Project Final Report:

Measuring and Mapping the Impacts of Hurricane Michael in the Florida Panhandle to Better Understand the Role that Nature Plays in Coastal Resilience

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***Additionally**, please reach out to Steven Scyphers (s.scyphers@northeastern.edu) and Christine Shepard (cshepard@tnc.org) to inquire about any potential re-use of the research results in this report in other publications.

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Executive Summary

Hurricane Michael made landfall in the Florida Panhandle on October 10th, 2018 as a Category 5 storm. With maximum sustained winds reaching 160 mph, Michael was the first category 5 storm to impact the Florida Panhandle, as well as the first to make landfall in the United States since Hurricane Andrew in 1992

The Mexico Beach area in eastern Bay County bore the brunt of the storm's devastation, with storm surge resulting in water levels reaching 9 to 14 ft above ground level, as well as dune overwash and major inland flooding. However, large impacts occurred across the broader Panhandle region, including Panama City, Port St. Joe, and Apalachicola, where extensive marshes and wetlands, coastal forests, and bays support the culture and economies of these coastal communities.

Northeastern University and The Nature Conservancy partnered to study the impacts of Hurricane Michael within Bay, Gulf and Franklin counties, with an emphasis on identifying potential benefits of nature-based features such as salt marshes and undeveloped green spaces. To explore how nature influenced the impacts of the storm, we:

- researched and synthesized available data sets that characterized Hurricane Michael's impacts on the people and nature of the region;
- conducted household surveys of residents throughout the region to collect household-level data on storm impacts and recovery to both homes and shorelines;
- used field approaches and remotely-sensed (satellite) data to characterize storm impacts on nature-based features including marshes, shorelines, and residential structures; and
- evaluated relationships between land-cover, such as the amount of nearby green space, and storm impacts and recovery by using spatial modeling approaches.

The findings from this study will feed into and directly inform a regional nature-based solutions planning project funded by the National Fish and Wildlife Foundation National Coastal Resilience Fund. The regional coastal resilience planning effort, led by The Nature Conservancy and the Northwest Florida Water Management District, began in March 2021.

Collecting and Synthesizing Existing Data about Hurricane Michael

About one year after Hurricane Michael, we compiled available data sets and reports from state and federal agencies to help characterize the storm's impacts and identify data gaps for our study to address. Multiple agencies provided quick reconnaissance and impact reports on a variety of topics ranging from insurance claims to forest damage. For example, the State of Florida's Department of Environmental Protection (DEP) assessed beaches and exposed coastlines and found that erosion and structural damage was greatest in east Bay County, near Mexico Beach

(close to the point of landfall). Property damage data was available through FEMA and Insurance Claim databases, although it was difficult to distinguish wind from flood damage. The Coastal Emergency Risk Assessment (CERA) program produced data on modeled storm conditions, including inundation, which showed the greatest flooding east of Panama City and along Mexico Beach, Island Pass, and St. George Island. All of these datasets reflected the devastating impacts of Hurricane Michael to the Florida Panhandle and helped set the foundation for our study of the potential role nature played in Hurricane Michael. However, we identified notable data gaps, particularly related to storm impacts on marshes and sheltered shorelines, and coastal residential properties.

Storm Perceptions, Impacts, and Recovery of Coastal Households

A little over a year after landfall, we surveyed 327 residents within 1km from the coast in Bay, Gulf, and Franklin counties (the selected counties from part 1 of the study). The survey consisted of 67 questions that covered the following major categories: a) *Household Property Damage & Recovery*, b) *Household Health Impacts & Recovery,* c) *Community Shoreline Impacts & Recovery*, and d) *Ecosystem Impacts & Recovery*. For each of these categories, we analyzed the potential influence of nearby shoreline type to assess the benefits of armored versus natural and nature-based shorelines. In summary, our survey results revealed that overall property damage was extensive with 6% of waterfront residents reporting that their property was ruined, 26% majorly damaged, and 36% moderately damaged. Our results also showed that home damage was similar across all shorelines types. However, the cost of repairing a vegetated shoreline was much less ($2,937) than a hardened shoreline ($14,117). Overall property damage was highly connected with reported mental stress, with only 14% of respondents reporting fully mentally recovered. In addition to providing similar protection to armored shorelines, marshes generally fared well in the storm. When asked about community shorelines, most residents perceived marshes as lightly damaged due to the storm and recovering well a year after, whereas bulkheads and seawalls were often perceived as majorly damaged or ruined. This suggests that marsh shorelines could provide a useful form of coastal protection, as they incurred minimal damage and have a high perceived effectiveness in reducing storm damage in the Florida Panhandle.

Damage, Resilience, and Recovery of Salt Marshes

In December 2019, we conducted fieldwork in the Florida Panhandle to document hurricane impacts and recovery. Additionally, as large areas of marshes were difficult to assess on site, we conducted visual damage and recovery assessments using aerial imagery from Google Earth. This provided high-resolution aerial imagery after Hurricane Michael's landfall (Oct. 2018, directly after the Hurricane's landfall). We used the USFWS National Wetlands Inventory to identify salt marshes in Bay, Gulf, and Franklin counties. We then visually determined areas of damage and categorized them into 7 types: deposition of sediment or marsh, man-made debris, fallen trees, lateral erosion, vegetation loss, conversion to open water, and channel cutting/widening. Lastly, we assessed marsh recovery where available, for parts of Gulf and Franklin county.

In total, out of the 173,259 km^2 of marsh analyzed, only 1.9% of marshes appeared damaged after the storm. These damages were primarily caused by deposition of vegetation, or sediment. Although the marshes were largely undamaged, those that did sustain damage had a low percentage of recovery (16%). Recovery was primarily based on the level of storm surge or winds impacting the area of marsh; the marshes were more likely to recover when they were impacted by less extreme environmental conditions during the storm. Marshes were more damaged and less recovered when privately owned; this parallels the reported differences between residents' shorelines and community shorelines (Part 2 of the study). Finally, out of the damage types present, marshes recovered most readily from vegetation loss.

Effects of Green Space on Storm Impacts and Recovery

We used spatial modeling to analyze our survey data on house-hold level damages and recovery outcomes alongside storm characteristics, land-use, and other spatial data in the Florida Panhandle. Using logistic regressions, and controlling for social and hurricane factors, we found that increasing green space surrounding a home was associated with higher probability of recovery. As expected, these analyses also showed that homes exposed to higher winds and situated closer to shorelines received higher damages. This was similar for predicting lower levels of recovery. In addition, as the surrounding environment becomes more built (and less green), the probability of property recovery was also lower. Home damage and mental stress are complexly intertwined. Through our spatial modeling, we found that lower levels of green space also increased the odds that respondents' homes or sense of well-being were less likely to be recovered.

Summary of Key Findings

- ***Overall property damage was extensive with 6% of residents describing their homes as ruined, 26% majorly damaged, and 36% moderately damaged.*** *Landscaping* was most frequently reported as majorly damaged, or ruined (68%), followed by *roof* (44%), *interior* (20%), and *walls* (19%).
- ***Armored shorelines, which can damage ecosystems, did not provide additional storm protection and greatly increased recovery costs for waterfront residents***. Home damage states were similar across the different shoreline types. On average, recovery costs for vegetated shorelines were $2,937, and $14,117 for hardened shorelines. Additionally, annual maintenance costs were estimated at $312 for vegetated shorelines, and $1,094 for hardened shorelines.

