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Research Paper

Assessing the tree health impacts of salt water flooding in coastal cities: A case study in New York City

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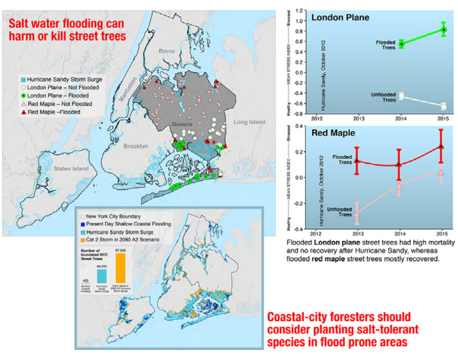
GRAPHICAL ABSTRACT



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ABSTRACT

Hurricane Sandy was the second costliest hurricane in United States (U.S.) history. The category 2 storm hit New York City (NYC) on the evening of October 29, 2012, causing major flooding, wind damage, and loss of life. The New York City Department of Parks & Recreation (NYC Parks) documented over 20,000 fallen street trees due to the physical impact of wind and debris. However, salt water flooding may have caused additional stress to approximately 48,000 street trees located in the storm's inundation zone. Early in the first growing season following Hurricane Sandy (June 2013), NYC Parks staff examined these street trees and found that 6,864 of the flooded trees had a significant proportion of their crown fail to leaf out. Thirty percent of those trees did not leaf out at all. The most commonly affected trees were London plane (*Platanus* × *acerifolia*) and maple species (*Acer* spp.). Here we show that red maple (*Acer rubrum*) is negatively impacted by salt water flooding but can recover over time. London plane trees, on the other hand, experience high mortality and show no signs of recovery 3 years post Sandy. We demonstrate that by 2080 a similar storm could impact almost 100,000 of NYC's street trees. These findings have global implications for coastal urban forests as we face sea level rise and an increasing frequency and magnitude of coastal storms.

1. Introduction

Hurricane Sandy was the second costliest hurricane in United States (U.S.) history (Blake, Kimberlain, Berg, Cangialosi, & Beven II, 2013). The category 2 storm hit New York City (NYC) on the evening of October 29, 2012, causing major flooding, wind damage, and loss of life. The New York City Department of Parks & Recreation (NYC Parks) documented over 20,000 fallen street trees due to the physical impact

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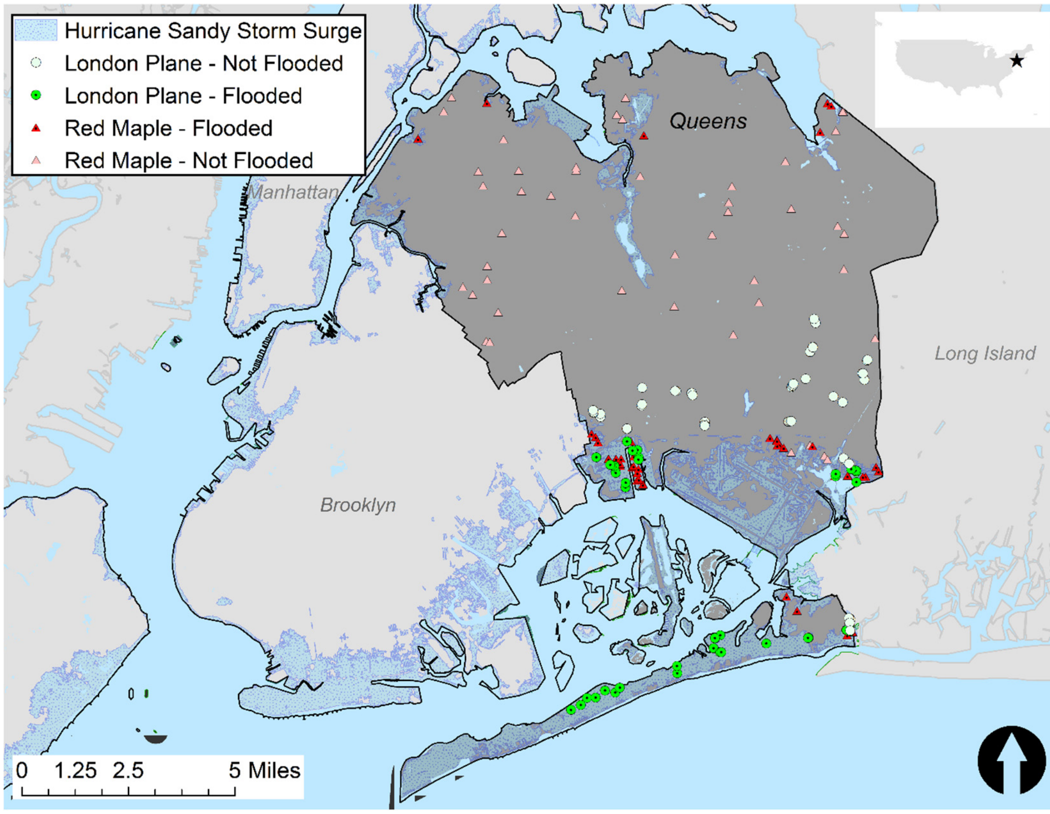

