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Assessment of Hurricane Sandy damage and resulting loss in ecosystem services in a coastal-urban setting

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ABSTRACT

We quantified the location and extent of damage from Hurricane Sandy in habitats within the complex coastal-urban region of Jamaica Bay, New York and calculated the values of ecosystem services (ESV) lost. Results were compared with those from Hurricane Katrina. We found that moderate flooding and sand deposition were the most prevalent types of damage, and they caused the most degradation to low salt marsh habitat. Compared with Hurricane Katrina, damage from Hurricane Sandy to built and natural capital was generally lower for almost all categories except beach erosion. This was especially damaging due to the high levels of disturbance prevention ecosystem services beaches and dunes provide. Our impact index revealed that the majority of damage was minimal in severity (60%) and would likely be reversed within five years (62%), with a total possible loss of up to US$ 6.5 million for Jamaica Bay, NY. We demonstrated the use of our results to identify vulnerable areas for protection and restoration, and to calculate gains in ESVs in each scenario. By quantifying the location, extent and type of damage from Hurricane Sandy and the ESVs lost, we can provide another dimension to protection and restoration efforts in this sensitive coastal-urban region.

1. Introduction

It is well known that hurricanes cause extensive disturbance, degradation and damage to infrastructure (Morton and Barras, 2011). The frequency and intensity of extreme events, such as hurricanes, tropical storms and cyclones, are forecasted to increase in the future due to global climate change (Edenhofer et al., 2014; Handel, 2013; New York City Panel on Climate Change, 2013). Theoretical arguments and modeling studies indicate that hurricane intensity will increase with increasing global mean temperature, which in turn increases sea surface temperature, and evidence is mounting to support this hypothesis (Elsner, 2006; Ercolani et al., 2015). As extreme events increase, there is an increased need to understand and quantify the damage done to coastal areas as a result of storm surge.

Erosion is a key factor in hurricane-related damage because storm surge can create and enlarge ponds and remove natural vegetation and thereby degrade existing infrastructure in coastal wetlands (Morton and Barras, 2011). Disturbance regulation and prevention, a service provided by coastal wetlands, serves to buffer against storm surge and to decrease damage to natural areas and human infrastructure (Costanza et al., 2006). The shallow depth and emergent vegetation of wetlands can protect coastlines from storm surges by providing frictional resistance that absorbs storm energy. Unfortunately, hurricanes reduce the processes that regulate disturbance through impacts such as marsh denudation and pond expansion and thus natural processes generally cannot remediate shoreline erosion in coastal wetlands (Morton and Barras, 2011).

Hurricane Sandy, which struck in October 2012, had a substantial impact on the communities and habitats along the northeastern coastline of the United States. In particular, Jamaica Bay, our study area located at the southern end of the Boroughs of Queens and Brooklyn in New York City, was one of the region's areas that was most heavily flooded during Hurricane Sandy. More than one-third of all buildings that incurred structural damage during the storm were located in South Queens (New York City Special Initiative for Rebuilding and Resiliency (NYCSIRR): New York City Office of the Mayor, 2013). In general, Jamaica Bay is highly vulnerable to impacts that affect the coast, which include sea level rise, storm surge, and ongoing wetland degradation. Thus, this coastal ecosystem presents an ideal case study to understand the effects of extreme events.

Extreme events impact coastal ecosystem services (ES) (Hauser et al., 2015). Ecosystem services are the benefits that humans receive from ecological functions either directly (e.g., recreation) or indirectly (e.g., waste treatment) from a given type of ecosystem (Costanza et al., 2014; Millennium Ecosystem Assessment, 2003). Typically, land managers use ecosystem services values (ESV), which are most often expressed in monetary units, to assess the value of an ecosystem and

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allocate resources efficiently (Li et al., 2014; Scolozzi et al., 2014; Troy and Wilson, 2006;Woodward and Wui, 2001). Jamaica Bay provides ES that include, but are not limited to, wildlife habitat, protection against coastal erosion, water purification and regulation, nutrient cycling, and recreation (Costanza et al., 2006; Martínez et al., 2007; Woodward and Wui, 2001) and understanding the value of these services would help in better managing this urban-coastal area of sensitive marsh complexes.

Others have studied the effects of hurricanes on marsh complexes (Neyland, 2007), have evaluated impacts of storm surge on a variety of habitats qualitatively (Gornish and Miller, 2010; Howard, 2012; Lugo, 2008; Murrow and Clark, 2012; Ramsey et al., 2012), and have even quantified total loss of ES for wetlands as a result of hurricane action (Costanza et al., 2008; Hauser et al., 2015). However, few have attempted to quantify the range of ES that were lost as a result of hurricane damage, compared the ESV losses to other hurricane events, or have used the information to develop a plan for protection and restoration. Recent calls have asked for science to incorporate ES research more directly into decision-making and restoration planning (Daily et al., 2009) especially for complex urban ecosystems (McPhearson et al., 2015). Tools for decision-making are being created for the Jamaica Bay ecosystem based on climate change, storm surge and other relevant factors ((SLAMM) Clough et al., 2010; (Marsh Equilibrium Model) Morris, 2016; (Visionmaker) Sanderson, 2013; Trust for Public Land, 2016) but little work has been done to include an assessment of ES with a focus on economic impacts. The Department of the Interior's Hurricane Sandy Mitigation Funding supports research projects throughout the Jamaica Bay region aimed at advancing the knowledge of resilience in urban coastal ecosystems (United States Department of the Interior National Park Service, 2015). These research projects will provide essential information to guide habitat restoration, adaptation and resilience efforts throughout Jamaica Bay with relevance to other urban coastal systems. The information provided in our study is the culmination of one of these research projects. By quantifying the location, extent and type of damage from storm surge, the types of ES and ESVs lost, and comparing our results to Hurricane Katrina, we can provide another dimension to the restoration efforts that are being implemented in these sensitive coastal regions (Liu et al., 2010; Troy and Wilson, 2006). Our hope and goal is that this information can be used collaboratively with other ongoing projects to better understand the response of coastal habitats to extreme events and to help create more resilient coastal ecosystems.