- ***At the community level, bulkheads or seawalls were most frequently categorized as majorly damaged or ruined (50%) and least often perceived as fully recovered (14%).*** Beaches were perceived as majorly damaged or ruined by 34%, rip-rap revetments 32%, and marshes 29%.
- ***Coastal marshes were largely resistant to storm impacts even under extreme conditions.*** Despite being subject to wind speeds greater than 60 m/s and inundation greater than 3 m, only 2% of coastal marshes in the study area were damaged.
- ***Residents also generally perceived marshes as effective at protecting coastlines against storm waves and inundation.***
- ***Damaged marshes did not quickly recover and actions should be taken to restore damaged marshes.*** Only 16% of damaged marshes recovered six months after landfall. However, marshes exposed to less extreme environmental conditions during the storm were more likely to recover (i.e. wind speed, or inundation)
- ***Increasing green space surrounding a home was associated with higher probability of recovery***, after controlling for social and hurricane-impact factors.
- ***More surrounding green space, in contrast to built environments, promotes home and mental recovery for residents.*** By linking our survey results with land-use data, we developed a spatial model for predicting levels of storm recovery for homes and the recovery of a sense of well-being among residents.

Discussion and Conclusions

The overall goal of our study was to understand the societal and ecosystem impacts of Hurricane Michael on the Florida Panhandle, and we were particularly interested in the role of natural and nature-based features (NNBF) at buffering impacts and promoting recovery. We leveraged field reconnaissance, remote sensing, household surveys, and spatial modeling to pursue this goal, and a few key findings of our study have direct relevance for hurricane preparedness and recovery, as well as the conservation of coastal habitats and ecosystems. Using remote sensing, we discovered that the vast majority of marshes and natural and nature-based features were resistant to the Category 5 conditions of Hurricane Michael; yet, areas that were impacted were also slow to recover. Through a household survey of waterfront residents, we found that armored shorelines do not enhance coastal protection benefits and instead add to rebuilding and repair costs. More broadly, we also found that coastal communities generally perceived armored shorelines to be among the most damaged and least recovered. By coupling our survey results with data on local land-use, we revealed that increased green space directly surrounding the home promoted higher levels of recovery from home damages and mental impacts Hurricane Michael caused.

Moving forward, these insights will be translated into coastal resilience planning efforts throughout the region. For coastal property owners, our survey results showing added costs but no additional benefits for storm protection provide a compelling case for nature-based solutions along residential shorelines. More broadly, our study highlights the benefits of nature-based solutions and green space for promoting disaster resilience in coastal communities.

Study 1: Synthesizing Existing Data on the Impacts of Hurricane Michael

Overview & Objectives - Hurricanes are one of the costliest and most devastating hazards that impact the United States yearly. Because of this, documenting and understanding the impacts caused by these storms is important. Rapid damage assessments of the environment, structures, economic impacts, and species allow researchers a deeper understanding of the interactions at play and provide initial information for decision-makers (Zhai and Peng 2020). Further, understanding a storm, and its impacts, provides future decision-makers with information to implement storm protective measures in known vulnerable locations (Xian et al. 2018). Many rapid reconnaissance efforts take place directly following a hurricane, and the response was no different for Hurricane Michael. This sub-study aims to collect and synthesize the immediate storm models and reconnaissance taking place for Hurricane Michael.

Methods - Post-storm characteristics of Hurricane Michael were collected from the Coastal Emergency Risk Assessment (CERA) website. Winds and inundation values were used to select locations for further damage investigations. Specifically, Franklin, Gulf, and Bay county had some of the highest wind and inundation values. Websites of known hurricane tracking and reconnaissance organizations were followed to be notified once information was released. Florida government websites and Florida Newspapers were followed for additional information about Hurricane Michael's impacts. We repeated our searches monthly for the first six months following the storm to identify new information released. Data sources were compiled and organized into subcategories of environmental and socioeconomic focuses. When available, data and shapefiles were collected and uploaded into ArcGIS to be combined onto a single map. Hot spots of damages were identified using these compiled sources.

Findings - A number of resources were available for assessing the impacts of Hurricane Michael in the Florida Panhandle (appendix: Table A1). In general, the coastal counties of Bay, Gulf, and Franklin saw some of the highest damages and storm impacts. Overall, Hurricane Michael was responsible for about $25 billion in damages and 16 direct deaths (Beven et al. 2019).

Figure 2.1. Graphic produced by FEMA to summarize the impacts Hurricane Michael had on the Florida Panhandle

In total, the number of insurance claims for Hurricane Michael was 149,773 with more than $7.4 billion in estimated insured losses (FOIR 2019). The highest amount of insurance claims were submitted within Bay and Gulf counties (Figure 2.2). The Florida Forest Service also estimates 2,808,645 acres of forest land area damaged from the storm costing just under $1.3 billion in total timber damage (Florida Forest Service 2018). The counties with the highest impacted acres of forested land were Gulf and Calhoun (Figure 2.2). Rapid damage assessments were completed by the Federal Emergency Management Agency (FEMA) and the Structural Extreme Event Reconnaissance network (StEER) finding a total of 1,039 destroyed structures throughout 11 different counties (FEMA Destroyed = 878, FEMA Affected = 24974, StEER Destroyed = 9, StEER Affected = 161) (appendix: Table A2). These destroyed and affected structures appear all along the track of the storm. The Florida Department of Environmental Protection (Florida DEP) categorized the beach and dune erosion from minor (1) to major (4). Severe beach and dune erosion conditions were recorded along Mexico Beach and St. George Island (Figure 2.2). Hurricane Michael had many direct impacts which were recorded throughout the Florida Panhandle.

Unsurprisingly, environmental and structural damage was greatest in Bay County, specifically Mexico Beach, near the point of landfall (Figure 2.2). Inland counties along the path of the storm had high structural damage, and high timber damage (Figure 2.2). Socio-economic damages were higher within Bay and Gulf Counties. Along the coast, inundation and shoreline change was greatest along Mexico Beach, Island Pass, and St. George Island. These areas had the most critical post-storm erosion conditions, given by Florida DEP. Notably, vegetated systems - such as marshes - were missing from the general damage assessments that were collected. A higher-resolution study of these damages will provide more insight on the interacting structural, environmental, and social impacts of the storm.

