Sedimentary evidence of intense hurricane strikes from New Jersey

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ABSTRACT

Nine Vibracores from the backbarrier marsh at Whale Beach, New Jersey, reveal three large-scale overwash deposits associated with historic and prehistoric storms. The uppermost and smallest overwash fan was deposited in the Ash Wednesday northeaster of March 5–8, 1962. A second more substantial overwash fan between 100 and 35 cm depth dates to the late eighteenth or early nineteenth century. This fan was most likely deposited during the 1821 hurricane, the only intense hurricane to make landfall in New Jersey in the past 350 yr. A third, larger overwash fan between 200 and 300 cm depth was deposited between A.D. 1278 and 1438 and is likely the result of a prehistoric intense hurricane strike. The combination of historical and stratigraphic evidence indicates that two intense hurricanes (winds $>$50 m s^{-1}) have likely made landfall on the southern New Jersey coast in the past 700 yr, resulting in an annual landfall probability of 0.3%.

Keywords: barrier beaches, overwash, salt marshes, storms, stratigraphy.

INTRODUCTION

Intense storms present a significant threat to lives and resources and can result in significant alteration of coastal environments. The most famous storm affecting the New Jersey shore in the twentieth century was the Ash Wednesday northeaster of March 5–8, 1962 (Stewart, 1962; Dolan et al., 1988). Storm surge associated with this storm overtopped many of the barrier islands of the New Jersey coast and deposited overwash fans across backbarrier marshes there.

The only major hurricane to strike the New Jersey coast since European settlement (ca. A.D. 1650) occurred September 3, 1821 (Fig. 1, inset; Ludlum, 1963). Even though the hurricane struck at very low tide and lasted less than four hours, storm-surge heights exceeding 3 m above the level of normal high tide were reported from southern New Jersey and the Delmarva Peninsula (Ludlum, 1963). The magnitude of the storm surge and reports of extensive damage as far inland as northern Massachusetts (Ludlum, 1963) are consistent with at least a category 3 hurricane on the Saffir-Simpson scale (winds 50–59 m s^{-1}). Given that the elevation of many of the barrier islands on the New Jersey coast is $<$3 m above mean sea level, storm surge from the 1821 hurricane likely deposited significant overwash fans across the backbarrier marshes. The rarity of intense hurricane landfalls on this coast necessitates the development of long records to estimate strike probabilities.

Several recent studies have used overwash deposits preserved in coastal sediments as records of intense hurricane strikes (Liu and Fearn, 1993, 2000; Donnelly et al., 2001). Records from coastal lake sediments provided evidence of hurricane-induced overwash deposits extending back several thousand years in Alabama and Florida (Liu and Fearn, 1993, 2000). A higher resolution record of overwash deposition from a backbarrier marsh provided

