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The effects of estuarine wetlands on flood losses associated with storm surge

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ABSTRACT

Wetlands are frequently cited for their ability to reduce the adverse effects of flooding.

Despite the growing negative impacts of storm surge and tidal flood events on coastal communities in the United States (U.S.), little if any, systematic, observation-based work has been done that measures the effects of estuarine wetlands in reducing actual flood loss.

This study quantitatively assesses the role of estuarine and tidal wetlands in mitigating the amount of surge-induced flood damage experienced on Galveston Island by Hurricane Ike in 2008. Using a novel approach to measuring potential wetland influence, statistical analysis is performed on site-level flood damage observations to detect under which locations and configurations naturally-occurring estuarine wetlands might reduce impacts to residential structures. Results suggest that tidal wetlands may reduce storm-surge induced flood damage under certain distance and location characteristics, yet increase damage in others. Specifically, structures that were within 500' and sheltered by tidal wetlands demonstrated decreased flood damage, however damages increased at distances beyond this threshold, relative to non-sheltered structures. These results provide critical information to the debate on the effectiveness of wetlands for coastal flood mitigation and provide guidance to local decision makers interested in facilitating the development of more flood resilient communities over the long term.

1. Introduction

Naturally-occurring wetlands are often cited for their ability to reduce the adverse effects of flooding. Intact wetland patches, particularly in coastal areas, have the potential to reduce wave action, absorb and slowly release storm-water runoff, and create an unpopulated buffer between human structures and vulnerable areas. Although the number of studies evaluating the protective benefits of wetlands has increased in the last decade, most of the work focuses on quantifying or modeling wave and surge attenuation (e.g. Costanza et al., 2008; Krauss et al., 2009; Gedan et al., 2011; Wamsley et al., 2010; Zhang et al., 2012) rather than measuring the effects of estuarine wetlands in reducing actual flood loss.

This study quantitatively assesses the role of estuarine and tidal wetlands in mitigating the amount of loss experienced by a coastal community during a storm-surge event. Specifically, we measure insured flood losses on Galveston Island caused by Hurricane Ike's storm surge in 2008 to detect under which locations and configurations naturally-occurring estuarine wetlands might reduce impacts to residential structures. Statistical analyses allowed us to estimate the dollar value of wetlands as naturally-occurring flood risk reduction devices after controlling for multiple environmental, socioeconomic, and structural characteristics. Study results add critical information to the debate on the effectiveness of wetlands for coastal flood mitigation and provide guidance to local decision makers interested in restoring and conserving wetlands to facilitate the development of more flood resilient communities over the long term.

2. Background on the relationship between wetlands and storm surge impacts

Communities worldwide are faced with the challenge of protecting coastal infrastructure and critical coastal ecosystems from damaging storms. Hurricane-induced storm surges are considered to be the greatest threat to coastal communities and are the world's leading natural hazard in terms of property damage and deaths (Murty, 1988; Smith and Katz, 2013). From 1900 to 2005, the average damage from hurricanes in the U.S. was estimated at $10 billion per year (Pielke et al., 2008), with much of this damage the direct result of storm surges. Insured flood damages for coastal counties/parishes along the Gulf of Mexico alone was over $20.3 billion between 1999 and 2009 (Brody et al., 2015). At the same time, research on hazard mitigation planning

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and policy has placed an increasing emphasis on a mix of structural and non-structural mitigation techniques to respond to the growing amount of financial loss as a result of storm surge (Brody et al., 2015).

There is currently no consensus on the role of estuarine wetlands in mitigating surge-induced flooding, and there have been few economic valuations of wetlands along the Gulf Coast (Engle, 2011; Barbier and Enchelmeyer, 2014). Previous research has reached various conclusions depending on the study area and methodological approach. For example, in an analysis of 34 major U.S. hurricanes Costanza et al. (2008) found the area of wetlands to be effective in reducing damage per gross domestic product—derived by spatially allocating county level data—based on a regression analysis. The authors calculated that 1 ha loss of wetland corresponds to an average increase of $33,000 (median = $5000) in storm damage from specific storms. A similar regression based analysis conducted by Farber (1987) for Louisiana that also relied on county-level data found that wetlands reduced wind damage, yet stated that effects on flood damage was too difficult to estimate.

Using a hybrid ADCIRC simulation/regression analysis, Barbier et al. (2013) found that wetland continuity and vegetation roughness in Louisiana was effective in reducing surge-induced damage. The authors found that a 0.1 increase in wetland continuity reduces property damages for the average affected area analyzed in southeast Louisiana by $99-$133; and a 0.001 increase in vegetation roughness decreases damages by $24-$43. Based on these calculations, the damage reduction is the same as saving 3 to 5 and 1 to 2 properties per storm for the average area, respectively. Other research using ADCIRC has led to varying findings. Wamsley et al. (2010) concluded that wetlands in Louisiana may reduce storm surge heights, but with variation across the landscape and storm characteristics. Finally, Resio and Westerink (2008) found that wetlands may actually increase storm surge heights under wind-driven storm conditions, again illustrating that the role of wetlands may vary spatially. Using Hurricane Rita as an example, surge heights were increased over some Louisiana marshes during this slowly progressing storm. The impact of coastal wetlands is clearly contingent on multiple factors, including vegetation type and density, landscape structure, storm characteristics, and the presence of human interventions, such as levees (Hu et al., 2015). At the minimum, many experts in the field question whether coastal wetlands would have any dampening effect on extreme storm surges, such as those produced by Hurricanes Katrina and Ike.