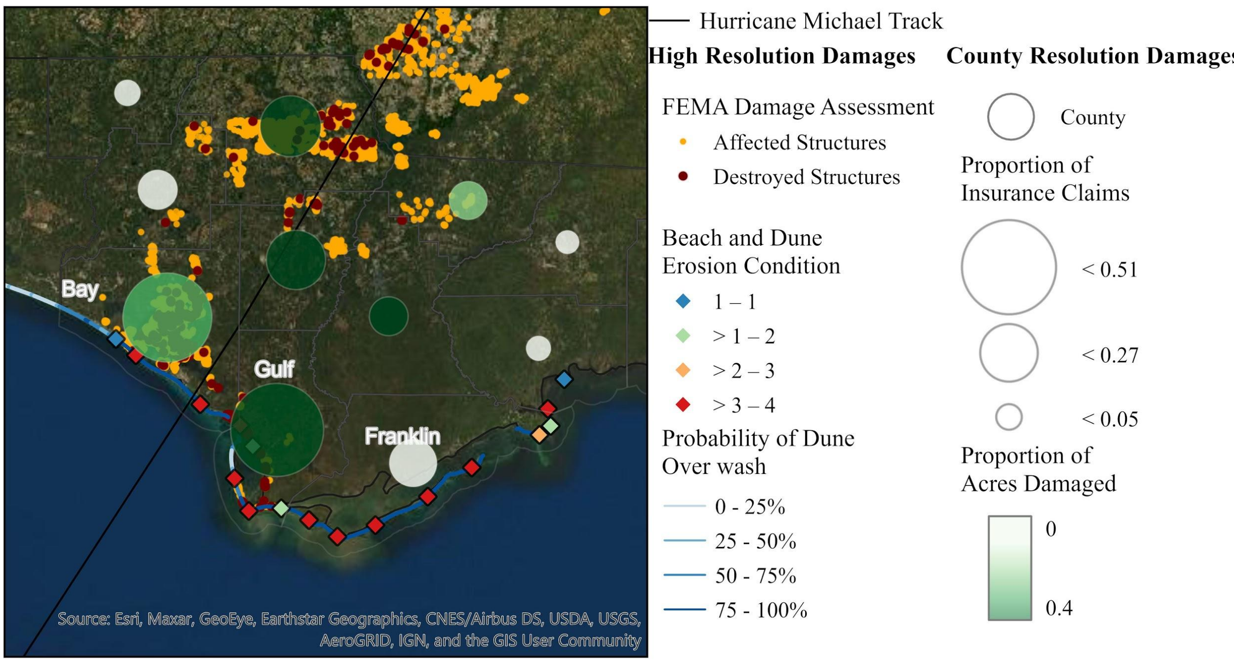

Figure 2.2. This map summarizes collected Hurricane Michael data sets, which show the areas impacted by the storm. Data sets are organized into two spatial scales: damages by county, and damages at smaller scales. Each dot (yellow or red) represents a building assessed virtually by FEMA, where yellow and red dots correspond to buildings assessed as affected or destroyed, respectively. The beach and dune erosion condition is displayed using diamonds. Diamond color represents condition number, where the greater the number, the more severe the erosion is. Based on USGS modeling, the probability that a dune was overwashed with stormwater is displayed along the coastline with darker blue colors representing 75-100% dune overwash. Each impacted county is represented by a circle centered on the county. The proportion of insurance claims (number of claims normalized by county population) are given by the size of the circles. The proportion of severely impacted acres of forestry (acres of severely impacted forest normalized by acres of county) is represented by the shade of each circle - darker green reflects a higher proportion of severely impacted trees.

Study 2: Storm Perception, Impacts, and Recovery of Coastal Homeowners

Overview & Objectives - With sea level rising, oceans warming, and coastal populations increasing, natural hazards increasingly impact both the landscape and the communities situated along coasts. Variations in the social landscape can lead to areas of vulnerable populations. Additionally, attributes of local to regional landscapes can create areas of high exposure and risk. Both the natural landscapes and human communities are important when understanding the outcomes of a disaster. This sub-study focuses on understanding the interaction between the ecosystem and residents' damage and recovery after a storm, by using a case study of Hurricane Michael's impacts on the Florida Panhandle region. This survey allows residents to self-assess their damage state and recovery from the storm, including both physical home recovery and psychological recovery one year after the storm.

Methods -
Data Collection: A parcel-level survey was conducted between December 2019 and February 2020 about 14 to 16 months after Hurricane Michael made landfall. The survey used an address-based sampling of residential properties in Gulf, Bay, and Franklin County. Addresses were obtained using the publicly available Monroe County tax database. Using ArcGIS and the National Oceanic and Atmospheric Administration (NOAA)'s Environmental Sensitivity Index (ESI) lines (describing the shoreline archetype) a 1km buffer was created from the coastline. Properties within this buffer were categorized into waterfront parcels or inland parcels. In total, 2000 residents (1000 waterfront and 1000 inland) were randomly selected to receive a letter in the mail requesting to participate. This survey used a mixed-mode survey technique and two mailings of both a physical survey and an online option (Dillman et al. 2014). The survey yielded a 17% response rate and the data of all 327 responses were entered into Qualtrics and downloaded for analysis in ArcGIS and R-studio.

Survey Instrument: The household survey instrument included 67 questions that covered potential impacts Hurricane Michael may have on the residents as well as their behaviors before and after the storm. Questions asked in this survey covered: Household Property Damage & Recovery, Household Health Impacts & Recovery, Community Shoreline Impacts & Recovery, and Ecosystem Impacts & Recovery. Variables collected were: home damages, personal damages, ecosystem impacts, community resilience, risk knowledge, fairness of outcome, and recovery. This survey allows residents to self-assess their damages from the storm, and report on their current recovery status. Home characteristics and personal demographic questions were asked at the end of the survey, with options of "*prefer not to answer*" for all of them.

Residents' home damage states were recorded using a variation of an engineering home damage assessment (Tomiczek et al. 2019). Respondents gave damage states on a 5-point Likert scale (*No Damage, Lightly Damaged, Moderately Damaged, Majorly Damaged,* and *Ruined*) for the categories: "Roof", "Walls", "Landscaping", and "Interior Items". Respondents were then asked to give an overall damage state to their home using the same scale. They were given an "Other" category to describe damage to any aspect of their home that was not included in the categories provided. A follow-up question asked residents to report their overall cost - or amount of time required - for repairing or replacing parts of their home. An overall cost of repair was calculated by adding together the cost of each category reported on. Further questions of household physical and mental health impacts were asked with the option of *yes* they were impacted or *no* not impacted. These survey questions allow residents to explain their perspective on the damage, and provide information potentially overlooked by researchers who typically rely on visual assessments. Respondent's ability to self-report the damage states of their home gives insight into the perspectives of residents after a storm and allows social impacts to be recorded.

Questions were asked about residents' home, mental, and physical recovery caused by the storm using the options: *Fully Recovered, Partially Recovered, Not Recovered,* and *Prefer not to answer*. The questions on recovery were analyzed as dependent variables individually in order to understand the nuances of a fully recovered resident. Each recovery question was analyzed, removing the respondents who responded with *Prefer not to answer*. Another category of *No Initial Damage* was added for each recovery question to account for residents who had no damage reported in the initial damage questions.

The community resilience category includes questions on residents' connection to their neighbors, their risk knowledge, and their perceptions of fairness on the hurricane impacts and recovery. Respondents' connection to their neighbors were measured using two sets of questions asking the knowledge of their neighbors (5-point Likert scale from *A great deal* to *None at all*), and how often they visit, or see their neighbors (5-point scale from *About once a week* to *Never*). Risk knowledge was measured on a 5-point Likert scale (*Strongly disagree* to *Strongly agree*) for having information concerning: "The area I live in is prone to hurricanes", "The elevation and flood risk of my home", "What to do to prepare for a hurricane", and "What to do after a hurricane". These questions were averaged for further statistical analysis, resulting in higher values representing those who have a greater risk knowledge of their area. Outcome fairness was recorded on a 5-point Likert scale (*Strongly disagree* to *Strongly agree*) of agreement with the statements: "Everyone received help promptly", "Resources were distributed to those with the most need", "Public authorities have listened to my community", and "Public authorities did all that they could to help”. The answers to these questions were also averaged, resulting in higher values representing unfair outcomes of Hurricane Michael.

