Evaluating stakeholder perceptions of coastal hazards in North Carolina using a social-ecological systems framework

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Abstract

North Carolina's coastal zone is of high economic value to the state, via tourism, fisheries support services, and real estate, to name a few. NC's coastlines are regularly impacted by tropical storms and hurricanes and NC is predicted to be one of the most vulnerable states in the USA to sea level rise (SLR). Furthermore, increasing residential populations in coastal areas are exacerbating rates of shoreline development and increasing the amount of vulnerable infrastructure; this will cause escalating individual and community maintenance costs in coming decades, particularly in concert with climate change related effects. The goal of this project was to gain a better understanding of how hazards like hurricanes and SLR are affecting coastal communities, and in turn how unique homeowner experiences impact decision-making and risk appreciation. I approach this overall research objective through a social-ecological systems framework by integrating environmental field data with socioeconomic homeowner surveys. For the empirical field surveys, I used a damage assessment protocol to evaluate estuarine shoreline damage after Hurricane Matthew (2016) along approximately 60 km of estuarine shoreline in Dare, Carteret, and Brunswick counties. For the social component, I used a Qualtrics survey targeting waterfront and non-waterfront residents in the same three coastal counties. I was particularly interested in the damage that Hurricane Matthew had caused to houses and shorelines and how and if homeowner experience with damage correlated with perceived risk to future hurricanes and SLR. This study found that empirical damage surveys after Hurricane Matthew underestimated shoreline damage as reported by homeowners. The data also show that past hurricane damage to shorelines and homes was a good predictor of damage during Hurricane Matthew, suggesting that there are patterns of repeated damage to certain properties. Finally, I found that home damage during Hurricane Matthew correlated with an increased concern about the impacts of SLR in the immediate future. In order to protect coastal habitats, infrastructure, and lives, it is critical that coastal managers and policy-makers understand how and when to promote new initiatives and policy in a way that will appeal to a diversity of coastal residents. These data can help coastal managers understand the risks that coastal residents face and also how those actual risks correlate with risk perceptions.

Introduction

Coastal regions worldwide have historically been home to some of the densest human populations (Small & Nicholls 2003), which has resulted in intense (and often conflicting) demands on coastal areas and resources (Lotze et al. 2006). As sea level rise (SLR) and a predicted increase in the frequency of major storm events interact with human population growth and coastal land development, it is likely that nuisance flooding will increase (Strauss 2014), the delivery and value of ecosystem services will decrease, and the economic costs associated with maintaining coastal infrastructure will skyrocket (Hinkel et al. 2014). In recognition of these growing risks, enhancing coastal resilience has become the subject of great environmental and socioeconomic focus (Barbier 2014), and a priority for governments, industries, and environmental advocates (Presidential Executive Order 13514).

Resilience, within a social-ecological systems framework, often refers to the ability of an ecosystem or community to absorb and reorganize after a disturbance (Walker et al. 2004). Adaptability is an important way in which humans can manage and enhance resilience. Along most of the Eastern and Gulf Coasts of the United States, where SLR is expected to inundate much of the coastal landscape over coming decades, and where tropical storms and hurricanes are fundamental agents of ecological and socioeconomic disturbance (Zhang et al. 2000), a lack of resilience is a major issue of concern (Executive Office of the President). Accordingly, coastal managers and policy-makers are trying to rapidly develop costal adaptation plans that will strengthen the ability of ecosystems and communities to respond to a variety of natural and anthropogenic disturbances. Understanding how coastal stakeholders experience and perceive the threats associated with different coastal stressors will be a crucial step to predicting acceptance and compliance with any new regulations or policies.

Widespread research has been conducted on the many stressors that are contributing to the decline in coastal resilience, including land-use change, eutrophication (Cloern 2001), overfishing (Jackson et al. 2001), climate change, and more recently shoreline hardening (Bozek & Burdick 2005; Dugan & Hubbard 2006; Gittman et al. 2016). Shoreline hardening is the placement of engineered structures (e.g. seawalls and bulkheads) along estuarine and oceanfront shorelines with the goal of reducing coastal erosion and enhancing resistance to storm events. Human modification of shorelines has taken place for centuries, but the unprecedented scale of shoreline armoring in recent decades has led to over 22,000 km of hardening in the US alone (Gittman et al. 2015). This widespread transformation of sloping littoral habitats into vertical walls fundamentally alters the land-water interface, and has accordingly been shown to have adverse effects on biological communities (Bozek & Burdick 2005; Seitz et al. 2006; Dugan et al. 2017). Furthermore, hardened shorelines reduce community resilience, because they lack the capacity for self-recovery after a perturbation and they necessarily require maintenance and repairs (Smith et al. 2017; Smith et al. 2018). One of the greatest environmental concerns associated with engineered hard shorelines is that they will prevent the up-slope transgression of salt marsh and other critical shoreline habitats as sea level rises. In areas with intense development, this "coastal habitat squeeze" will threaten habitats and the ecosystem services they provide (e.g., pollutant filtration, reduction of wave energy, habitat provisioning; Titus 1998; Peterson et al. 2008). Additionally, SLR is likely to intensify damage to fixed structures and increase the number of vulnerable structures, which will cause escalating individual and community maintenance costs. In fact, coastal property damage costs have already risen over recent decades (Zhang et al. 2000), and it has been shown that hardened shorelines have higher instances of hurricane damage and they are more costly to maintain than natural shorelines (Gittman et al. 2014; Smith et al. 2017).

Natural and social environments are deeply imbedded, and any move toward a more sustainable future will necessarily require a healthy environment, but also social support and economic growth (Lubchenco 1998). Sea level rise, shoreline hardening, ecosystem service delivery, and hurricane resiliency are complex and interconnected issues; working within a social-ecological systems framework makes it possible to investigate dynamic interactions among environmental and social factors in order to pursue sustainable adaptation strategies that improve people-environment transactions and strengthen our capacity to adapt (Berkes & Folke 2008). With large portions of coastal property managed by private homeowners and public agencies, the future of coastal habitats and the adaptive capacity of communities rely in part on understanding and modifying the decision-making process of stakeholders (Schultz 2011). Climate change adaptation is largely predicated on acknowledging and addressing vulnerabilities, and it is therefore critical that coastal managers understand how to properly communicate risk and promote new initiatives in a way that will appeal to a diversity of coastal residents, because societal and stakeholder engagement is critical for long-term success (Kelly & Adger 2000).

Objectives

This project used NC homeowner surveys to address the following three Sentinel Site Cooperative SLR and inundation focal areas: 1) impacts on coastal habitats and their associated ecosystem services; 2) economic and/or ecological assessments of SLR on human communities and/or coastal ecosystems; and, 3) vulnerability of natural and man-made environments to nuisance flooding. The surveys broadly addressed the following questions and hypotheses:

1) Do stakeholder observations of Hurricane Matthew damage align with environmental damage data collected before and after the storm?
    - H_a: Empirical field surveys will underestimate Hurricane Matthew shoreline damage, particularly to non-bulkhead shorelines
2) Which factors were the best predictors of damage during Hurricane Matthew?
    - H_a: Environmental factors (e.g. fetch and distance to water) will be stronger predictors of damage than home characteristics (e.g. home elevation and shoreline type)
3) Does hurricane damage correlate with an increased appreciation of hurricane and SLR risk?
    - H_a: Homeowners that experienced property damage during Hurricane Matthew will have higher perceived hurricane and SLR risk than homeowners that experienced no damage
4) Do homeowner perceptions of coastal threats align with perceptions from coastal managers?
    - H_a: Homeowners will perceive their communities to be less vulnerable to hurricanes than coastal managers

Methods

Study area

Coastal North Carolina was a perfect study system to test my questions because it is projected to be very vulnerable to sea level rise (Strauss 2014), it contains over 19,000 kilometers of estuarine shoreline (Mcverry 2012), it has been hit by more than 100 tropical storms and hurricanes since 1851 (North Carolina State Climate Office 2016), and it has a history of contentious SLR policy (NC House Bill 819 [S.L. 2012-201]). My approach involved a targeted dual-method (online and by mail) survey of waterfront and non-waterfront property owners in coastal NC. The surveys were distributed in three counties (Carteret, Dare, and Brunswick), in order to directly overlap and sample areas where I conducted field damage assessments before and after Hurricane Matthew. This approach allowed me to link damage data collected in the field with homeowner-reported levels of property damage and associated costs of repair, as well as perceptions of SLR and hurricane vulnerability.

Shoreline boat surveys

To evaluate estuarine shoreline damage caused by a hurricane, I conducted pre- and post-storm visual damage assessment boat surveys across the coast of Eastern North Carolina before and after Hurricane Matthew (2016). Hurricane Matthew was a Category 1 Hurricane that never made landfall in NC, but it passed by the NC coastline over the course of about 24 hours and caused severe flooding and estuarine shoreline damage in many areas of the state. The storm had maximum sustained winds of 67 knots and gusts up to 87 knots near Nags Head, NC. It had a maximum storm surge of over 6 feet in Hatteras, NC. Twenty-five deaths were attributed to the storm in NC alone, and the estimated property damage costs in Eastern NC were over $1.5 billion (Matthew & Stewart 2016).

I surveyed approximately 60 km of shoreline in the Northern (Hatteras and Frisco [OBX]), Central (Pine Knoll Shores [PKS]), and Southern (Oak Island) parts of coastal NC. The shoreline was surveyed before Hurricane Matthew in June 2015 (PKS and Oak Island) or April 2016 (OBX), and then re-surveyed within 2-weeks of Hurricane Matthew's passing in October 2016 (Figure 1). I evaluated storm damage using a visual damage assessment protocol based on Gittman et al. (2014), whereby a handheld Trimble Geoexplorer (2008 series) was used to record GPS coordinates by boat at the beginning and end of each uninterrupted stretch of a single shoreline type (e.g. bulkhead, revetment, natural marsh, etc.). Damage was evaluated using a classification scheme as follows: no damage; landward erosion; structural damage without breach; breach; and, collapse (Figure 2). I did not record damage for natural shorelines, as it was impossible to discern what erosion was caused by the storm. I photographed each shoreline stretch and any recorded instances of damage for future reference. GPS coordinates were entered into ArcGIS and overlaid with the

2012 NC Department of Coastal Management (NC DCM) shoreline shapefile (Mcverry 2012). Data points taken during the boat surveys were compared to the NC DCM shoreline shapefile, and when they were in disagreement, photographs of the structures along with aerial photography were used to confirm points. For each shoreline region, I calculated the total length of each type of shoreline surveyed, the percent of each shoreline type that was damaged during Hurricane Matthew, and the percent of bulkhead within each damage category. These data are presented descriptively.

