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Late Holocene marine transgression and the drowning of a coastal forest: Lessons from the past, Cape Cod, Massachusetts, USA

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ABSTRACT

Extra-tropical storms in the spring of 2010 swept the New England coastline resulting in significant erosion along South Cape Beach, a barrier system located on Cape Cod, Massachusetts. The erosion revealed 111 subfossil stumps and a preserved peat outcrop. We hypothesize that the stumps represent an ancient Eastern Red cedar, *Juniperus virginiana*, stand growing in a back-barrier environment and drowned by episodic storm events and moderate rates of sea-level rise. Stumps, bivalves, and organic sediments, were radiocarbon dated using traditional and continuous-flow Atomic Mass Spectroscopy methods. Six sediment cores elucidated subsurface stratigraphy and environmental setting. Subfossil stumps ranged in age from 413 ± 80 to 1239 ± 53 calibrated years before present. We assume that this age represents the time at which the ancient trees were drowned by marine waters. Based on elevation and age, an 826 year rate of submergence was calculated at 0.73 mm/yr with an R^2 value of 0.47. Core stratigraphy, microfossil assemblages, and radiocarbon ages indicate a dynamic barrier environment with frequent overwash and breaching events occurring during the past 500 years. Shoreline change analysis showed that between 1846 and 2008, the shoreline retreated landward by 70 m at a long-term rate of 0.43 m/yr. Future increases in the rate of sea-level rise, coupled with episodic storm events, will lead to the destruction of terrestrial environments at rate orders of magnitude greater than that during the time of the paleoforest.

1. Introduction

1.1. Background

General questions about the spatial and temporal response of barrier beach systems to marine transgression during the late Holocene remain unanswered. This leaves society vulnerable to ongoing and future climate change. When preserved in submerged paleolandscapes, remnants of coastal forests can yield a record of environmental change as the death of particular species and its replacement by more salt tolerant flora, can serve as a proxy for determining the character and timing of inundation (Hunter et al., 2006). Paleolandscapes submerged under coastal and marine sediments are a diminishing and important resource providing signatures of environmental change and a guide for locating cultural resources in coastal settings (Momber, 2004). Submerged terrestrial landscapes can also be used to determine a rate of transition between freshwater and saltwater environments elucidating local sea-level fluctuations (Long et al., 2006). In the light of accelerated rates of sea-level rise (SLR), information about coastal evolution may forewarn coastal managers and decision makers, thus enhancing their ability to anticipate future change (Orson and Howes, 1992; Momber, 2004). Failure to anticipate future changes, due to a lack of understanding about past changes, leaves society vulnerable to coastal hazards associated with climate change.

The drowning and preservation of ancient coastal forests can occur in response to both passive and active mechanisms. Relative SLR caused by gradual land subsidence, uplift, or eustatic changes occurring over centurial to millennial time scales is the primary passive mechanism of submergence (Belknap et al., 2005). Active mechanisms can occur at time scales as little as hours and include episodic flooding events brought on by sudden crustal movements and storm surges associated with tropical and extra-tropical storms (Atwater and Yamaguchi, 1991; Donnelly, 2005). As there is little known about how coastal forests respond to passive and active mechanisms of change, and what their preservation along continental shelves can tell us, it is important to investigate paleolandscapes that may illuminate the response of coastal forests to late Holocene sea-level rise and storminess.

Hunter et al. (2006) deciphered important chapters in the coastal evolution of Lake Heron based on a submerged conifer forest. In that

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study, dendrochronological analysis of subfossils deciphered lake level fluctuations and paleoclimate conditions during the mid-Holocene approximately 7300 years before present (ybp). Lyon and Harrison (1960) used the radiocarbon age and elevation of several *Pinus strobus* stumps from three drowned forests in coastal New England to determine an average rate of submergence for the region and substantiate the geomorphic evidence of transgression during the past few thousand years. Through comparing local submergence rates with rates of eustatic SLR, areas of crustal stability and downwarping were identified (Lyon and Harrison, 1960; Harrison and Lyon, 1963).

Similarly, Bloom (1963) documented fluctuations of relative sea level and crustal rebound using submerged tree stumps along the New England coastline dating to between approximately 1280–4200 ybp. Assuming the trees grew with their roots above the high-tide level, Bloom (1963) concluded that the stumps provided a minimum value of marine submergence during the past 4200 years.

Along the coast of Plymouth, Massachusetts, Gontz et al. (2013) documented the presence of 18 preserved *J. virginiana* stumps along the mudflats and fringing saltmarsh of Duxbury Bay. In that study, AMS radiocarbon dating revealed that the trees had been submerged between 2219 ± 94 and 2867 ± 79 calibrated years before present (cal BP), with the topographically highest sample returning the youngest date. Based on radiocarbon age and subfossil elevation, an approximate rate of landscape transgression for the site was calculated at 1.4 mm/yr with an R^2 value of 0.97. (Gontz et al., 2013).

Active submergence, brought about by flooding events caused by tectonic movements of the crust or catastrophic tsunamis, can also rapidly drown coastal forests (Atwater and Yamaguchi, 1991; Dawson, 1994). Along the Washington coastline, Atwater and Yamaguchi (1991) documented that buried marshes and forests record episodic inundation during the Holocene. At that location, the transition between fresh and marine environments was attributed to catastrophic tectonic subsidence combined with a tsunami (Atwater and Yamaguchi, 1991). Their findings were based on radiocarbon dated subfossil stumps, which showed marine flooding occurred rapidly, too quickly to attribute to passive SLR (Atwater and Yamaguchi, 1991). In their study, Atomic Mass Spectroscopy (AMS) radiocarbon analysis of subfossil cedar stumps provided valuable insights into prehistoric coastal response to active flooding events allowing for a greater awareness about potential future scenarios of marine submergence (Atwater and Yamaguchi, 1991).

