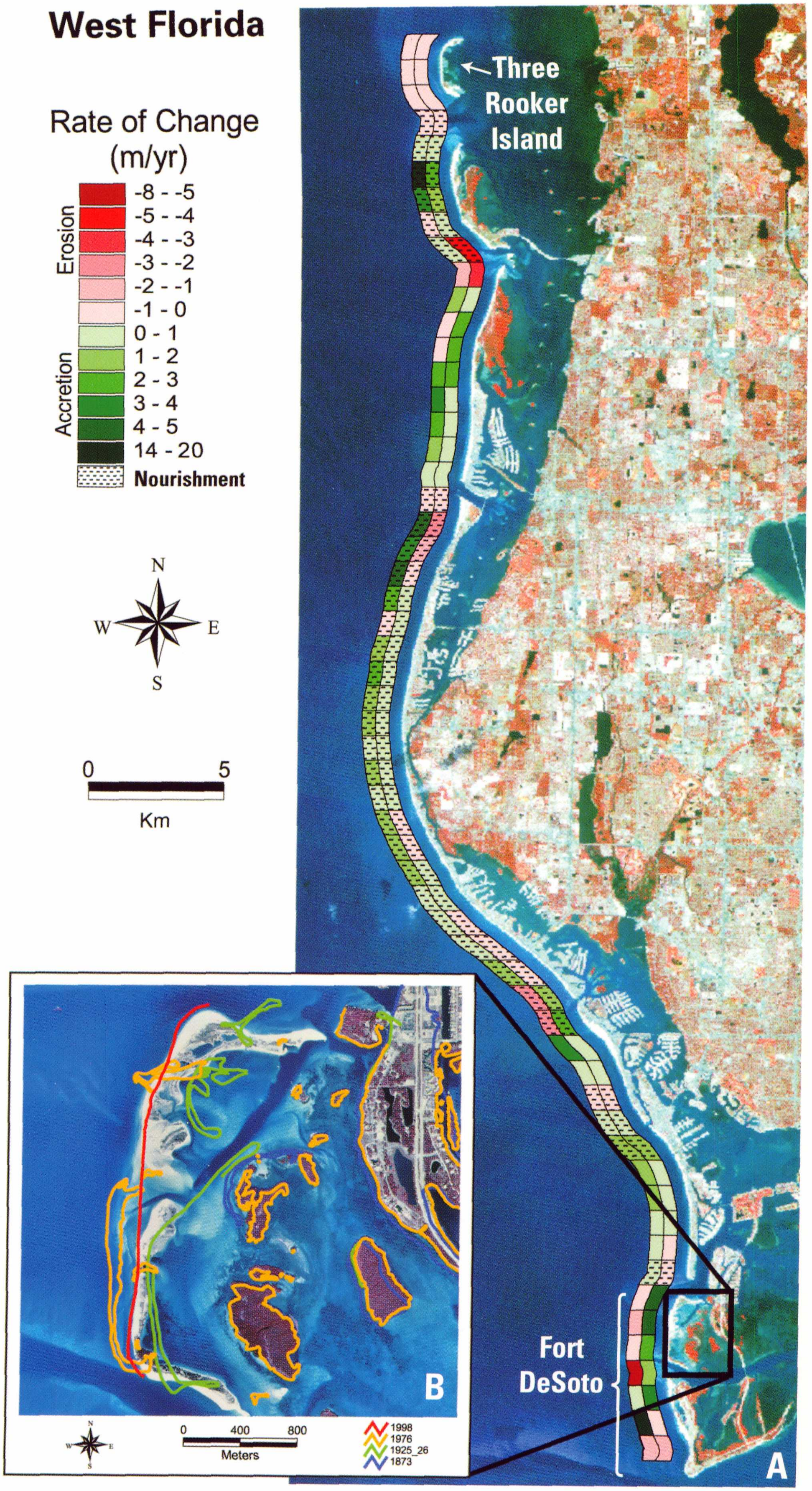

Figure 6 a) Results of Gulf Coast pilot study carried out for Pinellas County, FL, b) Historical shorelines used in Pinellas County, FL pilot study from Foster (1999).