Respondents’ perceptions of community shorelines were recorded through survey questions asking to rate the damages seen, the recovery a year after, and the effectiveness of storm protection for 6 different shoreline types near their residence. Respondents were able to report on “Docks or Piers”, “Marshes”, “Beaches”, “Bulkheads or Seawalls”, “Rip-rap Revetments”, and “Mangroves”. An option of “Other” was given, allowing residents to report on nearby shorelines not listed within the survey. Mangroves are only just beginning to reach these counties within the Florida Panhandle, resulting in many people not responding to this category. “Docks or Piers” were majoritively categorized as ruined and not recovered across all respondents. Therefore, both “Mangroves” and “Dock or Piers” were taken out of further assessments.

Statistics and Analysis: The data of all 327 responses was entered into Qualtrics, and downloaded for analysis in ArcGIS, Rstudio, and SPSS. Frequencies of damage states and recovery were collected for each type (home, physical, and mental). Damage states of the home categories provided were compared to the overall damage states using Spearman-rank correlations. Kruskal-Wallis tests were run to compare the distribution of damages and recovery across spatial (county), exposure (waterfront), and landscape (shoreline archetype) variables. Additional Dunn-tests were run for significant Kruskal-Wallis tests to find the groups with significantly different distributions.

Results -

Household Property Damage & Recovery : Residents’ homes were mostly *Moderately damaged* (n = 111, 36%) (Table 3.1). Overall home damages were skewed slightly (skewness = -0.096) towards higher damage states. On average residents spent $81,117.24 ($\pm$10.4 $\times$10^4 SE) on repairing or replacing home impacts. “Landscaping” was categorized as the most damaged home category (skewness = -0.852), with a majority reporting *Majorly damaged* (n = 117, 36.8%). The “Wall” category had the strongest correlation with overall home damages (Spearman’s rank correlation: R = 0.748, p = 0.00), followed by “Roof” (R = 0.743, p = 0.00) (Table 3.1). The “Other” category had 102 responses with most reporting on exterior buildings (n = 25), or personal docks (n = 13), as the missing factors in their damage assessments. These other factors were mostly categorized as *Ruined* (n = 39, 12%) and skewed towards higher damages (skewness = -0.799). Where residents lived showed significantly different home damages (χ^2 = 11.393, df = 2, p = 0.003), with Franklin county having overall fewer damages than Bay and Gulf counties (Table 3.2).

Table 3.1. Individual categories of home damage states are displayed followed by the skewness and Spearman’s rank correlation to overall home damage. The verified percent is shown for each damage state for all categories of home damages. The number of responses is displayed within the parentheses for each cell. The skewness shows the trend of damage distribution with negative numbers indicating higher damage, and positive numbers indicating less

damage. “Landscaping” is the most negatively skewed, and “Interior Items” is the most positively skewed. Spearman’s rank correlation is run to compare the categories of home damages to the overall home damage states. The strongest correlation is seen with “Walls”.

	Roof	Walls	Landscaping	Interior Items	Other	Personal Shoreline	Overall
No Damage	17.7% (56)	32.5% (102)	7.2% (23)	35.2% (112)	14.7% (15)	18.4% (30)	8.4% (26)
Lightly Damaged	15.8% (50)	28% (88)	9.4% (30)	27% (86)	7.8% (8)	28.2% (46)	23.1% (71)
Moderately Damaged	22.8% (72)	20.1% (63)	15.7% (50)	17.6% (56)	11.8% (12)	24.5% (40)	36% (111)
Majorly Damaged	27.8% (88)	12.4% (39)	36.8% (117)	12.6% (40)	27.5% (28)	24.5% (40)	26.3% (81)
Ruined	15.8% (50)	7% (22)	30.8%(98)	7.5% (24)	38.2% (39)	4.3% (7)	6.2% (19)
Skewness	-0.200	0.619	-0.852	0.670	-0.799	0.094	-0.096
Spearman’s correlation	R = 0.743, p = 0.000	R = 0.748, p = 0.00	R = 0.602, p = 0.00	R = 0.721, p = 0.00	R = 0.458, p = 0.000	R = 0.378, p = 0.000	--

Table 3.2. Average home damage, home recovery, physical illness or injury recovery, and mental illness recovery are all displayed by county. Kruskal-Wallis tests are run to find the difference between the distribution of damages and recovery by county. The output of the Kruskal-Wallis tests are shown for each damage and recovery within the table.

	Home Damage	Home Recovery	Physical Recovery	Mental Recovery
All	2.99	1.89	1.29	1.57
Bay	3.03	1.93	1.32	1.60
Gulf	3.05	1.68	1.20	1.53
Franklin	2.40	1.62	1.40	1.27
Kruskal Test	χ^2 = 11.393, p = 0.003	χ^2 = 6.963, p = 0.031	χ^2 = 5.899, p = 0.052	χ^2 = 5.394, p = 0.067

The distribution of waterfront residents’ (n = 194) home damage states were significantly different from inland respondents (χ^2 = 5.2995, df = 1, p = 0.0213). Waterfront residents had slightly higher damage states (skewness = 0.0324) compared to inland residents (skewness = 0.269). Shorelines of waterfront home owners were classified into 4 categories; Hardened (bulkheads, seawalls, and rip-rap revetments; n = 78, 40.2%), Vegetated (marsh systems; n = 51, 26.3%), Hybrid (hardened and vegetated; n = 28, 14.4%), and Beach or Tidal flat (n = 37, 19.1%). Waterfront residents' home damage states were significantly different by the type of shoreline they owned ($\chi^2 = 11.571$, $df = 3$, $p = 0.009$). However, the distribution of home damages were not significantly different for residents with Hardened, Vegetated, or Hybrid shoreline types. Beach/Tidal flat shorelines were significantly different given dunn-tests.

Overall, parcel-level shorelines did well and most respondents categorized their shoreline as lightly damaged (n = 46, 28.2%). The distribution of parcel-level shoreline damage was not significantly different by shoreline type ($\chi^2 = 0.871$, $df = 3$, $p = 0.832$). Parcel-level shoreline recovery was also not significantly different by shoreline type ($\chi^2 = 3.7324$, $df = 3$, $p = 0.292$). Hardened, Vegetated, and Hybrid shorelines were damaged and recovered similarly across waterfront residents.

On average, residents spent $20,231.85 (±10.4×10^4 SE) to repair, or replace their shoreline and $1,058.46 (±2.7×10^3 SE) annually to maintain their shoreline (Table 3.3; Figure 3.1). The reported cost to repair was significantly different for shoreline types ($\chi^2 = 10.135$, $df = 3$, $p = 0.017$), with Vegetated ($6,027.78 ± 1.25×10^4 SE) and Beach/Tidal flat ($2,844.44 ± 6.02×10^3 SE) shorelines having the lowest costs on average (Table 3.3; Figure 3.1). In comparison, the cost to maintain shorelines was not significantly different by shoreline type ($\chi^2 = 3.766$, $df = 3$, $p = 0.288$), and on average cost $1,058.46 (±2.72×10^3 SE).

Table 3.3. Overall home damage is shown, averaged by shoreline type, ± standard error of the mean. Shoreline damage and maintenance are displayed by the average damage state, the average cost to repair or replace the shoreline, and the yearly maintenance cost. Each row is split into the respective shoreline type of a respondent.