There have been several studies documenting how hurricanes can catastrophically change the physical and biological structure of coastal forests existing in the modern environment (Conner et al., 1997; Boose et al., 2001). Coastal forests are impacted during hurricanes through high winds, surged and blown saltwater intrusion, and barrier breaching (Baker, 1978). An early documentation of the impacts of hurricanes on coastal forests is provided by Hawes (1939), who reported that as a result of the 1938 Hurricane there was widespread destruction of several acres of cedar trees in Voluntown, Connecticut. In 2003, Hurricane Isabel caused widespread damage in the Great Dismal Swamp National Wildlife Refuge, located in North Carolina (Belcher and Poovey, 2006). Isabel resulted in the immediate destruction of 85% of the 1000 ha of mature cedar stands within the refuge. In another study, McCoy and Keeland (2006) documented high winds from Hurricane Katrina damaged at least 32% of the cedar trees within Grand Bay National Wildlife Refuge, located in Mississippi.

Surging marine waters often causes the most damage to coastal forests during storm events especially if topographical conditions allow for the pooling and infiltration of saltwater into underlying soils (Pezeshki and Chambers, 1986). Hook et al. (1991) documented the destruction of a South Carolina coastal forest as a result of Hurricane Hugo in 1987. In addition to heavy wind damage, wind-blown waves and storm surge carried saltwater into the forest causing significant tree mortality. At this location, a storm surge of 3 m was recorded and resulted in the destruction of over 3.47 ha of coastal forests.

1.2. Study site

During March 2010, the U.S. northeast coast experienced a series of large, slow moving extra-tropical storms, locally referred to as Nor'easters. The storm systems resulted in large amounts of precipitation and widespread flooding and coastal erosion. Along the south facing shores of Cape Cod, many beaches experienced an excess of 20 cm of beach and shallow shoreface lowering. Erosion along a 200 m section of the eastern end of South Cape Beach (SCB) barrier system revealed the presence of 111 preserved subfossil stumps in growth position in intertidal and subtidal areas within an intermittent peat deposit (Fig. 1). Areas containing drowned coastal forests in New England are often in transition to saltmarshes as soil salinity increases and then later buried by landward retreating barrier sands (Lyon and Goldthwait, 1934). In more recent times, the preserved remnants of forests became exposed by the retreat of the shoreline due to SLR and storms resulting in the scouring away of the foreslope (Lyon and Goldthwait, 1934).

The study site is located along the eastern end of the SCB barrier system on the south shore of Cape Cod, Massachusetts centered at 41°33′ 07.50″ north latitude and 70° 29′ 49.30″ west longitude (Fig. 1). The paleoforest site is part of the South Cape Beach State Park, managed through a partnership between the Massachusetts Department of Conservation and Recreation (DCR) and the Waquoit Bay National Estuarine Research Reserve (WBNERR). SCB is a 2.9 km barrier system adjacent to Nantucket Sound. Sediment supply arrives via wave and current transport from offshore shoals and eroding bluffs to the east. Net littoral transport generally trends from east to west (Berman, 2011).

The western end of the barrier is known as Dead Neck and terminates at the navigable entrance to Waquoit Bay which has been stabilized with jetties. Washburn Island extends the barrier further westward from the main channel. Looking to the east, the barrier protects an extensive saltmarsh system which connects two salt ponds, Sage Lot Pond to the west, and Flat Pond to the east (Fig. 1). The eastern end of the barrier becomes welded to uplands and has been heavily modified through the development of a private golf course and large estates fronted by seawalls and groins.

A narrow 20–30 m wide by 2–3.5 m high dune system lies between the active beach and the Flat Pond marsh system. Using ground penetrating radar and historic cartographic sources, Maio et al. (2012b), identified two buried channels within the barrier which formally connected Flat Pond to Nantucket Sound. The presence of buried channels indicates that there have been repeated morphologic and hydrologic changes likely resulting in rapid fluctuations between salt and fresh hydrologic regimes in the back-barrier environment (Orson and Howes, 1992). Currently, the only tidal input entering Flat Pond arrives through a restored culvert system on the eastern side and saltwater intrusion through the barrier.

1.3. Barrier plant communities

Today the plant communities along the barrier are typical of other New England coastal systems and generally include low marsh, high marsh, marsh fringe, upper boarder, and upland (Clark and Patterson, 1985; Orson and Howes, 1992). Along the SCB barrier, the regularly flooded low marsh areas fall below MHW and are often dominated by stands of short and long form *Spartina alterniflora*. High marsh falls at or above MHW and has plant communities dominated by *Distichlis spicata* and *Spartina patens*. Short-form *S. alterniflora* as well as *Juncus gerardi* are also found in this zone. The marsh fringe is co-dominated by *Iva frutescens* and *J. gerardi* and often contains dead or dying *J. virginiana* trees and stumps marking the lower threshold of this species (Clark, 1986). The upper boarder marks a transitional zone between the brackish fringe marsh and terrestrial upland. The upper boarder contains healthy stands of *J. virginiana*. Moving landward from the