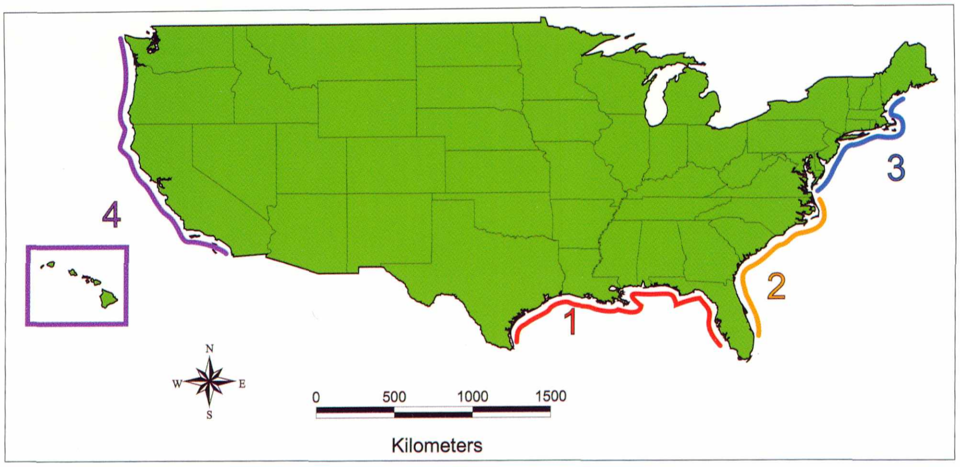

Figure 9. National Assessment historical shoreline change sequence.

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Summary

- Under the USGS National Assessment, we are working to compile a nationwide database of existing historical shoreline data. These historical data will be used in combination with recent lidar-based shoreline data to prepare regional maps of rates of shoreline movement.
- The historical data to be used in the National Assessment have been largely derived from NOS T-sheets by various university researchers and agencies throughout the United States.
- Rates of shoreline movement will be determined using the Digital Shoreline Analysis System initially developed by Thieler and Danforth (1994). Shorelines representing four time periods (mid-1800s, 1930s, 1970s and post-1995) will be used to calculate long-term (1800s - post 1995) and short-term (1970s - post 1995) rates of change.
- Three pilot studies, one for each coast of the conterminous United States, have been undertaken. Rates of shoreline change are averaged into 1-km bins and at this scale spatial patterns of short-term and long-term shoreline movement are discernable.
- We are currently working on the Gulf Coast of the United States. After the Gulf Coast mapping has been completed, we will work toward completing regional maps for the Southeast, Northeast and West Coasts.

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long-term rate of change appears relatively-small and, in places, is accretional.

East Coast

A 43-km-long barrier island extending from Oregon Inlet to Cape Hatteras, NC, was selected for the East Coast pilot study (Figure 7). Historical shorelines for this analysis were digitized from U.S. Army Corps of Engineers maps (USACE, 1990). Higher rates of change (darker colors) are apparent around the dynamic Oregon Inlet and at Cape Hatteras.

This stretch of coastline is representative of the eastern coastline of the United States. Analyzing shoreline change along sandy beaches such as this one is relatively straightforward, and is in contrast to the Gulf Coast and the West Coast, where shoreline change calculation is complicated by marshes and high relief features (cliffs and bluffs), respectively.

West Coast

Except for portions of Oregon and Washington, few regional digital shoreline change studies have been carried out for the west coast of the United States. Because there was not sufficient historical shoreline coverage for a typical high-relief location along the West Coast, our pilot study area is an accreted barrier in Southwest Washington known as Long Beach Penninsula, which extends from Leadbetter Point to the Columbia River entrance (Figure 8). The historical shorelines for this pilot study were provided by the Washington Department of Ecology (Daniels, 2000; Kaminsky et al., 1999) through the Southwest Washington Coastal Erosion Study.

Sequence of Assessment

In addition to carrying out pilot studies, we are currently calculating rates of shoreline movement for the United States Gulf Coastline. After the Gulf Coast study has been completed, we plan to calculate rates for the remaining United States coastline in the following order: Southeast Coast, Northeast Coast, West Coast and Hawaii (Figure 9). This order is largely determined by the availability and completeness of existing historical shoreline databases and lidar coverage.