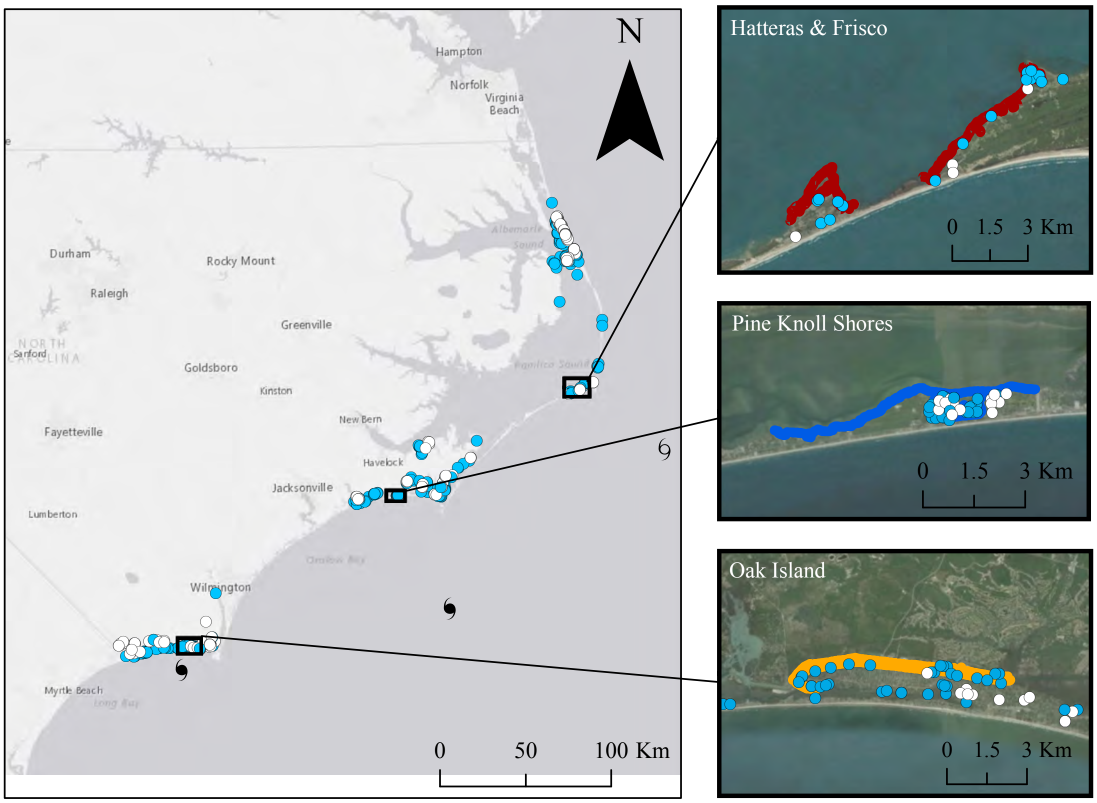

Figure 1 Map of respondent locations and damage assessment boat survey tracks in Hatteras & Frisco, Pine Knoll Shores, and Oak Island

Blue dots indicate waterfront property owners and white dots indicate non-waterfront property owners that responded to the survey. Hurricane symbols show the location of the eye of Hurricane Matthew (October 2016) in roughly 6-h intervals, and the fill indicates storm status (i.e. filled symbols = hurricane and unfilled symbols = tropical storm).

Figure 2 Shoreline damage types

(A) Landward erosion; (B) structural damage; (C) breach; and, (D) collapse.

Survey composition

The survey instrument was developed and pre-tested by an interdisciplinary team of scientists, coastal managers, and waterfront-property owners. Furthermore, all survey questions were developed to allow for comparison with complementary studies in NC, Alabama, and Massachusetts, including a survey distributed by NOAA Coastal Management Fellow Monica Gregory assessing the risk perceptions of NC coastal managers. The survey instrument was composed of four general sections: 1) damages and costs associated with Hurricane Matthew nuisance flooding and storm surge; 2) shoreline and home damage associated with past hurricanes (i.e. Floyd, Irene, and Arthur) and general hurricane risk perceptions; 3) perceived SLR vulnerability and policy; and, 4) demographic descriptors.

For the first section, investigating the impacts of Hurricane Matthew, property owners were asked to report the kind of property damage they experienced during the hurricane (e.g., shoreline erosion, damage to a shoreline stabilization structure, no damage), any accompanying damage to their homes, and specific costs (dollars and time) associated with damage/repair. Some questions directly overlapped with survey data that was collected as part of a 2014 homeowner survey (Smith et al. 2017), which allows for comparisons between Hurricane Matthew costs and average hurricane costs across multiple storms to determine if Matthew was perceived as an exceptional storm. For example, I asked the question, "*How much have you paid to repair Hurricane Matthew damage to your shoreline? (fill in the blank).*" For the second section, I asked similar questions about damage incurred during Hurricanes Floyd, Irene, and Arthur, to set up a comparison between multiple storms. I also asked homeowners to report how concerned they were about the future effects of hurricanes on their property, home, county, and state (5-point Likert Scale from Extremely Concerned to Not At All Concerned).

For the third section, I asked a series of questions to identify attitudes and perceived risk associated with SLR and climate change. I targeted questions at both a broad-spectrum (i.e., *How much would sea level have to rise for you to be concerned about your county?*) and individual level (i.e., *How much would sea level have to rise for you to be concerned about your house?*). I also asked homeowners to indicate the time period when they believed SLR might become a problem for their homes, county, and state. The final survey section covered demographic descriptors (e.g., age, education level, resident status, etc.), which will be used to compare results across different stakeholder groups.

In addition to the core components of the survey, I asked 5 questions about community vulnerability that were developed by NC Coastal Management Fellow Monica Gregory for a survey of NC coastal managers. For instance, I asked, "*What are the top three environmental issues most affecting your community"* and "*In what ways do the top three environmental issues affect your community?"* I duplicated her questions to investigate differences in perceived vulnerabilities between coastal residents and coastal managers.

Survey distribution and analysis

The survey distribution allowed for comparison across different geographies and between waterfront and non-waterfront property owners. In terms of geography, the surveys were concentrated within the Sentinel Site Cooperative defined area (i.e., Carteret County) as well as Dare and Brunswick counties to serve as comparisons. These three counties were chosen because they represent three distinct coastal geographies that are experiencing different rates of SLR (N.C. Coastal Resources Commission Science Panel 2010) and each county contains ~30 km of shoreline that I personally surveyed for shoreline damage after Hurricane Matthew. Including survey areas outside of the Sentinel Site Cooperative defined geography allowed me to contrast responses across the coast of NC and place the Sentinel Site Cooperative surveys into a broader context. Within each county, half of the surveys were mailed to waterfront homeowners and half to non-waterfront homeowners. I collected property owner addresses using county tax assessor websites. Once properties were selected, survey participants were recruited using a modified Dillman method (Millar & Dillman 2011) involving an initial invitation letter inviting participants to complete an online survey (with a link to the online survey) and one follow-up reminder letter. A total of 2915 surveys were mailed to verified addresses, equally distributed between the three counties. We attempted to boost the response rate by offering a random raffle drawing of prizes (five $25 - $100 Amazon.com gift cards) as incentive to take part in the study. The online survey was hosted and administered by Qualtrics Research Suite, and printed surveys were mailed to all individuals who requested them (n = 36). Once returned, I entered the printed surveys into Qualtrics by hand. Survey responses were recorded from May to September 2017.

Institutional Review Board survey approval

The research activities described in this report posed no more than minimal risk to human subjects, and received an expedited IRB review that was compliant with UNC Chapel Hill campus policies (UNC IRB #17-0455).

Environmental parameters

To supplement the homeowner reported survey data, we collected some additional environmental data based on the address where the initial survey invitations were sent (i.e. property elevation, home elevation, shoreline fetch, etc.). If the zip code from the initial invitation address did not match the zip code that the homeowner reported as their residence in the survey then we did not include environmental parameters for those respondents (n = 9). To determine the distance between each home and the water, we used ArcGIS to measure the distance between the center of each home and the nearest estuarine shoreline based on the NC Department of Environmental Quality shoreline shapefiles (Mcverry 2012). We used high-resolution Digital Elevation Maps to measure the bare-Earth elevation of each property measured at the location of the house (North Carolina Spatial Data Download 2018). We also used NC floodplain layers to extract the floodplain classification of each property. Finally, we used tax parcel data to assess property and land values (NC OneMap GeoPortal 2018).

To estimate relative wave exposure for waterfront properties, we used the fetchR package in R (Seers 2017) to calculate the average fetch (the average of 72 evenly spaced vectors) and direction of maximum fetch (i.e. North, South, East, or West) for each waterfront property. Finally, we used a combination of Google Streetview, and real estate websites Trulia.com and Zillow.com to evaluate whether or not houses were elevated (defined as elevated enough to fit a car underneath the house) and number of steps to the front door as a proxy for height when the stairs were visible (Kennedy et al. 2011).