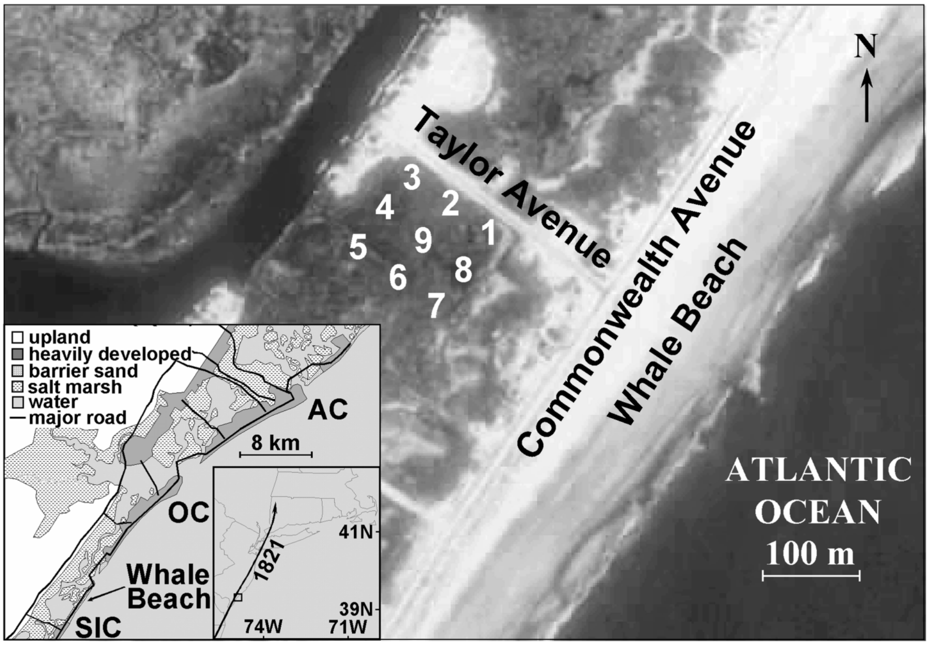

Figure 1. Location of Whale Beach study site (square) on southern New Jersey coast and approximate track of September 3, 1821, hurricane (inset). Whale Beach backbarrier marsh study site core locations are noted with numbers (photograph taken in 1994; courtesy of the U.S. Geological Survey). AC is Atlantic City, OC is Ocean City, an SIC is Sea Isle City.

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Figure 2. Aerial photographs of Whale Beach Marsh from 1940, 1961, and 1963 (source: State of New Jersey, Department of Environmental Protection). Area from where sediment cores were extracted is denoted with white squares (see Fig. 1). Dashed line represents position of marine edge of beach in 1842 Coast and Geodetic Survey Chart. Open arrow in 1940 photograph denotes vegetated pre-1932 overwash fan to northeast of core locations.

evidence of six intense hurricane strikes in the past 700 yr in Rhode Island (Donnelly et al., 2001).

Here we analyze core stratigraphy, use isotopic dating techniques, and examine historical aerial photographs to reconstruct the overwash history at Whale Beach, New Jersey (Fig. 1), and extend the record of intense storms into the prehistoric period. Calibrating the stratigraphic record to the historic record of storm surge and intense storms provides a means of evaluating prehistoric overwash deposits and the storms that deposit them.

RESULTS AND INTERPRETATION

Analysis of Aerial Photographs

We compiled a series of aerial photographs taken of the study site from 1932 to 1994 to aid us in understanding the impact of historic storms at the study site and document recent overwash deposition. Three of these aerial photographs, from 1940, 1961, and 1963, are shown in Figure 2. No new overwash is evident at any core location in the aerial photographs from 1940 or 1961 (Fig. 2).

A significant overwash fan is evident at the study site in the aerial photograph from 1963 (Fig. 2). The fan visibly extends past the location of cores 1, 8, and 7 (Figs. 1 and 2). In addition, significant erosion of the beachfront is evident since 1961; nearly the entire beach to the east of Commonwealth Avenue was lost. Additional aerial photographs from 1972, 1977, 1991, and 1994 indicate that Whale Beach remains in about the same position today as in 1963; there is no evidence of additional overwash deposition across the back-barrier environment since then.

Aerial photographs and the U.S. Coast and Geodetic Survey Chart from 1842 (Fig. 2) reveal that ~100 m and ~300 m have eroded from the beachfront since A.D. 1940 and 1842, respectively. This evidence indicates that the barrier beach migrated landward at a rate of ~2 m/yr over the past 150 yr.

