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Impact of Hurricane Sandy on salt marshes of New jersey

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ABSTRACT

Hurricane Sandy, one of the largest Atlantic hurricanes on record, made landfall as an extratropical cyclone on the coast of New Jersey (29 October 2012) along a track almost perpendicular to the coast. Ten days later a northeaster caused heavy precipitation and elevated water levels along the coast. Two years of pre-storm monitoring and research in marshes of Barnegat Bay and the Delaware Estuary provided an opportunity to evaluate the impacts of Hurricane Sandy and the succeeding northeaster across the region. Peak water levels during Sandy ranged from 111 to 184 cm above the marsh surface in Barnegat Bay and 75–135 cm above the marsh surface in the Delaware Estuary. Despite widespread flooding and damage to coastal communities, the storm had modest and localized impacts on coastal marshes of New Jersey. Measurements made on the marsh platform illustrated localized responses to the storms including standing biomass removal, and changes in peak biomass the following summer. Marsh surface and elevation changes were variable within marshes and across the region. Localized elevation changes over the storm period were temporary and associated with subsurface processes. Over the long-term, there was no apparent impact of the 2012 storms, as elevations and regression slopes pre- and several months post-storm were not significant. Vegetation changes in the summer following the fall 2012 storms were also variable and localized within and among marshes. These results suggest that Hurricane Sandy and the succeeding northeaster did not have a widespread long-term impact on saline marshes in this region. Possible explanations are the dissipation of surge and wave energy from the barrier island in Barnegat Bay and the extreme water levels buffering the low-lying marsh surface from waves, winds, and currents, and carrying suspended loads past the short-statured marsh grasses to areas of taller vegetation and/or structure. These findings demonstrate that major storms that have substantial impacts on infrastructure and communities can have short-term localized effects on coastal marshes in the vicinity of the storm track.

1. Introduction

Hurricanes have the potential to cause abrupt and occasionally long-term changes to the hydrology, morphology and biological community of coastal marshes. However, recent studies call into question the relative importance of episodic large storms on important physical processes such as sediment deposition (Smith et al., 2015) and lateral erosion (Leonardi et al., 2016) over the long-term. These studies suggest that for coastal marshes, frequent and regular events (e.g., river flooding, tides, wind) have a greater influence on marsh morphology over the long-term than infrequent high energy storms. This is significant because episodic disturbances have been thought to represent important mechanisms for marshes to overcome sediment deficits and keep pace with sea-level rise (Goodbred and Hine, 1995; Roman et al., 1997). In addition to their temporal importance, the magnitude of hurricane effects on marshes is also determined by the spatial breadth of impact. The effects of storms on low-lying marshes are often localized and spatially variable depending on factors such as storm intensity, location relative to storm track, and geomorphology (Guntenspergen et al., 1995). Factors such as hurricane size, intensity, coastline elevation and angle to which the hurricane makes landfall all contribute to wetland impacts (Resio and Westerink, 2008). Erosion of marsh edges and surfaces may depend on the coupling between water and wind, specifically water depths during time periods of maximum wind stress (Morton and Barras, 2011). Landscape features such as barrier islands, which may be a source of sediment for back-barrier marshes (Donnelly et al., 2001), can reduce storm impacts on mainland marshes by reducing wave energy and wave heights (Stone and McBride, 1998; Dietrich et al., 2011).

Nonetheless, localized, and occasionally regional, effects of

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storms can be impressive. Immediate effects include temporary increases in water levels associated with storm surge, storm tides, and heightened wave activity, which can have direct impacts such as the uprooting and removal of vegetation (Chabreck and Palmisano, 1973; Guntenspergen et al., 1995), deposition of sediments (Cahoon et al., 1995a) and organic debris (Mckee and Cherry, 2009), and scour and erosion (Howes et al., 2010). Physical impacts can include folding, tearing, and compression of the marsh (Guntenspergen et al., 1995), altering local flooding dynamics and elevation. Ponds formed by storm-induced erosion can remain part of the marsh landscape for decades or longer (Morton and Barras, 2011). While evidence of storms such as sediment deposits can be found 214 km from the storm track (Tweel and Turner, 2012), they are more often found in the vicinity of inlets or overwash fans (Roman et al., 1997; Donnelly et al., 2004). Individual storms can deposit sediments three orders of magnitude higher than pre-storm deposition (Cahoon et al., 1995a) and 9 cm thick (Nyman et al., 1995). Hurricane Katrina (29 August 2005) was implicated in leaving behind a 50-cm thick coarse-grained sand layer in a marsh along Bay Champagne in south Louisiana (Naquin et al., 2014). Locally, vegetation structure can influence spatial variation in storm deposition. During Hurricane Andrew in 1992, sediment deposition in stands of *Juncus roemerianus* was almost two times greater than in stands of *Spartina alterniflora* associated with a greater stem density (Nyman et al., 1995). In turn, sediments and organic material deposited from storms can serve as a source of nutrients (Nyman et al., 1995) and provide an escape from high sulfide concentrations, increasing plant productivity (Mckee and Cherry, 2009; Baustian and Mendelssohn, 2015). Sedimentation from hurricanes can often be greater than long-term annual accretion (Nyman et al., 1995; Baumann et al., 1984) and can lead to longer-term elevation changes. Hurricane Katrina deposited 3–8 cm of organic sediment in two subsiding salt marshes in the Mississippi River delta, Louisiana, and this deposition aided in a net elevation gain of 0.7–1.7 cm when recorded two years after the event (Mckee and Cherry, 2009). However, much of what we know about the effect of hurricanes on coastal wetlands is from the rapidly subsiding deltaic marshes of the northern Gulf of Mexico (Baumann et al., 1984; Connor et al., 1989; Reed, 1988; Day et al., 1995; Cahoon, 2006), where large storm events are relatively frequent. Less is known about the effects of hurricane strikes on marshes along the Atlantic coast, particularly in the mid-Atlantic where return periods for hurricanes of $\geq$64 kt range from 15 to 20 years (http://www.nhc.noaa.gov/climo/#returns). Understanding the impacts of hurricanes on coastal systems along the Atlantic is important as the frequency of the strongest hurricanes is predicted to increase (Bender et al., 2010).