Statistical analyses

Data were analyzed spatially within ArcGIS 10.2 and with correlation and regression analyses in SPSS and R v. 3.2.3. Pearson's chi-squared tests and one-way ANOVA were used to evaluate differences between groups (i.e. waterfront versus non-waterfront). I also used Chi-squared Automatic Interaction Detection (CHAID) trees to determine the most predictive variables in the data set. The Chi-squared Automatic Interaction Detection (CHAID) tree-based classification model can be used to isolate independent variables (from multiple variables within the data set) that have the strongest predictive power at different levels. CHAID trees merge categories that are not significantly different. Trees were separately computed for multiple response variables and the factors included in each of the different trees are listed with the results. Finally, to assess differences between stakeholder groups, I used Non-metric multidimensional scaling plots to visual differences among priority concerns for waterfront homeowner, non-waterfront homeowners, and coastal managers. I followed this with a PERMANOVA of the response matrix to assess multivariate differences between stakeholder perceptions.

Results

Field assessments of shoreline damage from Hurricane Matthew

I surveyed 18 km of estuarine shoreline in PKS, 21 km in Oak Island, and 28 km in OBX for damage before and after Hurricane Matthew. Only 37% of the shoreline in PKS was natural, whereas 56% and 49% were natural in Oak Island and OBX, respectively (Figure 3A). Bulkheads were the most common shoreline stabilization technique in all three regions. The three survey areas differed greatly in the amount of observed damage that could be attributed to Hurricane Matthew. One hundred percent of the damage observed in PKS was attributed to bulkhead shoreline. Eight-five percent of the damage observed in Oak Island was attributed to bulkhead shoreline. Ninety-three percent of the damage observed in OBX was attributed to bulkhead shoreline. Of the bulkhead shoreline surveyed in each region, less than 5% was damaged in PKS and Oak Island (2% and 5%, respectively), whereas 32% of the shoreline was damaged in OBX (Figure 3B).

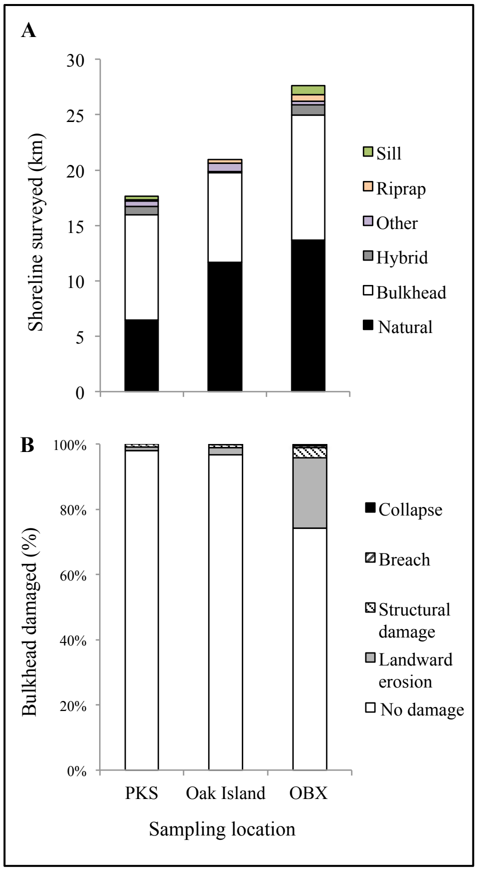

Figure 3 Hurricane Matthew shoreline damage

(A) Total shoreline surveyed by region, and (B) percent of bulkheads damaged during Hurricane Matthew.

Survey demographics

We received 527 surveys, but only 489 were 100% completed (17% response rate). Respondents were evenly divided between Dare (33%), Carteret (33%), and Brunswick counties (32%), with a handful of respondents from outside of these counties (n = 9). Sixty-six percent of respondents were waterfront property owners and only 33% were inland property owners. On average, respondents were mostly male (70%), older (64 ± 12 years [mean ± SD]), and had lived in NC for 33 ± 21 years. Forty-six percent of respondents made over $100,000 in 2017, though there was a divide between waterfront homeowners (54%) and non-waterfront homeowners (31%). Sixty-eight percent of respondents had completed at least a 4-year college degree, though again there was a divide between waterfront homeowners (74%) and non-waterfront homeowners (56%). On average, homeowners had been in their current home for 14 ± 11 years.

Of the 333 waterfront homeowners that responded to the survey, the majority described the waterfront access of their property as exposed sound (31%) or a man-made canal (32%; Figure 4). The majority of Carteret county residents described their shoreline type as natural marsh (46%), followed by bulkheads (36%). Homeowners in Brunswick and Dare counties described their waterfront most commonly as bulkhead (both 56%), followed by natural shoreline (36% and 23%, respectively). Homeowners with riprap shorelines were relatively common in Carteret (10%) and Dare (7%) counties but they occurred rarely in Brunswick (n = 1; Figure 5). On average, homeowners with bulkheads and riprap had shoreline lengths of 136 ± 249 ft. and 178 ± 139 ft., whereas natural shorelines were generally longer at 219 ± 428 ft. Houses with bulkheads and riprap were also generally closer to the water, with average distances between the house and the water (at high tide; as estimated by the homeowner) of 89 ± 173 ft. and 131 ± 114 ft., whereas houses with natural marshes were on average 221 ± 422 ft. from the water.

There were some major differences in geographical setting among the three counties. Waterfront homeowners in Dare County had significantly higher average shoreline fetches than homeowners in Carteret and Brunswick counties (One-way ANOVA, $F_{2,277} = 30.29$, $p < 0.001$). Houses in Brunswick and Dare were closer to the oceanfront than houses in Carteret ($F_{2,471} = 30$, $p < 0.001$), but Brunswick houses tended to be further from the estuarine shoreline ($F_{2,471} = 25$, $p < 0.001$). There were significant differences in the distribution of flood zones among each of the three counties (Chi-squared test, χ (8) = 154, $p < 0.001$). Twenty-two percent of respondents from Brunswick were in the highest risk flood zone (VE) versus only 2% and 5% in Carteret and Dare, respectively. Conversely, no homeowners in Dare County were outside of a flood zone, whereas 39% and 16% of homeowners in Brunswick and Carteret were not in a flood zone.

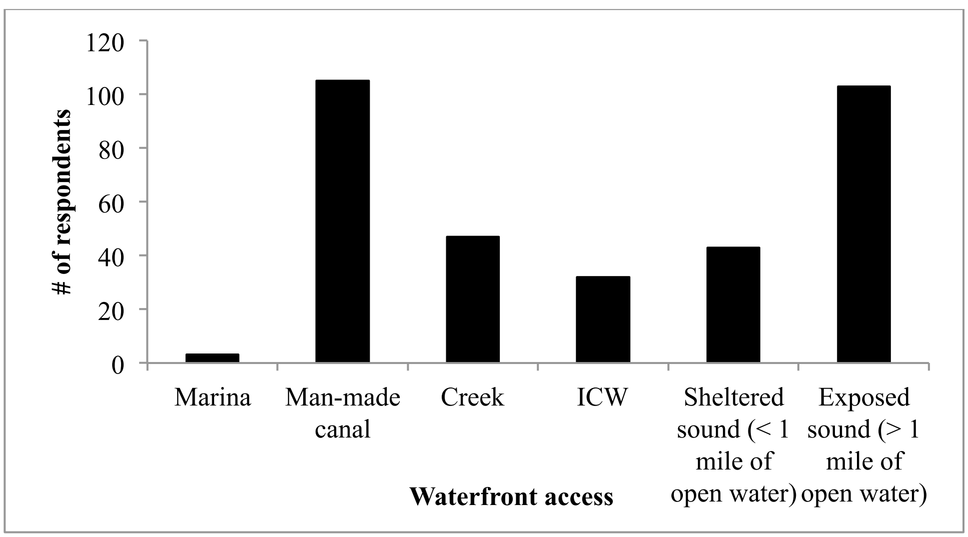

Figure 4 Number of waterfront respondents with different types of waterfront access

ICW = intracoastal waterway.

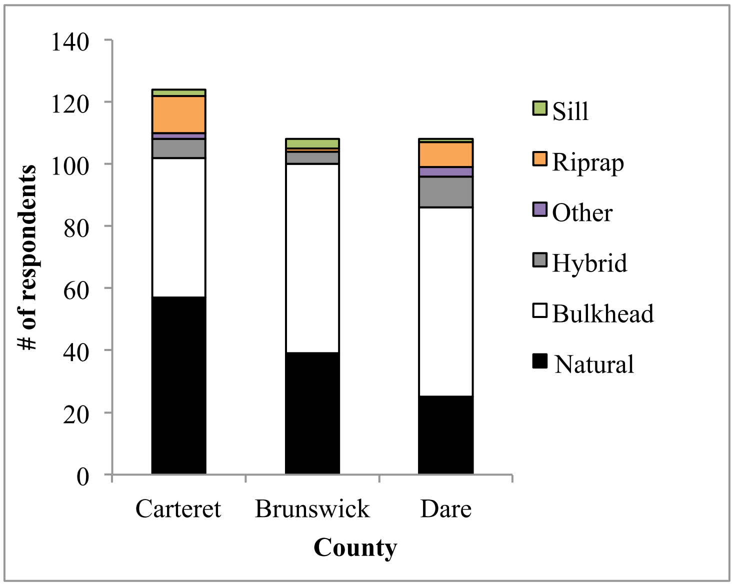

Figure 5 Number of waterfront respondents with each shoreline type by region

Homeowner reported damage from Hurricane Matthew

Nineteen percent of homeowners in Carteret county reported some kind of damage (minor or major) to their shoreline after Hurricane Matthew, which was significantly less than homeowners in Brunswick (46%) and Dare (43%; χ (2) = 19.0, $p < 0.001$; Figure 6A). Across all three counties, 29% of homeowners with bulkheads reported shoreline damage, which was significantly less than the 42% of homeowners with natural shorelines, but not significantly different from the 36% of homeowners with riprap shorelines (χ (2) = 6.2, $p = 0.044$; Figure 6B).