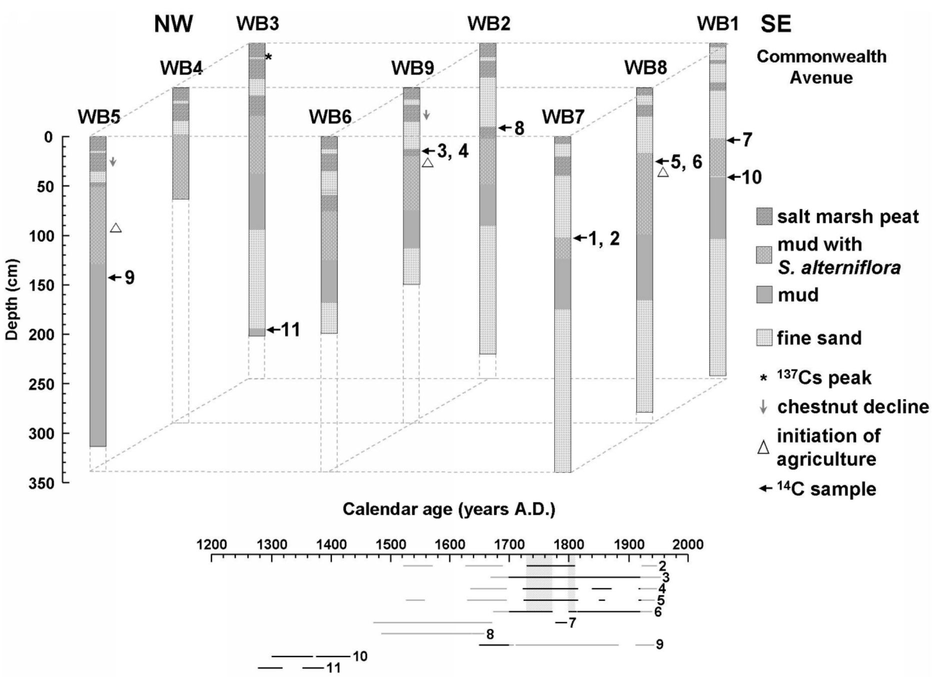

Figure 3. Core logs from Whale Beach Marsh. Each core is separated by 50 m and is plotted to illustrate stratigraphy in three dimensions. Open triangles denote stratigraphic interval where native weed pollen increases, indicating widespread European-style clearance of landscape (ca. A.D. 1700). Downward-pointing arrows denote stratigraphic interval where chestnut pollen decreases (ca. A.D. 1920). Asterisk marks interval in core 3 where activity of ^{137}Cs peaks, indicating deposition ca. A.D. 1963. Solid arrows with numbers mark locations of radiocarbon-dated samples (dates and 2 σ calibrated age ranges presented in Table 1). 2 σ calibrated age ranges are plotted at bottom; numbers to right indicate sample. Gray lines represent portions of calibrated ranges that can be eliminated based on pollen results. Shaded area denotes mutual overlap of remaining highest probability age ranges (see Table 1).

Whale Beach Stratigraphy

Three extensive sand layers, likely of overwash origin, are interbedded within the upper 350 cm of salt marsh and estuarine-mud deposits (Fig. 3). The contact between the sand units and the underlying mud or peat deposits is abrupt, often displaying soft-sediment deformation. The uppermost organic sediment, a brown, fibrous to muddy peat dominated by *Spartina alterniflora* fragments, consistently extends to a depth of 50–100 cm. This unit grades to a brown mud with numerous *S. alterniflora* fragments, which in turn grades into a brownish-gray mud with a few shell fragments.

The uppermost sand layer is a relatively thin sand unit between 5 and 20 cm depth that extends across all cores and tapers from 15–20 cm thick in the cores closest to the barrier to ~1 cm thick in the cores farthest from the barrier (Fig. 3). The second sand layer, between 30 and 100 cm depth, is also evident in all cores from this site (Fig. 3). The top of the third and lowermost sand layer recovered is between 160 and 215 cm in all cores except cores 4 and 5 (Fig. 3). Core 3 was the only core that penetrated through this sand layer to the underlying brownish-gray mud at 294 cm (Fig. 3). Another sand layer that does not appear to correlate with sand layers in other cores is evident in core 1 between 22 and 41 cm.

Activity of ^{137}Cs within recent salt-marsh sediments can provide stratigraphic markers associated with nuclear weapons testing (Delaune et al., 1978). We measured the ^{137}Cs activity in the top 30 cm of core 3 to date the overwash fan in the upper 20 cm of marsh sediments. The peak in ^{137}Cs activity corresponding to ca. A.D. 1963 is evident just above this sand layer in core 3 (Fig. 3), indicating that deposition occurred just prior to 1963. In addition, an overwash fan is evident in the 1963 aerial photograph and is not in the aerial photograph from 1961 (Fig. 2). Stratigraphic and historic evidence indicates that this fan was deposited by the only major storm in this interval, the Ash Wednesday northeaster of 1962.

Pollen preserved in lake and marsh sediments in the northeastern United States records the decline of chestnut (*Castanea*) associated with a blight that spread to southern New Jersey by 1920 (Anderson, 1974), and the increase of native weeds *Ambrosia* and *Rumex*, associated with European-style forest clearance and agriculture ca. A.D. 1700 (Brugam, 1978; Clark and Patterson, 1985).

We counted pollen samples from cores 5, 8, and 9 in order to provide additional age control. The relative abundance of chestnut pollen decreased from between 3% and 10% at ~35–40 cm to <1% above 20 cm in cores 5 and 9 (Fig. 3; Table A[1]), and is likely associated with the chestnut blight that drastically reduced the population of mature chestnut trees between A.D. 1915 and 1920.

Rumex and *Ambrosia* pollen increase in abundance between 90 and 80 cm in cores 5, 8, and 9 (Fig. 3), and likely represent the initiation of widespread forest clearance and agriculture ca. A.D. 1700. This rise in agricultural indicators and the decline in chestnut pollen indicate that the overwash fan between 30 and 100 cm was deposited roughly between A.D. 1700 and 1920.

