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Differences in impacts of Hurricane Sandy on freshwater swamps on the Delmarva Peninsula, Mid-Atlantic Coast, USA

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ABSTRACT

Hurricane wind and saltwater surge may have different influences on the subsequent composition of forests. During Hurricane Sandy, while damaging winds were highest near landfall in New Jersey, inundation occurred along the entire eastern seaboard from Georgia to Maine. In this study, a comparison of damage from salinity intrusion vs. wind/surge was recorded in swamps of the Delmarva Peninsula along the Pocomoke (MD) and Nanticoke (DE) Rivers, south of the most intense wind damage. Hickory Point Cypress Swamp (Hickory) was closest to the Chesapeake Bay and may have been subjected to a salinity surge as evidenced by elevated salinity levels at a gage upstream of this swamp (storm salinity = 13.1 ppt at Nassawango Creek, Snow Hill, Maryland). After Hurricane Sandy, 8% of the standing trees died at Hickory including *Acer rubrum*, *Amelanchier laevis*, *Ilex* spp., and *Taxodium distichum*. In certain plots of Hickory, up to 25% of the standing trees were dead, corresponding with high soil salinity. The most important variables related to structural tree damage were soil salinity and proximity to the Atlantic coast as based on Stepwise Regression and NMDS procedures. Wind damage was mostly restricted to broken branches although tipped-up trees were found at Hickory, Whiton and Porter (species: *Liquidamabar styraciflua*, *Pinus taeda*, *Populus deltoides*, *Quercus pagoda* and *Ilex* spp.). These trees fell mostly in an east or east-southeast direction (88–107°) in keeping with the wind direction of Hurricane Sandy on the Delmarva Peninsula. Coastal restoration and management can be informed by the specific differences in hurricane damage to vegetation by salt vs. wind.

1. Introduction

Hurricane impacts on coastal freshwater forests are related to both breakage from wind and mortality from salinity intrusion, but few studies have attempted to disentangle the relative impacts of these two disturbances. The components of disturbance by hurricanes, wind and saltwater surge have different effects on coastal freshwater systems (Gresham, 1993a) and subsequent vegetation dynamics (Middleton, 1999). While wind damage is usually emphasized in post-hurricane studies (Middleton, 2009a), saltwater surge may affect much larger areas of the coast (Conner, 1995; Stanturf et al., 2007).

Hurricane Sandy had the potential for both wind and saltwater surge with flooding from Georgia to Maine (0.5–9 m; NOAA, 2013). Other hurricanes including Isabel caused 1.5–2.0 m of flooding in Chesapeake Bay (Shen et al., 2006), and Katrina caused up to 10 m of flooding in coastal Mississippi (Fritz et al., 2007). While the force of the tidal waves from storms can cause physical damage to vegetation (Stanturf et al., 2007), even a low amount of salinity can have severe effects on freshwater vegetation (Williams, 1993; Conner, 1995; Stanturf et al., 2007; Piazza and La Peyre, 2009; Werner et al., 2013). After a salinity intrusion event associated with a hurricane in a coastal wetland, salinity levels in the surface water may stay elevated for months (Steyer et al., 2006), with freshening not occurring for as long as one year after a hurricane (Chabrek and Palmisano, 1973). The time required for the freshening of salinified wetlands depends on the amount of rainfall, and the salinity levels of the surface and groundwater (Kaplan et al., 2010), and the process can take longer if soil salinity levels have increased (Overton et al., 2006). This topic is of specific interest to managers because post-hurricane management may depend on whether a hurricane-impacted site was affected by salinity intrusion.

Salt water intrusion damages freshwater wetlands (Gresham, 1993b; Craft, 2012), by causing species composition changes, e.g., tidal fresh to saltmarsh (Crain et al., 2004), and *Salix* – to *Tamarix* – dominated forests (Salinas et al., 2000; Vandersande et al., 2001). Certain marsh species are slow to recover after salinity intrusion from hurricanes, e.g., *Panicum repens* and *Myriophyllum*

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spicatum (Chabrek and Palmisano, 1973). Freshwater palm forests subjected to higher salinity have smaller trees and higher dominance by saltwater tolerant species in the understory, e.g., mangrove fern (*Acrostichum aureum*; Feagin et al., 2013). In freshwater swamps, higher tree density and production occur in *Taxodium distichum* (baldcypress) freshwater nearest 0 ppt (Wicker et al., 1981; Middleton et al., 2015, respectively).

The effects of salinity on species vary depending on life history stage (Middleton, 1999). For example, elevated salinity levels affect *T. distichum* seedlings more than adults (Conner and Askew, 1992). Sensitivity of early life history stages to salinity is typical of many freshwater species (e.g., *Sabal palmetto*: Williams et al., 1999, respectively); older established individuals can survive longer by utilizing stored belowground resources (Sutter et al., 2014). Because salinity intrusion causes regeneration suppression in freshwater species, vegetation may recover slowly after storms (Barry et al., 1993; Gresham, 1993b; Conner, 1995; Allen et al., 1997; Williams et al., 1999), depending on storm frequency and intensity (Michener et al., 1997; Stanturf et al., 2007). In the absence of salinity, conspecific tree seedlings (Middleton, 2009b) or saplings may re-establish after storms (Uhl et al., 1988), depending on the nature of the post-hurricane environment with respect to flooding, chemical characteristics, shading and seed supply (Middleton, 1999, 2009b).