Five percent of homeowners in Carteret county reported Hurricane damage to their homes, which again was significantly less than homeowners in Brunswick (25%) and Dare (24%; χ (2) = 26.4, $p < 0.001$; Figure 7A). Twenty-three percent of homeowners with bulkheads reported home damage, which was significantly higher than 14% with natural shorelines and 18% with riprap shorelines (χ (2) = 6.6, $p = 0.036$; Figure 7B).

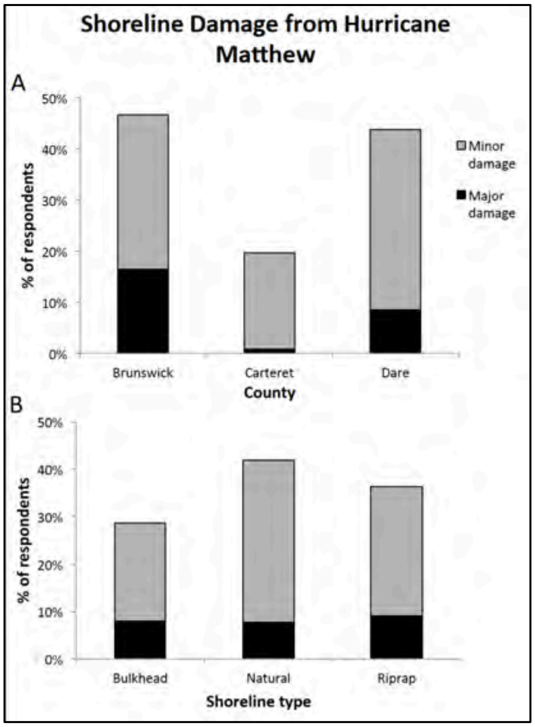

Figure 6 Homeowner reported shoreline damage from Hurricane Matthew

By (A) county and (B) shoreline type.

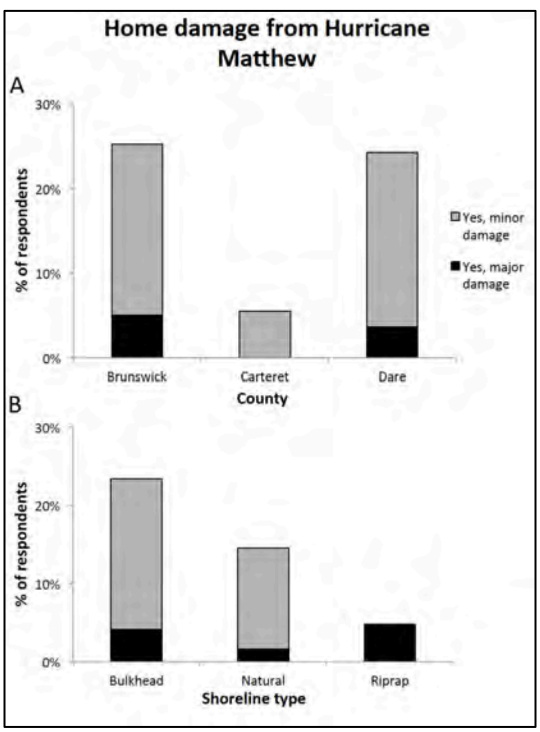

Figure 7 Homeowner reported home damage from Hurricane Matthew

By (A) location and (B) shoreline type.

In total, 55 homeowner survey responses directly overlapped with the empirical shoreline damage surveys (8 responses in OBX, 27 in PKS, and 20 in Oak Island). There was 96% agreement (all but 2 responses) between my shoreline classifications from the damage surveys and homeowner reported shoreline classifications. One homeowner classified their shoreline as a bulkhead, whereas we classified it as a sheetpile sill; considering that sheetpile sills are constructed using similar material to bulkheads this was probably just an issue of terminology. The second homeowner classified their shoreline as natural unvegetated, but also reported that their waterfront access was a man-made canal, and I classified this shoreline in the damage assessment as bulkhead shoreline.

There was 80% agreement between my damage classifications from the shoreline surveys and homeowner reported shoreline damage classifications. Eighteen percent of shoreline damage was under-represented in the shoreline surveys and only 2% was over-represented. Of the damage that was under-represented, 50% was attributed to erosion of a natural shoreline (n=5; which was not evaluated in the shoreline boat surveys), 10% was attributed to dock damage (n=1; which was not evaluated in the shoreline boat surveys), and 40% was attributed to bulkhead damage (n=4; landward erosion and structural damage) that was not picked up during the shoreline boat surveys. Damage was over-represented at one property; this is likely because damage was mistakenly attributed to one property when it actually occurred at the neighbor's property. This homeowner's survey indicated that their shoreline had fared "much better" than their neighbors', indicating perhaps that their neighbor experienced the structural damage and landward erosion that we attributed to their shoreline.

Of the 11 homeowners that reported damage to their shoreline, 64% indicated that they had repaired the damage (at costs ranging from $0 [self repaired] to $2000). Of the 4 homeowners that had not yet repaired their shoreline, 1 homeowner with a bulkhead indicated that they were on a waiting list, and the other three homeowners (with natural marsh shorelines) indicated that their wetlands were protected and thus they could not repair them ("natural process, protected wetlands" and "slight erosion. CAMA regs").

Hurricane vulnerability and risk perceptions

For this section, I assessed the relative importance of physical variables (i.e. fetch, distance between home and shoreline, etc.), home characteristics (i.e. is the home raised, what kind of shoreline stabilization was is in place, etc.), and past hurricane damages on the likelihood of damage during Hurricane Matthew. I exclusively analyzed waterfront property owner responses for this section (n = 333) because I was particularly interested in investigating any links between shoreline characteristics and home damage.

The best predictor of shoreline damage during Hurricane Matthew was whether or not the homeowner's shoreline had been damaged during the previous hurricane, Hurricane Arthur (CHAID regression tree; factors included were: county, waterfront type, shoreline type, average fetch, direction of maximum fetch, shoreline damage during Hurricane Arthur; Figure 8). Homeowners whose shorelines were damaged during Hurricane Arthur were twice as likely to report shoreline damage during Hurricane Matthew. Of the homeowners that did not have shoreline damage during Hurricane Arthur, county was a significant predictor of shoreline damage during Hurricane Matthew, with damage rates in Dare and Brunswick counties three times higher than those in Carteret county.

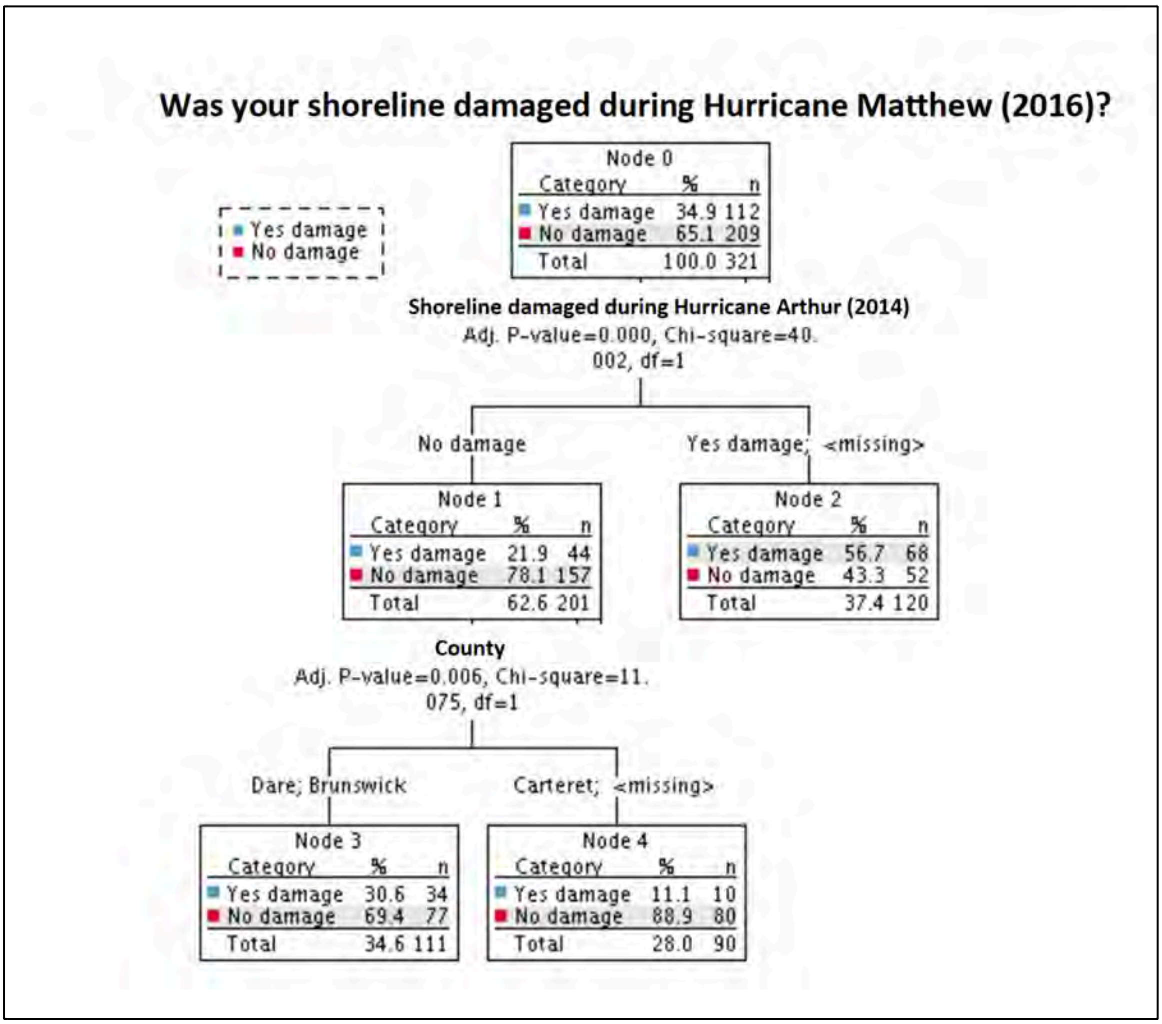

Figure 8 CHAID Regression Tree showing the best predictors of shoreline damage from Hurricane Matthew

The best predictor of home damage during Hurricane Matthew was floodplain as predicted by the North Carolina Floodplain Mapping Program (CHAID regression tree; factors included in the model were: county, waterfront type, shoreline type, average fetch, direction of maximum fetch, shoreline damage during Matthew, home damage during Arthur, flood zone, house raised, distance between house and shoreline; Figure 9). Homeowners in floodplain VE (the highest risk flood zone) were five times more likely to have experienced home damage during Hurricane Matthew than homeowners in other flood zones. Of the homeowners in lower risk flood zones, the best predictor of damage was whether or not the home had been damaged during the previous hurricane, Hurricane Arthur. Finally, of those that did not experience any damage during Hurricane Arthur, shoreline damage during Hurricane Matthew was the best predictor of home damage; properties that experienced shoreline damage during the storm were three times more likely to have experienced home damage than those that had no shoreline damage.