Accelerator mass spectrometer ^{14}C dates were obtained for 11 samples and the results calibrated for secular changes in ^{14}C concentrations using the Calib 4.1 program (Stuiver et al., 1998) at two standard deviations (Table 1). In order to quantify the probability that the age of any one sample is represented by each of its calibrated age ranges, we used method B of the Calib 4.1 program.

TABLE 1. RADIOCARBON DATES FROM WHALE BEACH, NEW JERSEY

Index No.	Laboratory number	Core	^{14}C age* (yr BP)	Species	2 σ calendar age range(s) in yr A.D. (probabilities)	Sample depth (cm)
1	Beta-129431	WB7	>Modern	*S. alterniflora*	N/A	102–104
2	Beta-131489	WB7	230 ±40	*S. alterniflora*	1522–1571 (0.074) 1627–1689 (0.413) 1729–1811 (0.426) 1923–1948 (0.087)	102–104
3	Beta-129433	WB9	60 ±40	*S. alterniflora*	1670–1955 (1.000)	65.5–66.5
4	Beta-128149	WB9	210 ±40	*S. alterniflora*	1537–1538 (0.007) 1635–1696 (0.312) 1723–1815 (0.525) 1840–1872 (0.023) 1917–1949 (0.133)	64–65
5	Beta-131490	WB8	220 ±40	*S. alterniflora*	1526–1558 (0.030) 1630–1695 (0.368) 1725–1815 (0.490) 1851–1861 (0.005) 1918–1944 (0.106)	75–75.5
6	Beta-129432	WB8	110 ±40	*S. alterniflora*	1674–1773 (0.360) 1800–1940 (0.640)	75–75.5
7	Beta-124176	WB1	290 ±50	*S. alterniflora*	1472–1671 (0.968) 1778–1798 (0.032)	98–99
8	Beta-124177	WB2	300 ±40	*S. alterniflora*	1486–1658 (1.000)	88–89
9	Beta-129430	WB5	180 ±40	*S. alterniflora*	1649–1708 (0.214) 1712–1884 (0.645) 1912–1943 (0.142)	140–142
10	Beta-123305	WB1	560 ±50	*S. alterniflora*	1301–1370 (0.525) 1376–1434 (0.475)	136–136.5
11	OS-26451	WB3	680 ±30	*S. alterniflora*	1278–1319 (0.581) 1353–1389 (0.419)	294–295

* Radiocarbon ages were determined by accelerator mass spectrometry based on a ^{14}C half-life of 5568 yr.

Eight samples were ^{14}C dated from the base of the overwash fan present between 30 and 100 cm, including duplicate samples from cores 7, 8, and 9. Five of these ^{14}C-dated samples (2, 3, 4, 5, and 6) produced multiple calibrated ranges in the sixteenth, seventeenth, eighteenth, nineteenth, and twentieth centuries; the highest probability ranges were in the late eighteenth and early nineteenth century (Fig. 3; Table 1). These most-probable calibrated ^{14}C age ranges are consistent with the age range of A.D. 1700–1920 derived from pollen data. Sample 1, one of the two samples from core 7, yielded an anomalous age of greater than modern (A.D. 1950) and was not calibrated. Two of the eight samples (7 and 8) yielded older calibrated age ranges, primarily between the late fifteenth and seventeenth centuries (Table 1). This discrepancy in age is likely the result of the loss of mud-dominated sediments, which are easily deformed and eroded during storm events (Klein, 1986). Soft-sediment deformation at the contact between overwash sand and underlying mud and muddy peat deposits in many of the cores indicates that some sediment may have been removed as the barrier was overtopped by storm surge.

Pollen and ^{14}C results indicate that this overwash fan most likely originated in the early nineteenth or late eighteenth century. The calendar ranges after A.D. 1920 and before A.D. 1700 can be eliminated given the additional age limitations provided by the pollen data (Fig. 3). The overlap of the remaining calibrated age ranges provides the best age estimate of the organic sediments below this sand layer at A.D. 1729–1773 and A.D. 1800–1811 (Fig. 3). The most significant storm striking the New Jersey coast in the historic interval was the hurricane of September 3, 1821; therefore, this overwash fan was most likely deposited by this storm. Because the position of the beachfront in 1821 was at least 300 m farther seaward than it is today (Fig. 2), the 1821 overwash fan must have been transported significantly farther than the smaller fan associated with the 1962 northeaster.

