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Ecological indicators of flood risk along the Gulf of Mexico

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ABSTRACT

Despite mounting economic losses from both acute and chronic flood events in coastal areas of the U.S., little empirical research has been conducted on the importance of existing landscape-level ecological components in mitigating the economic impacts to vulnerable coastal communities over the long term. In recognition of this lack of knowledge base, we examine several ecological indicators across 144 counties bordering the Gulf of Mexico. Specifically, we identify and measure the following four indicators: floodplain area, soil porosity, naturally occurring wetlands, and pervious surfaces. We then statistically test the degree to which these indicators reduce insured flood losses observed across the study area over a five-year period from 2001 to 2005. Results based on multiple regression models controlling for various environmental and socioeconomic characteristics support the notion that certain features of the natural environment help mitigate the negative economic consequences that arise from floods. The findings provide guidance to local and regional policy makers on where to guide future development. Reducing the amount of flood losses helps building more flood-resilient human communities along the Gulf coast not only in terms of economic savings but also to reduce human loss.

1. Introduction

The Gulf of Mexico coastal margin has long been one of the regions in the U.S. most vulnerable to the adverse impacts of storms and associated flooding. Rapid population growth and development in low-lying areas have only exacerbated flood-related losses. For example, from 2000 to 2005 Gulf coast counties incurred over $52 billion in overall flood damage with $19 billion reported through the National Flood Insurance Program (NFIP). With mounting losses from both acute and chronic flood events, decision makers are beginning to focus on how to construct coastal communities that are more resilient to economic loss over the long term. Despite the increasing impacts of floods on localities, little research has been conducted on defining, measuring, and testing the effectiveness of ecological indicators related to flood risk.

We address this issue by examining ecological conditions indicative of flood risk across 144 counties bordering the Gulf of Mexico. Specifically, we identify and measure four ecological indicators critical to protecting local communities against the adverse impacts of floods, then statistically test the degree to which they reduce flood losses observed across the study area over a five-year period. Study findings identify certain features of the natural environment that work to moderate the effects of floods and provide a foundation for building less flood-prone communities over the long term. Local and regional policy makers can use this information to develop more flood-resilient communities and reduce the amount of flood-related economic and human losses accruing along the Gulf coast.

2. Deriving ecological indicators of flood risk

Earlier work in the field of disaster reduction and hazard mitigation recognizes community vulnerability as a place-based concept (Longhurst, 1995). In this sense, susceptibility to the adverse effects of natural hazards is based on the interaction of biophysical risk and socioeconomic conditions within a specific geographic domain (Cutter, 1996). When conditions associated with ecological risk coincide with human settlements, social and economic functions are disrupted (Smith and Petley, 2009). Recognizing that the social component critically interacts with the ecological component in social–ecological systems provides the basis for building more hazard-resilient communities (Berkes et al., 2003; Folke et al., 2005).

The concept of an integrated socio-ecological system provides insights into how to facilitate community development while minimizing risk (Lebel et al., 2006; Paton and Johnston, 2006). It is important for planners and decision makers to

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reduce pre-existing vulnerabilities by reducing exposure to hazards, such as flooding and storm surge (Mileti, 1999; Godschalk, 2003). Ecological components essentially moderate the impacts of natural hazards on human populations and the built environment (Beatley, 2009). Precisely where human communities persist within ecological and geophysical landscapes thus become a central aspect in determining the degree of risk and vulnerability. Jurisdictions that locate or build in risk-prone areas will be more likely to incur adverse impacts associated with natural hazards unless they can adopt appropriate coping strategies.

While scholars recognize the importance of location-based factors when seeking to develop communities in vulnerable areas, they often stop short when it comes to identifying and measuring specific features of the natural environment that provide a foundation for minimizing flood hazard impacts. In response to this lack of study, we propose four baseline ecological indicators that serve as essential moderators between flood events and their degree of economic impact on local communities. Decision makers along the Gulf coast can use these measures to better understand their level vulnerability to flooding and help guide future development that is less damage-prone over the long term.

2.1. Floodplain area

The 100-year floodplain (where there is a 1% change of flooding every year) is a longstanding marker for determining the possibility of an area being inundated by a rainfall event. Communities developing within designated floodplain boundaries are at a greater risk of flood impacts unless mitigation measures are in place. In fact, over the course of a 30-year mortgage, there is a 26% chance that a home in the floodplain will experience flooding (NRC, 2000). Filling-in areas of the floodplain or raising sites above flood elevation may be a protective measure for a specific development, but flooding risks are often increased downstream. The cumulative impacts of seemingly minor alterations can compromise the ability of hydrologic systems to store runoff and literally alter the boundary of a floodplain. For example, Brody et al. (2007a) found that, on average, increasing areas of floodplain in Florida were correlated with larger amounts of property damage from floods. We expect that jurisdictions along the Gulf of Mexico coast with larger percentages of floodplain area will experience significantly greater amounts of flood losses. We statistically test the hypothesis: localities with larger areas outside of the floodplain will experience lower amount of losses from flooding events.