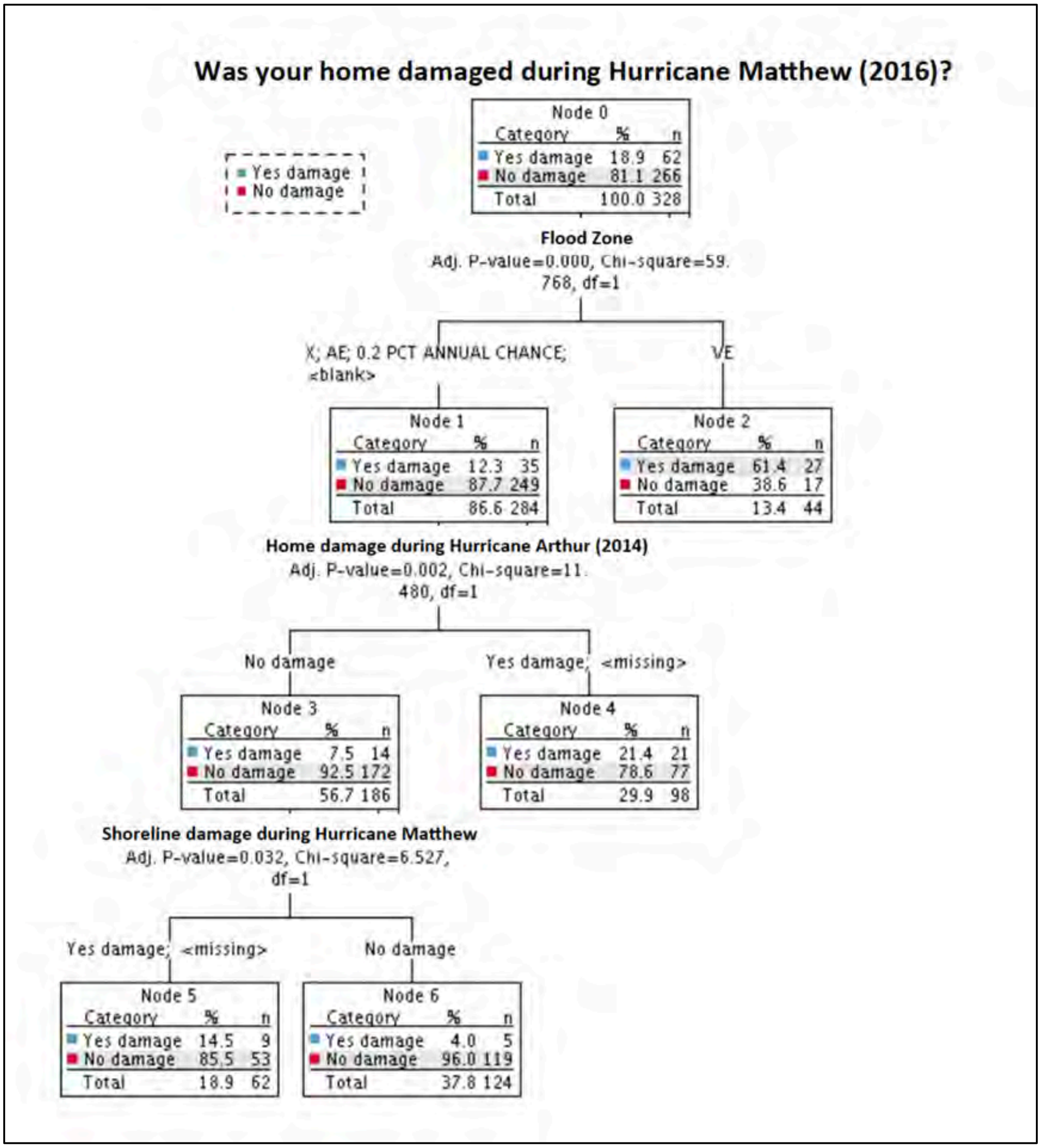

Figure 9 CHAID Regression Tree showing the best predictors of home damage from Hurricane Matthew

Sea Level Rise perceptions

Forty-three percent of homeowners believed that sea level was definitely rising, as opposed to 2% that believed sea level was definitely not rising. The best predictive factor of whether or not a homeowner believed in SLR was how knowledgeable they considered themselves about climate change (factors included in regression tree: county, waterfront/non-waterfront, years in NC, gender, age, household income, level of education, self-designated level of knowledge about climate change, self-designated level of knowledge about SLR; Figure 10).

Interestingly, homeowners that self-identified as "extremely knowledgeable" and "not knowledgeable at all" grouped together as the most skeptical of SLR. Of those that considered themselves moderately knowledgeable about climate change, there was a divide between male and female residents, with male residents generally being more skeptical about SLR (Figure 10).

Looking exclusively at the waterfront resident population, the majority of homeowners believed that SLR would affect their homes between 26-50 years from now, though there was fairly equal representation for each time frame. The best predictor of the timeframe when homeowners believed their houses would be vulnerable to sea level rise, was whether or not their homes were damaged during Hurricane Matthew (factors included: county, waterfront access, shoreline type, shoreline length, distance between home and water, shoreline damage during Hurricane Matthew, house damage during Hurricane Matthew, years in NC, gender, age, level of education, income, years at current home; Figure 11). Respondents whose houses had been damaged during the Hurricane were four times more likely to believe that SLR would impact their houses sooner than those whose houses had not been damaged during the storm. Among the residents whose houses were not damaged, county was a significant factor, with Dare and Brunswick residents believing that SLR would effect their houses much sooner on average than Carteret county residents (Figure 11).

The majority of waterfront residents believed that SLR would become a problem for their counties and for North Carolina more generally in the next 25 years. The only significant factor predicting the timeframe when homeowner thought that SLR would impact their county/state was the homeowner's county (Figure 12).

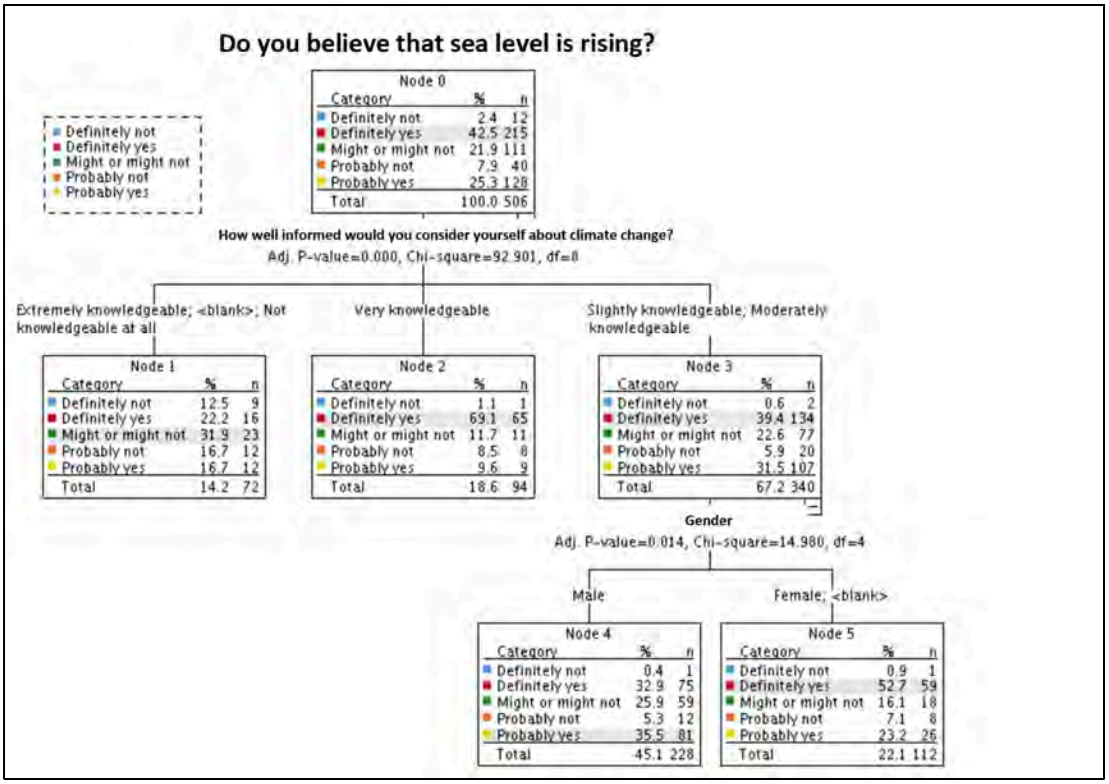

Figure 10 CHAID regression tree of the best predictive factors for whether or not a homeowner believes that sea level is rising.