	Hardened	Hybrid	Vegetated	Beach/Tidal Flat	Total
Damage Cost	$35,045.64 ± 1.57×10^5	$20,027.28 ± 3.73×10^4	$6,027.78 ± 1.25×10^4	$2,844.44 ± 6.02×10^3	$20231.85 ± 1.03×10^5
Maintain Cost	$851.79 ± 2.27×10^3	$2,259.09 ± 4.64×10^3	$762.96 ± 1.97×10^3	$840.01 ± 1.93×10^3	$1058.46 ± 2.72×10^3
Shoreline Damage	2.78	2.68	2.75	2.55	2.71
Overall Home Damage	3.19	3.14	3.24	2.58	3.08

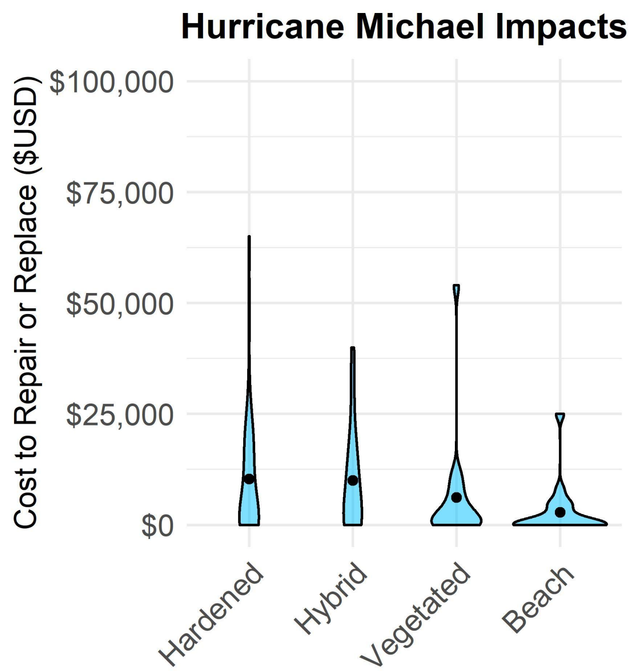

Figure 3.1. Distribution of the reported cost to repair or maintain a shoreline divided by shoreline type. The average cost to repair or replace for each shoreline is displayed by a black dot within the distributions.

Property recovery one year after the storm was mostly categorized as *Partially Recovered* (n = 170, 54.8%) and slightly skewed towards fully recovered (skewness = 0.138). These two factors (Property recovery and Property damage) were positively correlated (*rs* = 0.530, *p* = 0.000). Where residents live also showed a significant difference in home recovery (χ^2 = 6.963, *df* = 2, *p* = 0.031) with Bay county having less property recovery (Table 3.2). Similar to home damage, home recovery was not significantly different by shoreline archetype (χ^2 = 3.732, *df* = 3, *p* = 0.292).

<u>*Household Health Impacts & Recovery*</u>:

Respondents reported on their household's physical and mental well-being following Hurricane Michael. About 9% (n = 29) of residents reported a household member experiencing a physical injury or illness as a direct impact of the Hurricane. Out of all respondents, 75.8% (n = 194) of people reported feeling fully physically recovered. However, of those people who reported physical injury or illness (n = 29), only 40.6% (n = 13) reported feeling fully recovered. About 26% (n = 79) of respondents reported a household member experiencing some level of emotional or mental illness following the storm. Out of all respondents, 50.2% (n = 139) reported feeling fully recovered. However, only 13.7% (n = 13) of people who reported mental illness reported feeling fully mentally recovered. Both recovery variables and home damages were significantly correlated (Physical recovery: *rs* = 0.311, *p* = 0.00; Mental recovery: *rs* = 0.439, *p* = 0.00). Home damage and all three recovery variables were significantly different by the county that respondents' homes were situated in, using a confidence interval of 90% (Table 3.2).

Similar to property impacts, shorelines are tested against both Injury and Mental recovery using Kruskal-Wallis tests. Recovery from injuries was not significantly different by shorelines ($\chi^2 = 2.206$, $df = 4$, $p = 0.698$). However, recovery from mental impacts was significantly different by shoreline ($\chi^2 = 11.178$, $df = 4$, $p = 0.025$), but only for Beach/Tidal flat shoreline types. Those with Beach/Tidal flat shorelines had higher levels of recovery.

The fairness of hurricane response was compared across levels of physical and mental recovery. Those who reported that outcomes were fair were more likely to report full physical home recovery ($\chi^2 = 12.98$, $df = 2$, $p = 0.002$) and higher mental recovery ($\chi^2 = 11.685$, $df = 2$, $p = 0.003$).

Community Shoreline Impacts & Recovery:
Overall, community shorelines were Moderately Damaged with a response of 251 (30.0%), excluding Mangroves and Dock or Piers (Figure 3.2.A). Specifically, most hardened bulkheads or seawalls were reported between Moderately damaged to Ruined (skewness = -0.551) with the plurality of respondents reporting Bulkheads as Majorly Damaged (n = 82, 36.1%). Marshes were mostly reported as Moderately Damaged (n = 58, 32.2%, skewness = -0.001), Rip-rap as Lightly or Majorly damaged (n = 40, 24.8% for both categories, skewness = 0.075), and Beaches as Moderately Damaged (n = 88, 32.8%, skewness = 0,059). The distribution of damage states were significantly different for shoreline types tested ($\chi^2 = 30.958$, $df = 3$, $p = 0.000$). The shorelines with the lowest percent reported as fully recovered were Bulkheads or seawalls (n = 39, 18.8%; Figure 3.2.B). Alternatively, Rip-rap shorelines had the highest percentage of fully recovered responses (n = 51, 31.9%). The distribution of recovery status across the selected shoreline types were significantly different ($\chi^2 = 19.427$, $df = 3$, $p = 0.000$). For all shorelines, there was a significant difference in recovery based on the damage state initially received ($\chi^2 = 199.41$, $df = 4$, $p = 0.000$).

When asked about the effectiveness of each shoreline type at protecting coastal properties from storms, beaches were reported least effective, with only 17% of respondents categorizing beaches as very or extremely effective. Additionally, 28% of respondents reported the same regarding marshes, 30% for bulkheads or seawalls, and 38% for rip-rap revetments (Figure 3.2.C). The distribution of shoreline storm protection effectiveness was significantly different across shoreline types ($\chi^2 = 72.891$, $df = 3$, $p = 0.000$). Shoreline damage and recovery were significant predictors of protection effectiveness for marshes and hardened shorelines. Spearman correlations between damage and effectiveness were significant for Marsh ($rs = 0.206$, $p =$

0.001), Bulkhead or Seawalls ($rs = 0.123$, $p = 0.048$), and Rip-raps ($rs = 0.152$, $p = 0.020$). Spearman correlations between recovery and effectiveness were significant for Bulkheads or Seawalls ($rs = -0.165$, $p = 0.021$) and Rip-raps ($rs = -0.297$, $p = 0.000$).