Shepard et al. (2011) conducted an extensive review of existing research related to wave attenuation and marsh wetlands. They addressed the following ecosystem services associated with coastal protection: *wave attenuation*, *shoreline stabilization*, and *floodwater attenuation*. The authors concluded that marshes did have a significant positive effect on wave attenuation as measured by reductions in wave height per unit distance across marsh vegetation. However, all of the evaluated research for this meta-analysis was conducted in either the UK or northeastern U.S. It was also noted that most of the identified wave attenuation studies evaluated small to moderate waves (Hs < .5 m) and there was a lack of field studies quantitatively evaluating large waves and storm surge.

Most recently, Narayan et al. (2017) used industry-based high-resolution flood and loss models to estimate the impacts of coastal wetlands in the northeastern USA on regional flood damages by Hurricane Sandy and local annual flood losses in Barnegat Bay, New Jersey. The regional study estimated that wetlands avoided $625 Million in direct flood damages during Hurricane Sandy. The local study evaluated a suite of synthetic storms in Ocean County, New Jersey and estimated a 16% average reduction in annual flood losses by salt marshes with higher reductions at lower elevations. Although this study provides insight into the role that wetlands play in reducing flood losses, the findings are based on scenarios rather than explicitly evaluating the influence of wetlands on actual flood claims.

The above literature review demonstrates large gaps in the literature and the need for increased understanding of the relationship between estuarine wetlands and surge reduction. On the whole, previous research is mixed regarding the effects of tidal wetlands on surge. Much of the existing research relies on simulations and numerical models, which is certainly a contribution to the knowledge base on the topic, but is also an approach that many of the authors have noted is fraught with limitations surrounding the parameterization and representation of estuarine wetlands. Further, there has been some observational research, but it was conducted using spatially coarse data with few statistical controls. Finally, with the attention that Hurricanes Katrina and Rita received in light of wetland loss throughout southern Louisiana, there is clear over-representation of this area of the Gulf of Mexico, which is likely not generalizable.

We seek to address this research gap through a parcel-level study of property damage caused by storm-surge. This observation-based analysis explicitly considers the potential spatial variation in reduction of surge resulting from the presence of tidal wetlands. We ask the research question: *To what degree and under which conditions do naturally-occurring estuarine wetlands effect the amount of flood loss incurred by local coastal communities?*

To address this question, we measured insured flood losses on Galveston Island caused by Hurricane Ike in 2008 to detect under which locations and configurations naturally-occurring estuarine wetlands reduce storm surge impacts to residential structures. Statistical analyses allowed us to estimate the dollar value of wetlands as naturally-occurring flood risk reduction devices. Results add critical information to the debate on the effectiveness of wetlands for flood mitigation and provide guidance to local decision makers interested in facilitating the development of more flood resilient communities over the long term.

3. Research methods

3.1. Study area

We examined insured flood losses from the storm surge produced by Hurricane Ike in 2008 on Galveston Island. Galveston Island is a barrier island located in the northwestern portion of the Gulf of Mexico (see Fig. 1). Based on land cover data from the 2006 NOAA Coastal Change Analysis Program (CCAP), over 99% of the approximately 26 km^2 estuarine wetlands in the study area are classified as estuarine emergent, which NOAA classifies tidal wetlands that are composed of typically perennial herbaceous hydrophytes (NOAA, 2006). On Galveston Island, these emergent estuarine wetlands are dominated by smooth cordgrass (*Spartina alterniflora*) and also include saltwort (*Batis maritima*), saltgrass (*Distichlis spicata*) and glasswort (*Salicornia* spp.) (USFWS, 2012).

Hurricane Ike made landfall on the east end of Galveston Island as a Category 2 storm in the early morning of 13 September 2008 (see Fig. 1). Despite decreasing in intensity from a Category 4 to a Category 2 storm following its path over Cuba, Ike still resulted in damage that would place it as one of the costliest hurricanes in U.S. history at that time. Twelve fatalities in Galveston and Chambers Counties are directly attributable to Ike (Berg, 2009). Total financial damage from Ike in Texas, Louisiana, and Arkansas was estimated at $24.9 billion dollars (Berg, 2009). While Ike generated maximum sustained winds of 110 mph in the Galveston area, this storm was known more for its surge. The maximum high water mark recorded by FEMA was 17.5′, located on Bolivar Peninsula across the mouth of the Bay from Galveston Island. Galveston Island did not receive the equivalent surge on the Gulf side, yet high water mark values still ranged from 10’ – 13', the result of surge pushed into Galveston and West bay, forcing water back over the island from the north (Bay) side.

3.2. Concept measurement

We calculated the residential losses claimed under the National Flood Insurance Program (NFIP) during Hurricane Ike. Several control

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