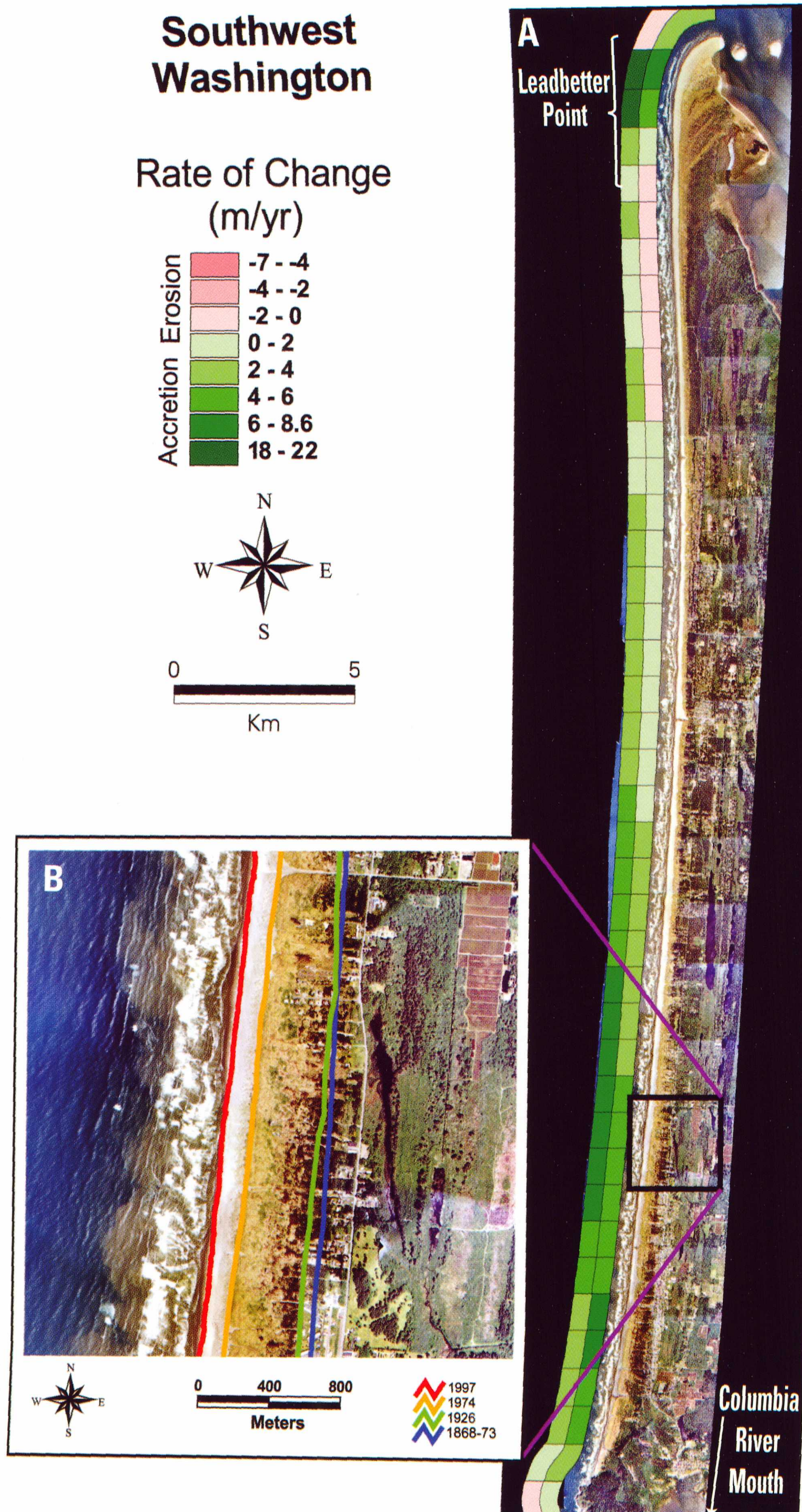

Figure 8. a) Results of West Coast pilot study for southwest Washington State from Leadbetter Point to the Columbia River Entrance, b) Historical shorelines used in the Southwest Washington pilot study, from Kaminsky et al. (1999).

of change are averaged alongshore into bins and converted into an ArcInfo coverage. For this preliminary analysis the bins are 1 km long, and are color coded according to class interval. They are presented on a base image with green colors indicating accretion and red colors indicating erosion. The color bar closest to the shoreline depicts long-term rates of change, whereas the color bar farthest from the shoreline depicts short-term rates of change (Figure 5).

Pilot Studies

Three pilot studies, one for each coast of the United States, have been carried out using shorelines from the four time periods mentioned above. The lidar shorelines for these pilot studies were not generated by the profile extraction method and final products will likely differ from what is presented here. Thus, the pilot studies are presented as examples only. Color bars are approximately 1 km long and represent an average of approximately 20 erosion rates (50-m transect spacing).

Gulf Coast

The Gulf Coast pilot study was conducted on the west coast of Florida in Pinellas County from Three Rooker Island to Fort Desoto (Figure 6). Historical shorelines for this analysis were provided by the Florida Department of Environmental Protection (FLDEP, 2001). Pinellas County is extremely urbanized and much of the coastline is affected by beach nourishment projects and coastal structures. Where the coastline is natural (for example at the southern end of the county), it is extremely dynamic, displaying high rates of both accretion and erosion (darker colors) over the long and short term.