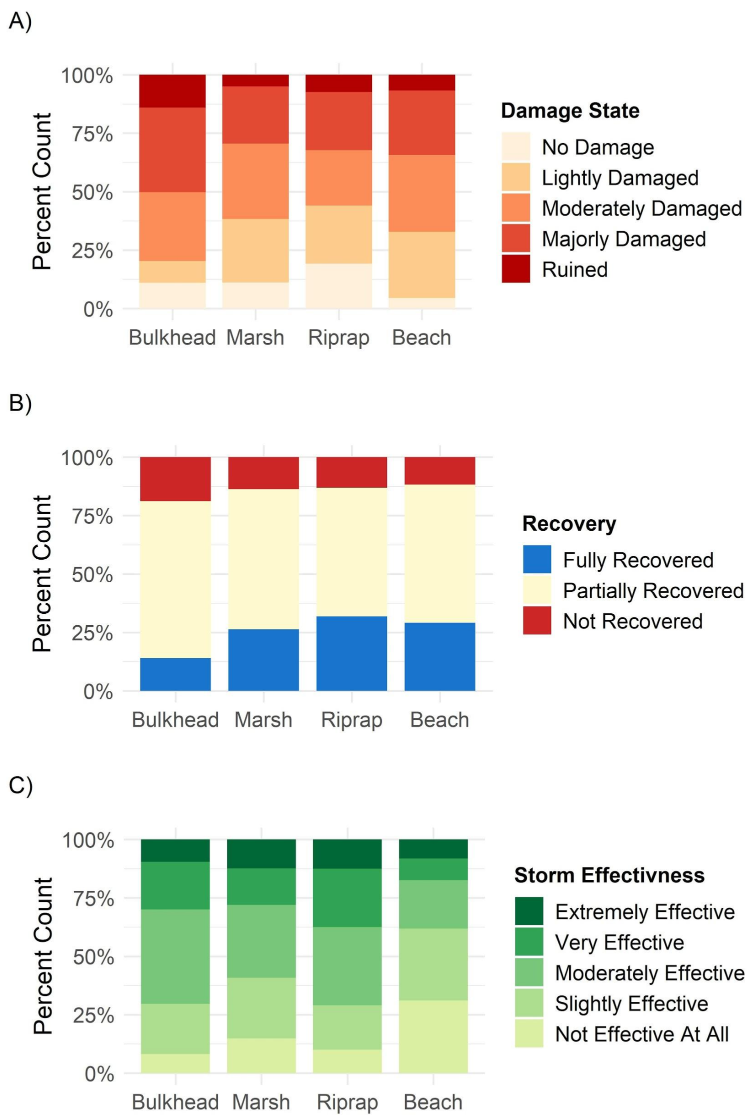

Figure 3.2. Multi-panel figure showing respondents' perceptions on community shorelines. A) shows perceptions on the damage of community shorelines, B) shows perceptions on the recovery of community shorelines, and C) shows the perceived effectiveness of shoreline storm protection.

<u>*Ecosystem Impacts & Recovery*</u>: Residents were asked to rate 9 coastal, marine, and terrestrial species on a 5-point scale ranging from not harmed (1) to severely harmed (5), with people as a 10th category for comparison. Perceptions on damage and recovery were compared using

respondents' perceived human ecosystem connection. Trees were by far the most harmed (mean = 4.8), followed by people (3.6). All other species, including squirrels (3.1), deer (3.0), scallops (2.9), sea turtles (2.6), alligators (2.2), anoles, lizards and geckos (2.2), horseshoe crabs (2.1), and manatees (2.0), were scored substantially lower and had fewer overall responses. Likewise, trees were perceived as the least recovered with no respondents scoring them as fully recovered, and only 26% indicating partially recovered. About 36% of residents believed that humans are strongly connected to their ecosystem.

Discussion

Overall, homes were moderately damaged and partially recovered one year after Hurricane Michael. Landscaping was the most damaged category. However, Walls were the highest correlated with overall home damage. Shorelines, other than beaches, fared well during the storm, both at the parcel and community level. Respondents perceived humans and trees as the most damaged species and the least recovered. Individually, respondents reported low levels of household physical or mental impacts. Many of those who reported distress were not recovered one year after the storm. Hurricane Michael was an intense storm that will take years for the community to fully recover.

Impacts and recovery from the storm were all significantly different by county. The storm characteristics impacting these counties differed depending on where the hurricane made landfall. Damages and recovery were less severe for Franklin county, those closer to the storm received higher damages and lower recovery. Many studies discuss the direct impacts of hurricane-force winds, inundation, and wave height (Tomiczek et al. 2019). However, recovery from storm impacts has been shown to be a complicated process and other factors, such as the social and environmental landscape, should be taken into account (Kates et al. 2006, Bullard and Wright 2009).

Overall, impacts and recovery from Hurricane Michael were not noticeably different by hardened or vegetated shoreline types. This implies that when comparing vegetated shorelines to hardened shorelines, their level of protection was about the same for this coastal area. With the negative impacts hardened structures have to the local ecosystems, and the protection vegetated systems still provide from storms, the implementation of natural features along the coasts is further supported (Scyphers et al. 2015a, Gittman et al. 2016, Tomiczek et al. 2019). The largest difference between vegetated and hardened shorelines was the cost of repairing, or replacing, the shoreline structure. Vegetated shorelines were reported to cost less to repair, or replace, than hardened shorelines. Previous studies discuss the resilience of vegetated shorelines after an event, in comparison to the rigidness of hardened structures (Smith et al. 2017, Castagno et al. *in prep*). This allows for lower amounts of money and time to be spent on fixing a natural shoreline, since many vegetated systems are able to respond and recover from a disaster naturally. There are limitations to the amount vegetated systems can naturally respond, since storm debris and excess deposition of sediment can cause vegetation to die off (Radabaugh et al. 2019). However, the rigidness of hardened shorelines require engineering intervention once they fail. The difference in the reported performance of shorelines, and the cost of repairing or replacing, provides some evidence supporting nature-based solutions.

At the community level, residents reported that bulkheads were the most damaged form of shoreline and the least recovered. By contrast, residents reported that their surrounding marshes and rip-raps were the least damaged and the most recovered. Residents also reported, and understood, that marshes were generally effective at protecting coastlines against storm waves and inundation. Although Marshes were generally seen as an effective coastal resilient strategy against storms, they were still a minority of the parcel level shorelines throughout the panhandle. The survey suggests that residents are amenable to natural or nature-based features as a form of coastal protection, although this thought does not carry into the decision-making process of shoreline type. Many other factors are at play when residents choose their shoreline type, and these survey results should be analyzed further for potential decision-making factors waterfront residents had (Scyphers et al. 2015b). However, these results show that natural shorelines were less expensive than hardened shorelines when making repairs after a storm, and the ecological knowledge of marshes protection against storms was present. This provides a strong foundation for initial natural shoreline implementation and restoration to take place within the Florida Panhandle.

Interestingly, beaches showed significantly lower damages to homes. This survey did not account for dunes, and their protective benefits, therefore some beach homes could have been protected by vegetated dunes, which would explain the lower damage states (Barbier et al. 2011). This survey was also sent randomly across the three counties, therefore the areas with the most severe beach erosion may not be accounted for within these responses.

Study 3: Storm Impacts on Nature-based Features

Overview - Damage and recovery assessments can provide crucial information about the health and resilience of an environment. Previous research studies show that marshes and coastal vegetation can protect against storm damages by reducing storm wave heights and surges (Day et al. 2017; Narayan et al. 2017). Therefore, understanding how a marsh responds to major hurricanes is important for future coastal protection planning. As large areas of marsh were difficult to assess on-site, we completed damage and recovery assessments using aerial imagery from Google Earth. We used high-resolution aerial imagery directly after Hurricane Michael's landfall to characterize damage, and again at a later date to characterize recovery. This approach provided a system-wide understanding of the coastal resilience and resistance of marshes in the Hurricane Michael region.