Hurricane Sandy, one of the largest Atlantic hurricanes on record, made landfall as an extratropical cyclone near Brigantine, New Jersey at 2330 h on 29 October 2012. Sandy originated as a tropical wave along the west coast of Africa on 11 October (Blake et al., 2013). By late 21 October the circulation of the low pressure system was well defined south of Jamaica. The cyclone intensified as it passed over Jamaica and became a major hurricane with wind gusts of 100 kt prior to landfall in Cuba. As Sandy accelerated northward, it encountered colder waters and a high pressure pattern over the North Atlantic, which weakened the storm and prevented its passage out to sea, respectively (Blake et al., 2013). Storm-force winds extended over 900 km from the center, affecting Atlantic coast states from Florida to Maine (FEMA, 2013). The extratropical cyclone made landfall on the New Jersey coast with an estimated intensity of 70 kt. Wind gusts approached 80 mph (Sullivan and Uccellini, 2012) and just south of landfall at Atlantic City, storm surge peaked at 1.77 m (Blake et al., 2013). Coastal inundation and precipitation associated with the storm averaged 1.16 m and 15.60 cm, respectively (Blake et al., 2013). Hurricane Sandy's trajectory followed an almost unprecedented track, with an impact angle almost perpendicular to the shoreline. The likelihood of a hurricane following a similar track was estimated at 1 in every 714 years (Hall and Sobel, 2013) and storm surges of Sandy's magnitude in this region occur on average every 400–800 years (Lin et al., 2012; Aerts et al., 2013). Ten days after Hurricane Sandy made landfall on 8 November 2012, a northeaster delivered rain, snow, and gusty winds along the coast of New Jersey and neighboring states.

Pre-hurricane monitoring and research in coastal marshes of Barnegat Bay and the Delaware Estuary, New Jersey provided the opportunity to evaluate the impact of Hurricane Sandy and the northeaster that followed on marsh accretion, elevation change, and vegetation. In Barnegat Bay, Hurricane Sandy caused geomorphic changes to the barrier island including widespread shoreline retreat (46% of shoreline), which averaged 12 m and the creation of two breaches in the northern section near Mantoloking (Miselis et al., 2015). Marshes on the barrier island and mainland of Barnegat Bay, as well as marshes that lay south-west of the storm track on the New Jersey bay shore of the Delaware Estuary were the focus of this study. Accretion, elevation change and vegetation data collected since 2011 allowed an opportunity to examine the effect of the fall 2012 storms. Water level data were collected prior to and over the storm period. For this evaluation, we also collected post-storm soil bulk density and percent sand content to characterize potential storm deposition.

2. Study areas

The effects of Hurricane Sandy and the succeeding northeaster on salt marsh accretion, elevation change, and vegetation were examined in six marshes along the mid-Atlantic coast in Barnegat Bay and the Delaware Estuary. Marsh sites were within 35 km of the Atlantic Ocean and ranged from 26 to 72 km from the storm track. The eye of Hurricane Sandy tracked southwest of Barnegat Bay marshes and northeast of the Delaware Bay marshes (Fig. 1). The six marshes included in this study were part of a larger regional assessment of wetland integrity, the Mid-Atlantic Coastal Wetland Assessment (MACWA).

Geomorphic settings of the marsh study sites varied across the region (Fig. 1). Two back-bay and one barrier island marsh in Barnegat Bay and three marshes along tidal tributaries varying in size in Delaware Bay were included in this study (Fig. 2). Barnegat Bay is a shallow coastal lagoon (depth averaging ~2 m) extending 62.7 km along the coast of New Jersey. The estuary is connected to the Atlantic Ocean via Barnegat and Little Egg Inlets and experiences a relatively small tidal amplitude ranging from 20 to 50 cm depending on location in the bay (Defne and Ganju, 2014). Mean salinity in the bay ranges from 18 to 25 with lowest salinities in the northern part of the bay farther from the inlets and near Toms River (Kennish, 2001). Reedy Creek marsh (RC) is along a back-barrier tidal creek in the northern part of Barnegat Bay south of the Mantoloking Bridge. RC was directly across the bay from where Sandy created a new inlet in the barrier island, which was manually filled in within a week of the hurricane. The barrier island marsh in Island Beach State Park (IBSP) is located mid-bay on Barnegat Bay Island approximately 4 km north of Barnegat Inlet. IBSP marsh is bordered to the east by scrub forest and a road, however, it may be subject to overwash during large storms from sandy dunes approximately 400 m to the east. Channel Creek (CC) marsh was located in the southern part of the bay on a small (~0.8 km^2) peninsula just north of Dinner Point Creek. The Delaware Estuary, by comparison, is a large coastal plain estuary (~17,680 km^2) open to the coastal ocean and experiences a tidal amplitude of ~1.5 m