In this study, we first quantified the location and extent of the impacts from Hurricane Sandy on habitats within Jamaica Bay, New York using pre- and post-Sandy orthoimagery and land use/land cover (LULC) maps. We then calculated the types of ES and ESVs lost based on the degree of degradation and the types of habitats most affected, and we explored the relationships that exist among damage, habitat and ESVs. We statistically explored the relationship between damage and habitat for built and natural capital and compared damages and services loss from Hurricane Sandy with Hurricane Katrina. We next related damaged areas to property ownership to determine vulnerable parcels whose land could be acquired. Finally, we demonstrated our use of the results from our damage, habitat, and ownership analysis to identify vulnerable areas for protection, to locate possible restoration opportunities, and to calculate gains in ESVs in each scenario.

2. Materials and methods

2.1. Study area and damage mapping

Jamaica Bay, New York (Fig. 1) has a rich diversity of bird and fish species and the largest wetland complex in the New York City area (McPhearson et al., 2013). Despite these positive attributes, Jamaica Bay has changed enormously under human influence since European settlement. Three quarters of its wetlands have been lost, and fill has expanded the uplands to a large extent. The landscape that fringes the Bay has changed from natural coastal marshlands that were bordered by salt shrub and maritime forest into a dense urban matrix that supports over 800,000 people in the communities adjacent to the Bay (McPhearson et al., 2013). Hardened shorelines, pollution combined with sewer overflow inputs, dredging, sea level rise, and loss of freshwater tributaries have resulted in significant marsh fragmentation and loss, and these factors pose the most substantial threats currently facing Jamaica Bay (McPhearson et al., 2013).

Jamaica Bay is considered a priority study area for addressing marsh losses and conducting research, management and restoration of the ecosystem (McPhearson et al., 2013; New York City Parks, 2016). Plans exist to upgrade existing wastewater treatment plants, reintroduce native species, and develop green infrastructure in the surrounding areas to help reduce stormwater runoff and storm surge (New York City Department of Environmental Protection, 2007, 2010; New York City Special Initiative for Rebuilding and Resiliency (NYCSIRR): New York City Office of the Mayor, 2013). Because of anthropogenic alterations and projected climate and sea level changes, we need to learn how areas such as these respond to new ecological stresses.

Our entire methodology for this study is outlined in the flowchart shown in Fig. 2. The first step was to create a map of the areas affected by Hurricane Sandy in Jamaica Bay, NY, called our damage map. Locations in our damage map were delineated through comparison of pre- and post-Sandy aerial photographs (United States Geological Survey, 2012;Federal Emergency Management Agency, 2012, respectively) in ArcGIS 10.3 (Environmental Systems Research Institute, Redlands, CA, USA). Pre-Sandy imagery, with a resolution of 0.6 m, was taken March 1, 2012; Jamaica Bay was flown post-Sandy on November 3 and 4, 2012, with a ground sample distance for each pixel of 0.35 m. The study area boundary was delineated based on the watershed boundary for the bay and measures 356 km^2 in size. Imagery was loaded into ArcGIS with pre-Sandy imagery on the bottom, post-Sandy imagery on top, and a slider bar that we used to view the differences between the two.

Visual inspection of damage from aerial photographs is subject to several forms of bias and error including overlooking particular damage sites, missing entire areas, misattributing sites, and user bias toward certain types of damage recognition. To overcome these issues we created a systemized method for interpretation which included a grid (100 m×100 m) system which allowed focus on one area of imagery before moving on to the next and whose attribute could be changed so the viewer could keep track of areas already covered. We also ensured that the same viewer did all the damage site interpretation in the first round. Then, to overcome user bias and make sure nothing was missed, we had a second separate viewer error check the entire study area to find sites missed, misattributed, or improperly included by the initial viewer.

In both the initial interpretation and the second error-checking scan our viewers visually compared the imagery from the two time periods and digitized the outline of each type of damage observed within the study area boundary. Then they assigned metrics of 1 (present) or 0 (absent) for each damage type present noting that several damage types may be present in a single polygon. The damage types assessed were: minimal, moderate and severe flooding; minimal, moderate and severe artificial debris; minimal and moderate natural debris; sand deposition; and marsh dieback (Fig. 3). Floods were defined as areas with clear changes in depth and extent of water, not driven by tides, compared to the pre-storm condition. Flooded areas were apparent as dark sunken sections of grass or marsh in the aerial photos. Floods were quite clear on pavement and developed areas. Delineation of polygons depicting flood size was determined by the area of the flood visible on the imagery. If a flood took up less than one cell (100 m×100 m), it was digitized as a minimal flood; if a flood covered up to four cells, it was classified as a moderate flood; anything larger was considered a severe flood. Artificial debris was defined as anything