In December 2019, fieldwork was conducted in the Florida Panhandle about one year after Hurricane Michael, to document on-site hurricane impacts and recovery. Initial damage states were collected through organizations like FEMA and StEER. However, these miss the indirect impacts and the continuing efforts of recovery years after a storm (Kates et al. 2006, Lane et al. 2013). This sub-study collected follow-up damage states one year after Hurricane Michael, providing an initial scale of recovery. This information can give an engineering view of home recovery in the area, and provide important follow-up to initial structural assessments. Additionally, follow-up interviews were conducted with 15 different residents in the Gulf, Bay, and Franklin counties to gain local insight and knowledge on top of the visual assessments.

Many studies show vegetated shorelines, such as marshes, provide coastal areas protection against storm-force winds and inundations (Smith et al. 2018, Tomiczek et al. 2019). However, marsh systems, and the surrounding ecosystems, are also impacted in a variety of different ways during a storm (Leonardi and Fagherazzi 2015). An understanding of marsh resistance and resilience from a storm is critical for understanding their role in reducing storm damages and for helping to manage the recovery of surrounding ecosystems. Organizations such as Florida DEP provided erosion assessments of beaches along the impacted area. Large areas of marsh were difficult to assess in person; therefore, damage and recovery assessments were completed visually using aerial imagery from Google Earth. This provided high-resolution aerial imagery directly after landfall.

Methods

Field Assessments:

Opportunistic damage assessments were conducted for houses and shorelines throughout Bay, Gulf, and Franklin County approximately one year after the storm. Homes and privately owned shorelines were assessed given their current damage states, and aspects of active repair, or recently repaired items, were recorded. Damage states (DS) were assigned following the survey techniques of Tomiczek et al. (2019). Each house and shoreline were given DS0-DS4, depending on the damages seen. While completing these surveys, notes were taken on structures that appeared new, as well as areas that were empty lots. Audio of a primary researcher's visual damage assessments were recorded. In total, 531 homes were assessed, recorded, and transcribed. Shorelines were assessed visually both at their access points and from a boat in St. Andrew Bay, where notes were taken on the assessments. In total, 192 shorelines were assessed. However, beaches were excluded from the results due to the small number assessed. The other shorelines were categorized into Hardened (bulkhead, seawalls, or rip-rap revetments; n = 111), Hybrid (hardened and vegetated aspects present; n = 33), and Vegetated (only vegetation present along the shoreline; n = 23). The notes were transcribed into excel after the trip. Follow-up interviews were conducted with residents from the mailed survey. A total of 15 residents were available for in-person interviews to follow-up on questions asked within the parcel-level survey.

Marsh Analysis:
Salt marshes were identified in Bay, Gulf, and Franklin counties using the U.S. Fish and Wildlife Service's (USFWS) National Wetlands Inventory (Figure 4.1). Marshes were divided into 30 m by 30 m grids (0.9 km^2). Areas of damage were determined visually using aerial imagery from Google Earth, which provided high-resolution images from directly after Hurricane Michael's landfall (11-12 October 2018). Damages were categorized into 7 types; deposition of sediment or marsh, man-made debris, fallen trees, lateral erosion, vegetation loss, conversion to open water, and channel cutting/widening. The imagery collected was compared to aerial photography from before Hurricane Michael (October 2017, February 2017, October 2015). For parts of Gulf and Franklin county, for which aerial imagery from April 2019 was available, marsh cells identified as damaged during Hurricane Michael were assessed for recovery (yes/no) after six months.

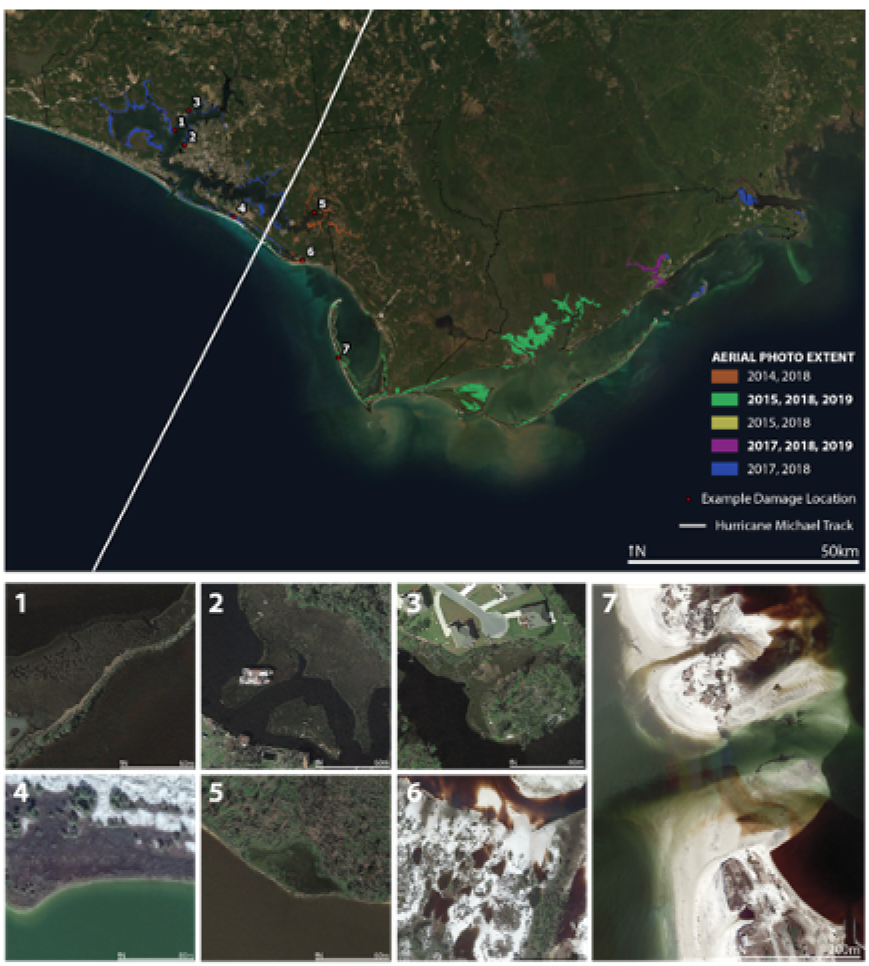

Figure 4.1. The top image shows the extent of aerial imagery coverage on study marshes. All marshes have aerial imagery from October 2018, within 1-2 days of Hurricane Michael's landfall. Areas with bolded dates (green and purple) have aerial imagery from April 2019, six months after landfall, and are used to study marsh recovery from damage. Bottom images show examples of marsh damage from Hurricane Michael in different locations. Damage types include: *1)* deposition of vegetation or sediment, *2)* man-made debris, *3)* fallen trees, *4)* lateral erosion, *5)* vegetation loss*, 6)* conversion to open water, and *7)* channel cutting/widening.