Beach locations affected by sand nourishment are denoted by hatch marks. At the 1-km scale, the "success" of shoreline stabilization efforts is apparent and demonstrated by the relatively low rates of change in hatched areas. It is critical to remember that all rates presented are averages over time. For example, prior to stabilization efforts, rates of change for the central portion of the county likely resembled those currently seen at the southern end. However, because the 1970 and 1990 shoreline positions have been artificially moved seaward through nourishment, the average

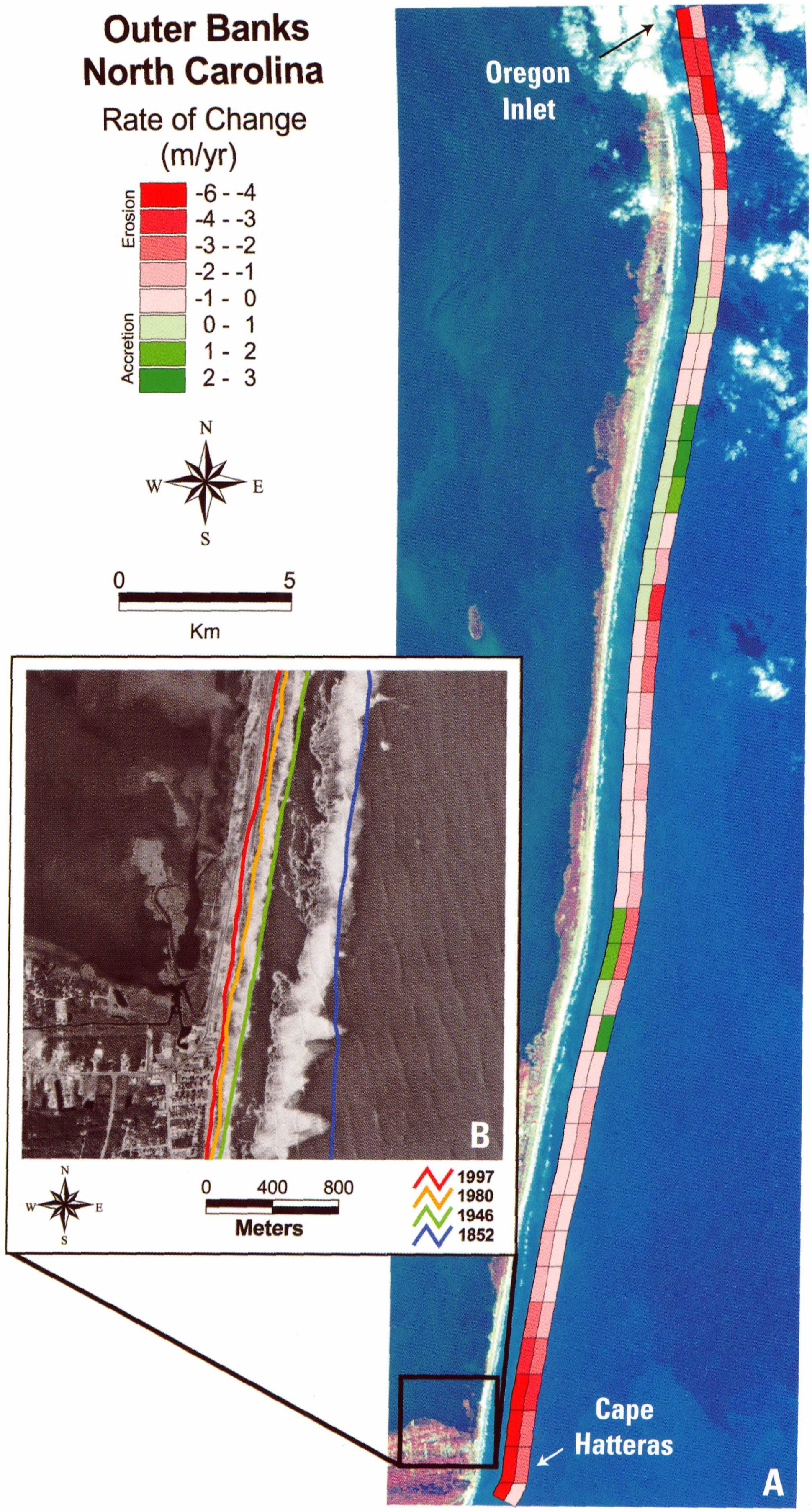

Figure 7. a) Results of the East Coast pilot study carried out in North Carolina from Oregon Inlet to Cape Hatteras, b) Historical shorelines used in North Carolina pilot study from Everts et al. (1983).