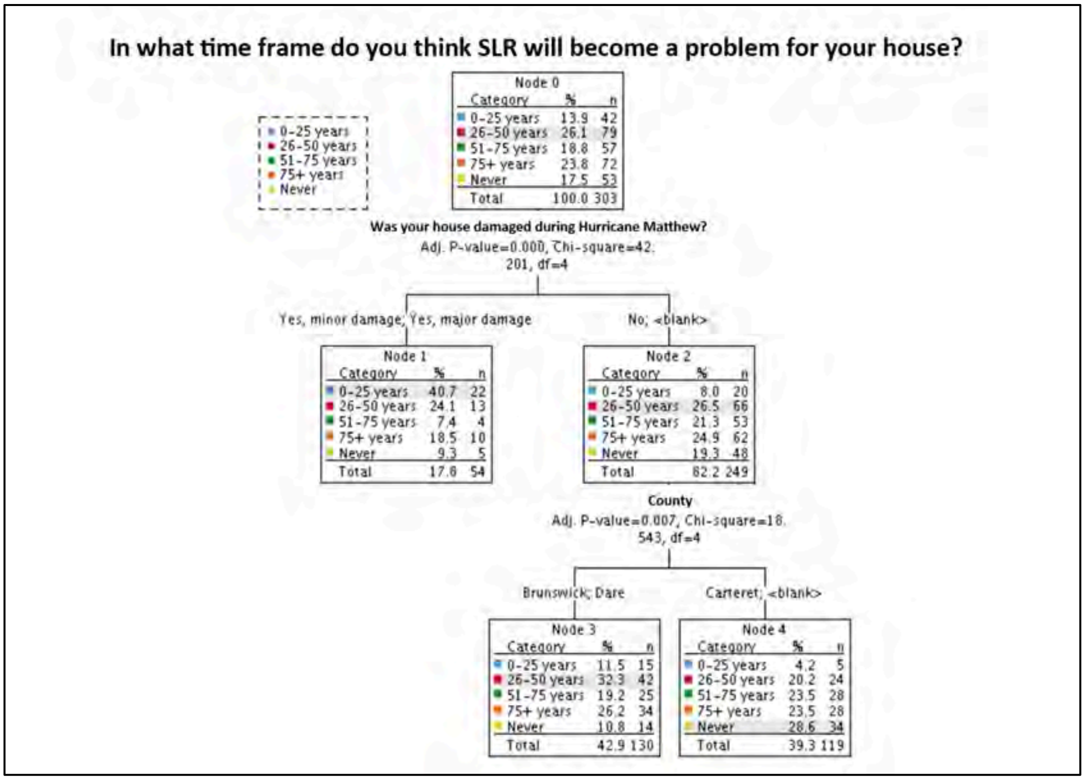

Figure 11 CHAID regression tree of the best predictive factors for the timeframe during which residents think that SLR will become a problem for their houses.

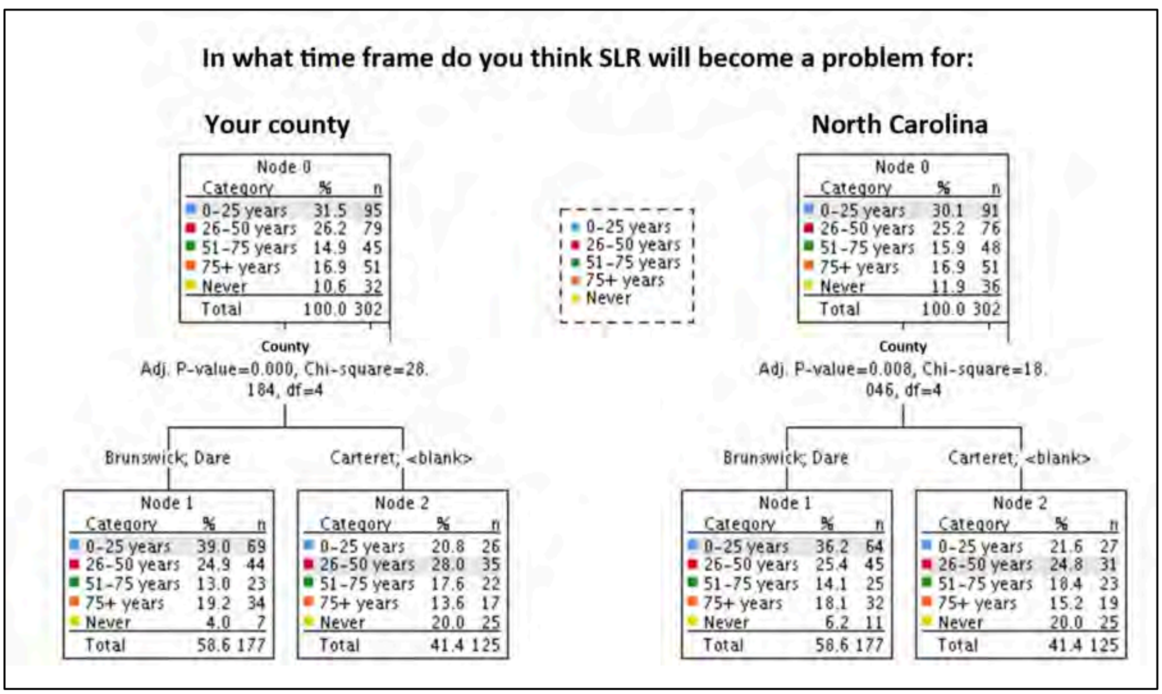

Figure 12 CHAID regression tree of the best predictive factors for the timeframe during which residents think that SLR will be a problem for: 1) their county; and, 2) North Carolina.

Homeowner versus coastal manager perceptions

Homeowner and coastal manager perceptions were well aligned in terms of the perceived ability of their communities to recover from storm events. On a scale of 1 to 10, with 1 being "completely unable" to recover and 10 being "fully able" to recover, all stakeholder groups rated their communities as an 8.5 during a minor storm and between 5.6 and 6.3 for a major storm (Figure 13). A higher proportion of coastal managers compared to residents checked that riverine flooding, infrastructure failure/damage, drainage problems, and algal blooms were all issues that their communities had experienced. In contrast, a higher proportion of residents indicated that hurricanes, Nor'easters, tidal flooding, storm surge, and beach erosion were issues that their communities had faced (Figure 14). Waterfront and inland resident perceptions were generally well aligned. NMDS analysis revealed that there was a difference between the issues that managers selected versus residents (PERMANOVA, $p = 0.001$; Figures 15). SIMPER analyses revealed that differences in experiences with Nor'easters and beach erosion were driving the differences in perceptions.

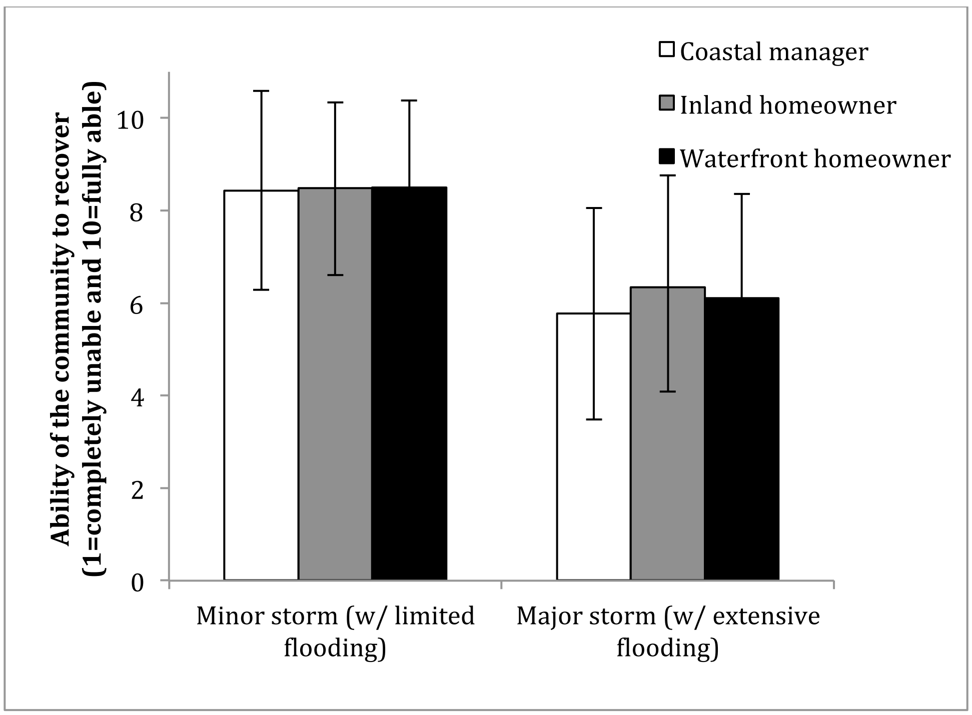

Figure 13 Coastal stakeholder perceptions of the ability of their communities to recover from storms.