T. distichum (baldcypress) is an important component of southeastern swamps (Middleton, 2009a), which could have individuals that are resistant to salinity intrusion. Some studies have found higher salinity tolerance in certain populations of *T. distichum* (Allen et al., 1997). Nevertheless, recent genetic studies do not support this idea; the genetics of *T. distichum* individuals surviving and succumbing to high salinity were the same in Gulf Coastal populations of *T. distichum* (Kusumi et al., unpublished data).

Episodic disturbance due to hurricanes may become more frequent with future climate change (IPCC, 2014). At the same time, hurricane events may become a tipping point for permanent shifts in vegetation (Hayden et al., 1991), because salinity intrusion can produce long-term changes in freshwater vegetation composition (Williams, 1993; Conner, 1995; Stanturf et al., 2007; Hoeppner et al., 2008; Shields et al., 2011; Werner et al., 2013). For example, a severe 3 m saltwater surge occurred during Hurricane Hugo in Hobcaw Forest, South Carolina, even though wind damage was minimal (Gresham et al., 1991). During the two years after Hugo, 66% of the trees died including *T. distichum* (Hook et al., 1991). After Katrina and Rita, most of the mid-story trees died in Lake Maurepas, Louisiana due to flooding and high salinity (Shaffer et al., 2009). Natural regeneration may be poor after hurricanes because the post-hurricane window for freshwater tree regeneration may be limited. Pre-emption may curtail the regeneration of freshwater trees if fast-growing and salt tolerant macrophytes move into swamps after storms; three years after Hugo in Hobcaw Forest, macrophytes established (e.g., *Typha* sp., *Phragmites australis*, *Alternanthera philoxeroides*, and *Cladium jamaicense*; Conner, 1995). Beyond lingering salinity in the environment after a hurricane, the establishment of non-resident species also can slow the recovery of an ecosystem (Halpern, 1988).

The objectives of this study were to explore the nature of forested swamp damage by saltwater intrusion and/or wind and water surge from Hurricane Sandy on the Delmarva Peninsula of Maryland and Delaware. Environmental and geographical variables and their inter-relationships to any tree structural damage were also examined.

2. Materials and methods

2.1. Hurricane Sandy

Hurricane Sandy made landfall on October 29, 2012 with highest winds near Atlantic City, New Jersey, but with storm impacts

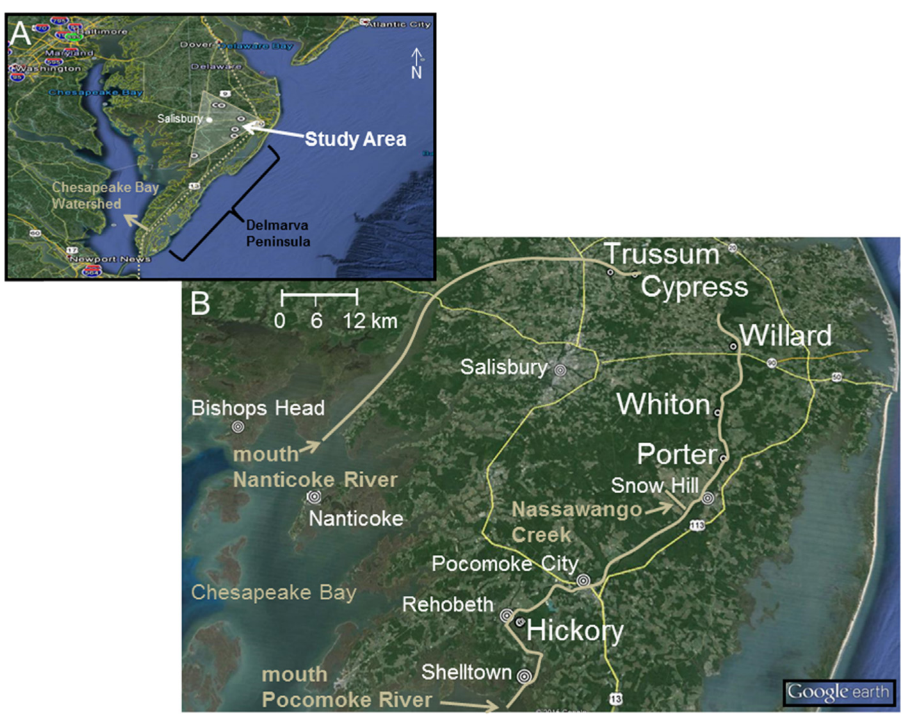

Fig. 1. (A) Location of tree damage study by Hurricane Sandy in *T. distichum* swamps of the Mid-Atlantic Coast on the Delmarva Peninsula. (B) Riverine freshwater swamps included Trussum Pond (Trussum) and Cypress Point (Cypress) along the James Branch, a tributary of the Nanticoke River (Delaware Department of Natural Resources), and Willards (Willard), Whiton's Crossing (Whiton), Porter's Crossing (Porter) and Hickory Point Cypress Swamp (Hickory; tidally affected) along the Pocomoke River (Maryland Department of Natural Resources; Google Earth, 2015). Water gage information came from near Snow Hill MD (Nassawango), and salinity information came from the Shelltown and Pocomoke City Drawbridge gages.