Fig. 1. Study area in Queens, NY showing red maple (red triangle) and London plane (green circle) study trees. Trees located in light blue areas within the NYC boundary were inundated with salt water during Hurricane Sandy. All other trees were not impacted by salt water. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

of wind and debris. However, salt water flooding may have caused additional stress to approximately 48,000 street trees located in the storm's inundation zone. Early in the first growing season following Hurricane Sandy (June 2013), NYC Parks staff examined these street trees and found that 6864 of the flooded trees had a significant proportion of their crown fail to leaf out. Thirty percent of those trees did not leaf out at all. The most commonly affected trees were London plane (*Platanus* × *acerifolia*) and maple species (*Acer* spp.). Here we show that red maple (*Acer rubrum*) is negatively impacted by salt water flooding but can recover over time. London plane trees, on the other hand, experience high mortality and show no signs of recovery 3 years post Sandy. We demonstrate that by 2080 a similar storm could impact almost 100,000 of NYC's street trees.

Hurricane Sandy was an unusual storm and one analysis suggests that the conditions that propelled Sandy into the east coast of the U.S. are not likely to occur again (Barnes, Polvani, & Sobel, 2013). On the other hand, the world's largest port cities are expected to experience increased exposure to coastal flooding due to sea level rise and storm surge during the next 50 years (Hanson et al., 2011). Increased coastal flooding of urban landscapes will also impact our cities' trees, yet little is known about the tolerance of urban street trees, park trees, and forests to salt water inundation.

The projected increase in urban coastal flooding comes at a time when cities, both large and small, in the U.S. and around the world are engaging in urban greening projects (Pincetl, 2010). The increased effort and investment in urban green infrastructure reflects a broad based recognition that trees provide valuable ecosystem services (Seamans, 2013) and are important to the health and wellbeing of urban populations (Kardan et al., 2015). The hope is that street trees planted today will still be alive, healthy and reaching their peak value in terms of ecosystem services they provide in approximately 50 years. A greater understanding of different tree species' tolerance of periodic salt water inundation can inform urban greening strategies in cities' flood prone areas.

NYC Parks survey data provided initial evidence that salt water flooding during Sandy may have impacted the health of all street trees located in the flood zone. Although we are not aware of research specifically looking at the effects of salt water flooding on urban trees, there is extensive literature about the negative effects of flooding and salinity on non-halophyte plants. Soil inundation causes many physiological changes in woody plants not adapted to flooding, including: suppression of leaf formation and expansion; premature leaf abscission and senescence; shoot dieback; inhibition of photosynthesis and carbohydrate transport, macronutrient absorption, root formation and growth (Kozlowski, 1997). Salinity induces a separate suite of symptoms, including: leaf scorching, leaf shedding, twig dieback, and decreased metabolic functions leading to inhibition of vegetative growth (Kozlowski, 1997; Paludan-Müller, Saxe, Pedersen, & Randrup, 2002). Combined flooding and salinity decrease tree growth and survival more than either stressor alone (Kozlowski, 1997). Tolerance to both flooding and salinity varies widely by tree species and genotype (Allen, Chambers, & Stine, 1994; Kozlowski, 1997; Paludan-Müller et al., 2002).

In this study we set out to understand street tree response to salt water inundation by using fine-scale tree health metrics designed to assess physiological stress of trees (Pontius & Hallett, 2014). Our questions were: 1) How much does salt water flooding during a major storm surge event affect the health of street trees? 2) Do flooded street trees recover from stress caused by salt water inundation and how long does recovery take? 3) Are some tree species more sensitive to salt water flooding than others?