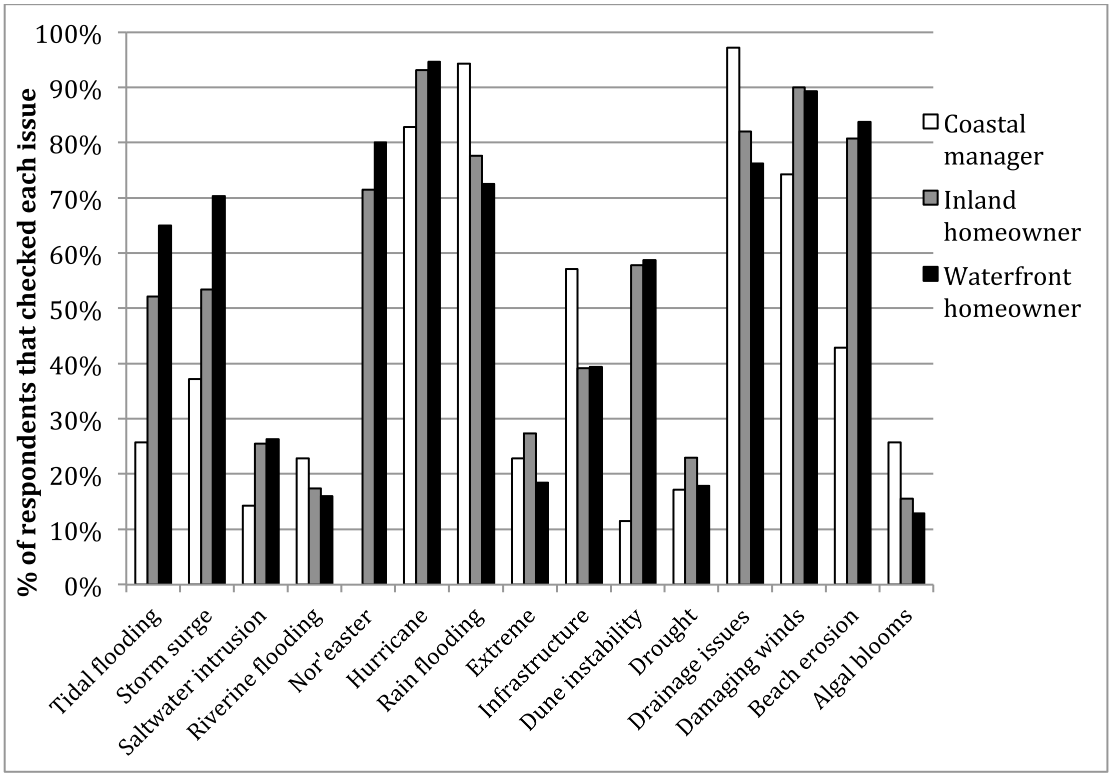

Figure 14 Percent of stakeholder respondents that believe their communities have experienced each issue in the last 10 years.

Figure 15 3D NMDS plot, showing the grouping of different stakeholder groups with respect to the issues they believe their communities have experienced in the last ten years.

Discussion

Empirical shoreline assessments underestimate hurricane damage particularly along natural shorelines

My empirical shoreline damage assessments, in conjunction with survey results from homeowners along the same shoreline damage assessment tracks, suggest that there is good agreement (80%) between field and survey data; however, damage to natural shorelines is underestimated (because it could not be assessed in the boat surveys) and patterns observed in the empirical damage assessments do not necessarily match county-wide patterns of damage. These results are consistent with our hypothesis that field surveys would underestimate Hurricane Matthew shoreline damage, particularly to non-bulkhead shorelines; however, we saw that damage was only underestimated along natural shorelines and shorelines with docks. The empirical shoreline damage assessments show that Dare County had significantly more shoreline damage from Hurricane Matthew than Carteret and Brunswick Counties, which is in contrast to the survey responses suggesting that Brunswick and Dare both had more damage than Carteret. This is likely because shoreline boat surveys were localized and only assessed a small portion of shoreline within each county, which may not have been indicative of shoreline damage trends across the entire county. In contrast, the homeowner surveys were much more widely distributed throughout each county. This dual method comparison of damage (field surveys and homeowner surveys), allowed me to assess the accuracy of a field damage protocol that has been widely used (Thieler & Young 1991; Gittman et al. 2014; Smith et al. 2017). These results suggest that the shoreline damage assessments are an accurate method of estimating storm damage along hardened shorelines, but that this data should not be extrapolated out to generalize larger geographic damage trends.

Previous studies (Smith et al. 2017; Gittman et al. 2014) have shown that hardened shorelines (bulkheads in particular) are damaged frequently during storm events, but neither of these studies were able to effectively assess damage to natural shorelines, because visual damage is less obvious along a natural shoreline than an artificial shoreline. My survey results show that homeowners with natural shorelines report significantly more shoreline damage than homeowners with bulkheads. Smith et al. (2017) was not able to assess relative hurricane damage during individual storms, but did find that homeowners with bulkheads on average reported higher hurricane property damage costs than homeowners with natural shorelines and riprap shorelines. They attributed this difference to both higher rates of damage and also more expensive maintenance costs. My survey results suggest that natural shorelines did not experience lower shoreline damage rates than hardened shorelines, but that shoreline damage costs were lower. These lower costs may be attributed to the fact that homeowners themselves can often repair damage to natural shorelines without actually spending any money or the fact that “repair” of natural shorelines may be unlawful as wetlands are protected. Current permitting for bulkheads allows for homeowners to build a bulkhead back in the same position where it was initially constructed within two years of the damage (USACE Nationwide Permit 13). Conversely, if a natural shoreline is eroded away it is often impossible to replace that property. This inability to "maintain" natural shorelines may be a contributing factor in the lower natural shoreline maintenance costs reported in Smith et al. (2017).

Despite lower rates of shoreline damage, homeowners with bulkheads reported higher rates of home damage when compared to homeowners with natural shorelines. Rather than a causal effect (i.e. bulkheads are causing home damage) this is probably a reflection of differences in geographic vulnerability among homes with different types of shorelines. While previous studies have shown that shoreline type in North Carolina does not necessarily track with shoreline vulnerability (e.g. natural shorelines and hardened shorelines are often interspersed, even in high fetch areas; Smith et al. 2017), the correlation between home damage and shoreline type probably has to do with home vulnerability. Bulkhead homes in my study were on average three times closer to the shoreline than homes with natural shorelines, which likely increases storm surge vulnerability.

Past hurricane damage is a strong predictor of future hurricane damage

The National Flood Insurance Program (NFIP) was established in 1968 with the goal of providing flood insurance to more homeowners via a system that could be subsidized by the government in disaster years. The NFIP creates flood maps for coastal communities that estimate the probability that homes in different locations will experience a high water event (Michel-Kerjan 2010). The NFIP has been heavily criticized in recent years, with those in opposition arguing that flood risk maps are not accurate, that coverage encourages development in high-risk areas, and that repeated losses account for a large amount of claims. The regression tree analyses from my survey offer some support and opposition for these criticisms. Survey results show that the best predictor of Hurricane Matthew home damage was flood zone, though Zone VE (the highest risk zone with additional storm surge risk) was the only zone that grouped separately. This suggests that flood zones can be a good predictor of damage. Several studies have shown that perceived flood risk often correlates with actual flood risk as assessed by flood zone and more recently with past hurricane experience (Horney et al. 2010; Gotham et al. 2018), and our results show that actual flood risk during Hurricane Matthew was predicted by flood zone.

Survey results also suggest that past hurricane damage to shorelines and homes can be an important predictor of future damages. For both shoreline damage and home damage from Hurricane Matthew, shoreline and home damage from the previous hurricane (Hurricane Arthur) was a significant predictor of damage at some level of the regression tree. In fact, homeowner's whose shorelines were damaged during Hurricane Arthur were nearly three times more likely to have experienced damage during Hurricane Matthew. This offers some support for the repeated damages criticism of the NFIP. The idea that past hurricane damage can help to predict future hurricane damage could indicate that there are additional geophysical vulnerabilities, such as bathymetry waterward of the shoreline, that are not completely captured with traditional assessments of geographic vulnerability. Altogether, these results were somewhat surprising given my hypothesis that environmental factors like fetch and distance to shoreline would be the strongest predictor of damage during the storm, but not completely surprising that flood zone would be a good indicator of actual flood risk. With that said, no two hurricanes are exactly alike and many more data are needed that assess the power of flood zone and past hurricane damages in predicting hurricane damage.

Hurricane damage correlates with SLR risk appreciation

In the last decade alone, an extraordinary amount of human and monetary resources have been spent in the United States cleaning up after natural disasters. In fact, 2017 is expected to be one of the most (if not the most) expensive hurricane seasons on record, because of damages associated with Hurricanes Harvey, Irma, and Maria (NOAA 2017). Understanding how experience with hurricanes correlates with risk perceptions and decision-making can be an important component of outreach plans and the promotion of new policy. Furthermore, an understanding of how and if experiences with “pulse” hazards like hurricanes impacts perceptions of “press” hazards like SLR (that are harder to observe) could provide interesting insights for discussing climate change hazards.

In my survey, the best predictor of a homeowner’s belief in SLR was their self-identified knowledge of SLR and subsequently their gender. This corresponds well with other studies that have been published showing that people who are knowledgeable about a subject tend to perceive it as lower risk and that women tend to be more aware of environmental risks (Brody et al. 2008). However, the best predictor of when a homeowner thought that SLR might present a problem for their home was whether or not their home was damaged during Hurricane Matthew. This correlation could be due to the fact that homes damaged during Hurricane Matthew are located in more vulnerable locations and that homeowners perceive this and recognize that they are more vulnerable to all coastal threats. Alternatively, experience with a recent hurricane may make homeowners feel more vulnerable to other hazards, regardless of their actual vulnerability. The fact that damage from Hurricane Matthew was a better predictor than any of the environmental parameters (e.g. fetch, flood zone, etc.) suggests that perceptions may be at least part of the story. Regardless of their actual physical vulnerability, if homeowners feel more vulnerable directly after a hurricane, they may be more receptive to new climate change policy directly after a storm. These results support my hypothesis that there is a relationship between home damage during Hurricane Matthew and hurricane and SLR risk perception.

Homeowner and coastal manager perceptions largely align

There are often disconnects between "expert" and public assessments of risks and hazards, which can be an impediment to citizen acceptance of new hazard policy (Slovic 1987). To evaluate this in coastal NC, and also to evaluate differences in risk perception between waterfront and non-waterfront homeowners, we assessed different stakeholder groups' perceived abilities to recover from minor and major hurricanes. Across all groups, the perception was that the communities would have a harder time recovering from a major hurricane than a minor hurricane, but we found no major differences among groups in terms of the perceived ability of their communities to recover. This result was somewhat surprising, as I had hypothesized that coastal managers would perceive their communities to be less resilient to hurricanes than coastal residents and also that non-waterfront homeowners would perceive their communities to be more resilient than waterfront homeowners. Previous research has shown that higher exposure to hazards often results in a higher appreciation of risk (Peacock et al. 2004). Presumably, waterfront homeowners are at a higher risk, but I did not find any indication that they had an increased risk perception.