[1]GSA Data Repository item 2001068, Table A (pollen data from cores WB5, WB8, and WB9), Table B (^{137}Cs data from core WB3), and Figures A–C (assorted photographs), is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, editing@geosociety.org, or at www.geosociety.org/pubs/ft2001.htm.

The age of the lowermost sand layer at the base of all cores except 4 and 5 is best defined by two ^{14}C dated samples (10 and 11). The calibrated ^{14}C age of the sample from the interval 136–136.5 cm in core 1 (8) indicates that the underlying sand was deposited before A.D. 1434 (Table 1). A ^{14}C-dated sample from the mud unit at the base of this sand layer in core 3 (11) indicates that this sand was deposited after A.D. 1278 (Table 1). Extrapolating the barrier beach migration rate of 2 m/yr to this interval suggests that the position of the beachfront when this oldest overwash fan was deposited may have been close to 1 km farther seaward than it was in 1821. Because the sand layer deposited between A.D. 1278 and 1438 is thicker than the fan deposited in 1821 and was probably transported a greater distance, the 1278–1438 overwash fan was likely deposited during an intense hurricane strike, potentially more powerful than the 1821 hurricane.

Hurricane Strike Probabilities

Stratigraphic evidence from Whale Beach indicates that at least two intense hurricanes (winds >50 m s^{-1}) have probably struck the central New Jersey coast in the past 700 yr, indicating an annual landfall probability of $\sim$0.3%. This estimate is generally consistent with the estimate derived from a wind-speed probability model (Murname et al., 2000) defined by the 1900–1997 HURDAT data set (Neumann et al., 1993), which yields an annual probability of 0.15%–0.45% for winds in excess of 50 m s^{-1} at Whale Beach.

The probability of an intense landfalling hurricane strike on the coast of New Jersey derived from both historic and stratigraphic information is considerably less than the 0.9% annual probability estimate from southern Rhode Island (Donnelly et al., 2001). This regional difference in vulnerability to intense hurricanes likely reflects the tendency of hurricanes to track to the north and northeast in the western North Atlantic under the influence of prevailing westerly winds. Given this tendency for hurricane track recurvature and the geometry of the east coast of the United States, New Jersey is somewhat sheltered from the more common hurricane paths, whereas New England protrudes out into the western Atlantic and is much more often in the path of hurricanes that are slow to recurve to the northeast.

Liu and Fearn (2000) estimated that the annual probability for category 4 and 5 hurricane strikes (winds >59 m s^{-1}) on the Gulf Coast has been <0.1% in the past 1400 yr. Given these records, the northeastern United States may be between three and nine times more likely to be struck by a category 3 or stronger hurricane than the Gulf Coast of the U.S. is likely to be struck by a category 4 or 5 hurricane. This difference likely reflects the relative rarity of category 4 and 5 hurricanes compared to category 3 hurricanes. In the twentieth century, $\sim$30% of landfalling hurricanes in the United States were of category 3 intensity, whereas only $\sim$11% were of category 4 or 5 intensity (Neumann et al., 1993).

CONCLUSIONS AND IMPLICATIONS

This study provides evidence of historic and prehistoric storms striking the central New Jersey coast. Overwash deposition associated with the Ash Wednesday storm of 1962 is recorded within the marsh sediments at Whale Beach, New Jersey. A large overwash deposit dating to the late eighteenth to the early nineteenth century was most likely deposited by the hurricane of September 3, 1821. Another overwash fan was deposited between A.D. 1278 and 1438 and likely indicates a prehistoric intense hurricane strike.

Understanding how the position of the shoreline changes with time is necessary in order to evaluate how the sensitivity of a site to overwash deposition may have changed. Historic evidence of landward migration of Whale Beach at a rate of $\sim$2 m/yr indicates that older overwash fans must have been transported much greater distances to the study site.

These results suggest that intense hurricanes can transport significantly more sediment into backbarrier environments in a few hours than northeasters that may last for several days. Even though intense hurricane strikes are relatively rare events compared to northeasters, they likely play a significant role in the long-term evolution of barrier islands in the northeast United States.

This record of overwash deposition coupled with the historical record indicates that at least two intense hurricanes have made landfall in New Jersey in the past 700 yr. Intense hurricane landfalls on the New Jersey coast appear to be relatively rare events with an annual probability of $\sim$0.3%. The New Jersey coast may be about three times less likely to be struck by a category 3 hurricane than southern New England. New Jersey may be three times more likely to experience a category 3 hurricane than portions of the Gulf Coast of the United States are likely to be struck by a category 4 or 5 hurricane.

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