2.2. Soil porosity

Soil porosity is another important indicator of vulnerability to flooding because it helps determine the rate of surface water infiltration (Tollan, 2002; Chang and Franczyk, 2008). The amount of water that any given soil will infiltrate and retain depends primarily upon its texture and current moisture condition (Saxton and Shiau, 1990). Porous soils, such as those with high sand content drain much more quickly than low porosity soils, making them a potentially more suitable substrate for development. The potential for higher peak and mean annual flows from basins with low soil permeability is greater than that for basins with higher permeability soils, as higher permeability allows greater infiltration, more storage, and less runoff (Rasmussen and Perry, 2000). We test the hypothesis that: counties or parishes containing soils with higher levels of porosity will incur significantly lower amounts of property damage from floods.

2.3. Naturally occurring wetlands

Naturally occurring wetlands are also key ecological indicators when considering the risk to flood damage because of their ability to attenuate floods caused by precipitation and storm surge events (Bullock and Acreman, 2003; Costanza et al., 2008). Both anecdotal and empirical research suggest that wetlands may reduce or slow flooding (Mitch and Gosselink, 2000; Lewis, 2001; Bullock and Acreman, 2003).

For example, empirical research in Texas and Florida demonstrates the value of naturally occurring wetlands in reducing the adverse impacts of floods. Brody et al. (2007b) found that the development of wetlands significantly increased the number of exceedances in stream-flow across 85 watersheds in Texas and Florida. When controlling for multiple socioeconomic and geophysical contextual characteristics, Brody et al. (2008) found that the loss of wetlands across 37 coastal counties in Texas from 1997 to 2001 significantly increased observed amount of property damage from floods. Each permit granted by the USACE to alter a naturally occurring wetland under Section 404 of the Clean Water Act translated into an average of $211.88 in added property damage per flood over the five-year period. On average, wetland alteration added over $38,000 in property damage per flood (Brody et al., 2008). A companion analysis for every county in Florida showed similar results (Brody et al., 2007a). In this case, the alteration of wetlands increased the average property damage per flood by over $400,000. Given the evidence, communities that can maintain naturally occurring wetlands should be less vulnerable to flood disasters. Accordingly, we test the hypothesis that: wetland loss will exacerbate property damage from floods even over larger study areas, such as the Gulf of Mexico coast.

2.4. Pervious surfaces

Another key ecological indicator moderating flood impacts is the amount of area within a jurisdiction not covered by impervious surfaces, such as roads, rooftops, and parking lots (Arnold and Gibbons, 1996). Pervious surfaces (e.g. green space, protected areas, and coastal prairies) serve important hydrological functions because they absorb, store, and slowly release water (Tourbier and Westmacott, 1981). Conversely, large areas of impervious surface coverage correspond to a decrease in rainfall infiltration and an increase in surface runoff (Paul and Meyer, 2001). Impervious surfaces are especially implicated in increased peak discharge (Brezonik and Stadelman, 2002). Under compromised hydrological conditions, the lag time between the center of precipitation volume and runoff volume is compressed so that floods peak more rapidly (Hirsch et al., 1990). This reduced lag time occurs because runoff reaches water bodies more quickly when rainfall is unable to infiltrate into the soil (Hsu et al., 2000; Hey, 2002).

Overall, there is a substantial body of evidence to support the notion that development-based impervious surface increases runoff volume, peak discharges, and associated flood magnitudes. These conditions set the stage for more regular flood events and increasing human losses. For example, Brody et al. (2007b) found that an increase in impervious surfaces (as measured through remote sensing imagery) correlated with a significant increase in stream flow exceedances over a twelve-year period across 85 coastal watersheds in Texas and Florida. A follow-up study in coastal Texas examined the influence of the built environment from 1997 to 2001. The authors observed that over 37 counties, every square meter of additional impervious surface translated into approximately $3602 of added property damage caused by floods per year (Brody et al., 2008). Based on this evidence, undeveloped or pervious areas indicate a certain level of resiliency because they act to moderate flooding events and the degree of impact in terms