We did see some differences among groups in terms of the environmental issues that each group believed that their communities had faced in the last decade. Again, waterfront and non-waterfront resident perceptions were well aligned, but residents in general trended towards being more concerned about "pulse" hazards such as storm surge, hurricanes, Northeasters, etc. versus coastal mangers who were equally concerned about "pulse" and "press" hazards. It is important to note that while waterfront and non-waterfront homeowners were only located in Dare, Carteret, and Brunswick counties, the coastal mangers that were surveyed were distributed across the coast of NC. This could account for some of the observed differences in concerns about different coastal hazards, because it is possible that the hazard landscape was different for the two stakeholder groups.

Outreach and Research Dissemination Plan

The results presented in this report are currently being prepared for publication in a peer-reviewed journal. Additionally, I have already had the opportunity to present these results to academic audiences at the Coastal Estuarine Research Federation Conference in November 2017 and as a speaker in the Research in Progress Seminar Series at East Carolina University in March 2018. To disseminate results outside of the academic research community, I have: 1) involved and mentored a UNC undergraduate; 2) used the homeowner survey network to inform survey participants of major project findings; and, 3) in the future, I will share the project findings with NC science teachers as a part of the annual Scientific Research and Education Network (SciREN) workshop in early 2019.

As part of the outreach for this project, I mentored an undergraduate, Anna Brodmerkel, in survey design and implementation. She designed and implemented an independent survey of North Carolina homeowners specifically addressing their perceptions of SLR and her senior thesis, entitled "Homeowner perceptions of North Carolina Sea Level Rise Policy" was completed in May 2018. To circulate project results back to NC homeowners, I included an option at the end of my survey instrument where homeowners could elect to get an update on the major findings of the proposed research at the conclusion of the study. Of the 527 survey respondents, 288 provided an email address and indicated that they were interested in seeing any reports or publications that came from the study. In September 2019, I emailed these homeowners a copy of this final report as well as an abbreviated summary of the major project findings (Appendix A). To disseminate my results to NC science teachers, I will participate in the annual SciREN workshop in early 2019. I have begun to prepare a classroom-ready lesson plan based on this work (adhering to NC common core standards), and I will disseminate this lesson plan to NC schoolteachers at a networking even in February 2019, after which teachers can use it to enhance scientific literacy and understanding of SLR threats and anthropogenic habitat degradation among their students.

Data Management Plan

Data products

This study generated environmental data through the recording of survey responses from homeowners in NC. Data were collected and compiled using online Qualtrics survey software between May 2017 and September 2017. The dataset provided non-sensitive data from randomly selected, mixed-gender NC homeowners older than 18 years of age from Dare, Carteret and Brunswick counties. Data included information on homeowner perceptions of SLR and ecosystem service delivery, as well as socioeconomic data associated with hurricane damage to properties. Subjects were anonymously surveyed by following a web link and entering their own responses into the online Qualtrics survey software. If a subject requested a paper copy of the survey, I entered their responses by hand.

Data storage

Survey responses were compiled in Qualtrics online software and then exported as Microsoft Excel and SPSS files. Each file has an associated metadata tab as well as a descriptive title. Personal identifiers are stored in a separate file from survey responses. The files have been saved on multiple external hard-drives.

Data sharing and dissemination

Only personnel that are under the approved Institutional Review Board (IRB) protocol have access to the raw data generated during this project period. Data results and methodology will only be available to Carter Smith, PI Charles Peterson, and collaborators until the results have been published in peer-reviewed journals, or before June 1st, 2019, whichever comes first. After this date, the data will be deposited in and freely available through the Odum Institute Data Archive, which is a trusted and well-established social science archive. Any personal identifiers within the dataset will be removed before publication and storage in the archive. Data have been or are in the process of being disseminated through peer-reviewed manuscripts and conference presentations. Major finding will also be incorporated into a 9-12 grade lesson plan (based on NC Core Standards) that will be disseminated to NC science teachers through the Scientific Research Exchange Network in early 2019.

Acknowledgements

This research was supported by a North Carolina Sea Grant and North Carolina Sentinel Site Cooperative Graduate Student Fellowship, but there are many other agencies and individuals who were extremely helpful and contributed to the project's success.

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SEPTEMBER 2018

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EVALUATING STAKEHOLDER PERCEPTIONS OF COASTAL HAZARDS IN NORTH CAROLINA

North Carolina's coastlines are regularly impacted by tropical storms and hurricanes and NC is predicted to be one of the most vulnerable states in the USA to sea level rise (SLR).

The goal of this project was to gain a better understanding of how hazards like hurricanes and SLR are affecting coastal communities, and in turn how unique homeowner experiences impact decision-making and risk appreciation.

For the field component of this study, we used a damage assessment protocol to evaluate estuarine shoreline damage after Hurricane Matthew (2016) along approximately 60 km of estuarine shoreline in Dare, Carteret, and Brunswick counties.

For the social-science component, we used a Qualtrics survey targeting waterfront and non-waterfront residents in Dare, Carteret, and Brunswick counties. We mailed survey invitations to 3000 homeowners and received 489 completed surveys.

In particular, we were interested in the damage that Hurricane Matthew had caused to houses and shorelines across NC and how and if homeowner experience with damage correlated with perceived risk to future hurricanes and SLR.

These data can help coastal managers understand the risks that coastal residents face and also how those actual risks correlate with risk perceptions.

This research was supported by a North Carolina Sea Grant & North Carolina Sentinel Site Cooperative Graduate Fellowship

This research was also supported by a UNC Chapel Hill Royster Society Fellowship

We evaluated approximately 60 km of estuarine shoreline for damage after Hurricane Matthew. Ninety percent of observed shoreline damage could be attributed to bulkhead shorelines.

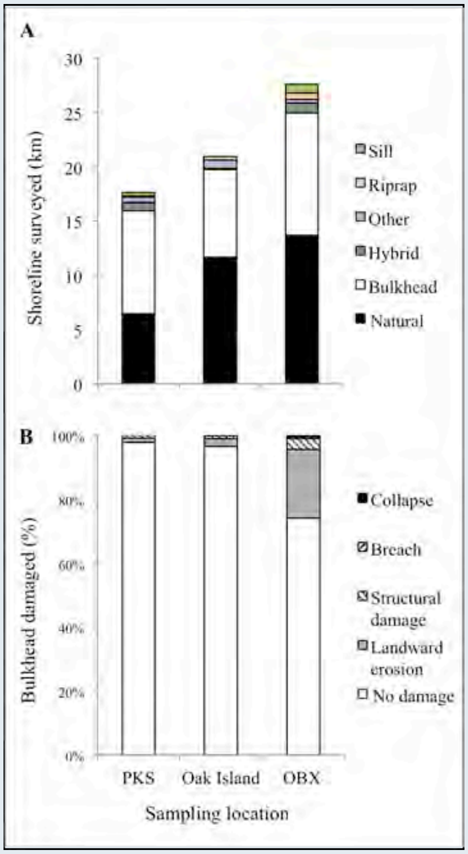

Figure 1 A) Total shoreline surveyed by shoreline type and region. B) Percent of bulkhead shoreline damaged in each region. PKS= Pine Knoll Shores (Carteret county), Oak Island (Brunswick county), and OBX = Outer Banks (Dare county).

Nearly 25% of the bulkheads surveyed in the Outer Banks had visual damage that could be attributed to Hurricane Matthew, which was significantly more damage than what was observed in Carteret and Brunswick counties (Figures 1 & 2).

Figure 2 Collapsed bulkhead in Dare County.

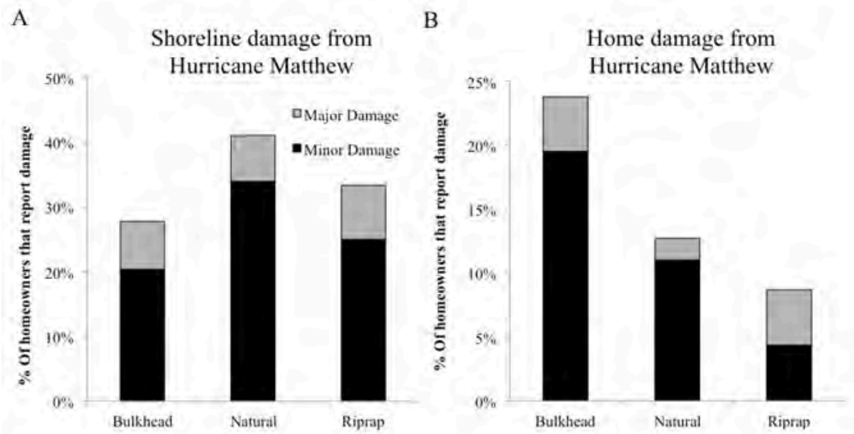

Figure 3 A) Percent of survey respondents that reported shoreline damage during Hurricane Matthew broken down by shoreline type. B) Percent of survey respondents that reported home damage broken down by shoreline type.

HURRICANE DAMAGE TO SHORELINES AND HOMES DURING PREVIOUS HURRICANES WAS A STRONG PREDICTOR OF DAMAGE DURING HURRICANE MATTHEW

There were no major differences in the rates of shoreline damage that could be attributed to bulkhead, natural, and riprap shorelines (Figure 3A). However, homes with bulkhead shorelines were damaged significantly more than homes with natural shorelines (Figure 3B). This may be because homes with bulkheads were on average 3X closer to the water than homes with natural shorelines.

In addition to looking at hurricane damage by shoreline type, we also investigated the best predictors of damage based on a variety of environmental factors (such as shoreline fetch, distance between the house and the water) and experience with past hurricanes.

The best predictor of shoreline damage during Matthew was whether or not the homeowner's shoreline had been damaged during Hurricane Arthur (2014). Shorelines that were damaged during Hurricane Arthur were 3X more likely to have been damaged during Matthew than shorelines that had not been damaged during Arthur.

These data are useful for coastal managers and residents that are seeking to understand how coastal counties are affected by hurricanes. For more information and discussion of these results, please see the full report.