Results

Field Assessments:

The majority of damage states were found to be 0 for both homes (n = 367, 69.3%) and shorelines (n = 158, 86.3%). Since shorelines and homes were mostly DS0, further analysis split the categories into groups representing no damage, some damage, or more damage. Roofs had the highest percent of damage greater than 0 (n = 72, 13.6%), followed closely by landscaping (n = 61, 11.5%) (Figure 4.2). For shorelines assessed, the only ruined damage states recorded were Hardened shoreline types, which additionally had the highest percentage of damage states greater than 0 (n = 18, 14.5%). Hybrid shorelines had the smallest percent of damage states greater than 0 (n = 4, 11.1%). New, or repaired, aspects were taken into account for both homes (n = 124, 23.4%) and shorelines (n =16, 8.7%). As expected, homes and shorelines with new aspects or repairs were generally assessed with low or no damages. Hardened shorelines had the highest number of shorelines with new aspects or repairs (n = 13), followed by Hybrid with only 3, and finally Vegetated with none.

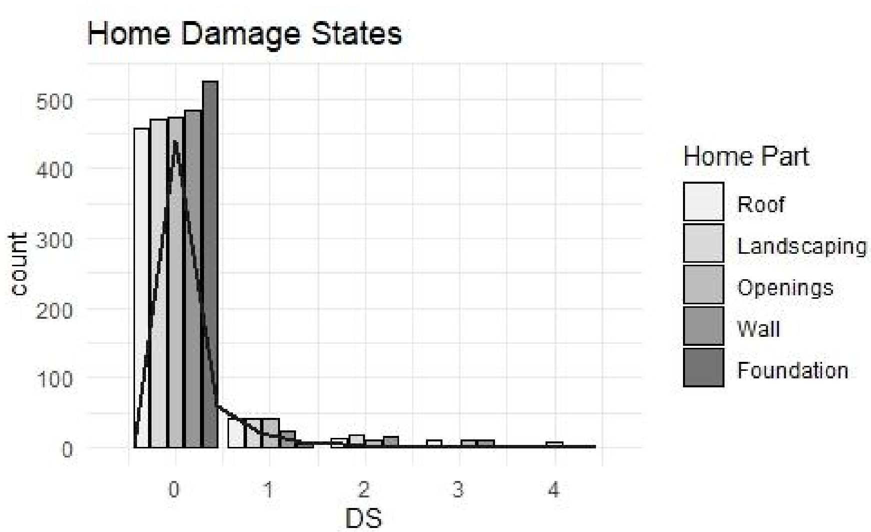

Figure 4.2. The above displays home damage states assessed in the field about one year after the storm. The count of damage states given for each home category of Roof, Landscaping, Openings, Walls, and Foundations are represented by bars. Frequencies of calculated overall home damages are displayed by the black line across the bars.

Marsh Analysis:

Marsh Damage analysis

Of the 173,259 km^2 of marsh analyzed across Bay, Gulf, and Franklin counties, 3,371 km^2 were classified as damaged after Hurricane Michael (1.9% damaged; Figure 4.3, Table 4.1). In Bay County 1.8% of marshes were damaged, in Gulf County, 4.3% of marshes were damaged, and in Franklin County, 1.7% of marshes were damaged (Table 4.1). Of total marsh damage, 85.8%, 87.9%, and 90.4% occurred at elevations at less than 1 m in Bay, Franklin, and Gulf counties respectively (Figure 4.3). Marshes were more likely to be damaged east of the storm track (Figure 2.7). West of the storm track, 1.5% of the marshes were damaged, whereas 2.1% of the marshes east of the storm track were damaged. Of the salt marshes in this study, 76,929 km^2 (44%) were private land and 96,333 km^2 (56%) were public land. Of marshes that were damaged, 1,633 km^2 (48%) were private land and 1,738 km^2 (52%) were public land. The relationship between damage status and land ownership was significant (X^2 [1, N=192514]=25.2, p<0.001). Damaged marshes were more likely to be on private land, given the difference in the proportion of damaged to undamaged marsh on private vs. public land.

The majority of the marsh damage was due to deposition of vegetation or sediment (79.5% of damage in all counties; Table 4.2). Fallen trees composed 7.3% of damage across all counties, largely concentrated in Bay County, where Hurricane Michael made landfall, and decreasing with distance from the storm track. Vegetation loss and fragmentation composed 5.5% of damage across all counties, and conversion to open water composed 4.8% of damage. The other damage categories (man-made debris on the marsh, lateral erosion, and channel-cut/widening) composed less than 3% of damage across all counties (Table 4.2).

Deposition occurred on marshes that were exposed to maximum wind speeds of up to 65 m/s (average 35 ± 9 m/s; Figure 4.3) and experienced up to 3.2 m of inundation (average 1.6 ± 0.7 m). There was no significant difference in mean maximum wind speed across all three counties studied. However, deposition-damaged marsh in Bay County experienced significantly lower average maximum inundation (0.9 ± 0.5 m/s) than that in Gulf County (1.1 ± 0.4 m/s), which was lower than that in Franklin County (average 2.2 ± 0.3 m/s; p<0.05).

Table 4.1. Area of marsh damage by county.

	Total Marsh (km^2)	**Damaged Marsh (km^2)**	**Percentage Damaged**
All Counties	173,259	3,371	1.9%
Bay County	56,130	991	1.8%
Gulf County	13,257	585	4.3%
Franklin County	103,872	1,795	1.7%

Marsh Recovery analysis

In total, 1,943.1 km^2 of the marsh (58% of damaged marsh across all three study counties) originally damaged from Hurricane Michael was included in the recovery analysis. Of that area, 309.6 km^2 (16%) recovered and 1,633.5 km^2 (84%) did not (Figure 4.3; Table 4.2). Marshes on public land were more likely to recover within six months. Of the 1,943.1 km^2 of salt marsh in the recovery study, 373.5 km^2 was private land and 1,569.6 km^2 was public. Of the private land, 92.7 km^2 (14%) recovered and 280.8 km^2 (86%) did not. Of the public land, 216.9 km^2 (25%) recovered, and 1,352.7 km^2 (75%) did not. The relationship between recovery and land ownership was significant (X^2 [1, N=2159]=30.3, p<0.001).

Average mean maximum wind speeds were not significantly different between recovered and non-recovered marshes (mean 35.1 ± 7 m/s) and ranged from 22-65 m/s. Average mean inundation was also not significantly different between recovered and non-recovered groups (2.0 ± 0.4 m) across all damage types and ranged from 0.2-3.2 m. Of the 1,647.9 km^2 of marsh with deposition damage, 14.6% had recovered by April 2019 (Table 4.2). For marshes that were damaged through deposition, the marshes that recovered experienced significantly lower (p<0.05) maximum wind speeds (33.3 ± 5 m/s) than the marshes that did not recover (34.4 ± 5 m/s). Of the 1,647.9 km^2 of marsh with deposition, 14.6% had recovered by April 2019. Of the 29.7 km^2 of marsh damaged by man-made debris, 21.2% recovered. Only 3.2 km^2 of marsh in the recovery study had fallen trees, none of which recovered. Lateral erosion accounted for 9 km^2 of damage, 30% of which had recovered. Vegetation loss was seen in 120.6 km^2 of marsh; 45.5% recovered. Within the recovery study, 119.7 km^2 of marsh was converted to open water; 3.8% recovered within six months. None of the 12.6 km^2 of marsh damaged through channel cutting, or widening, recovered within six months (Table 4.2).

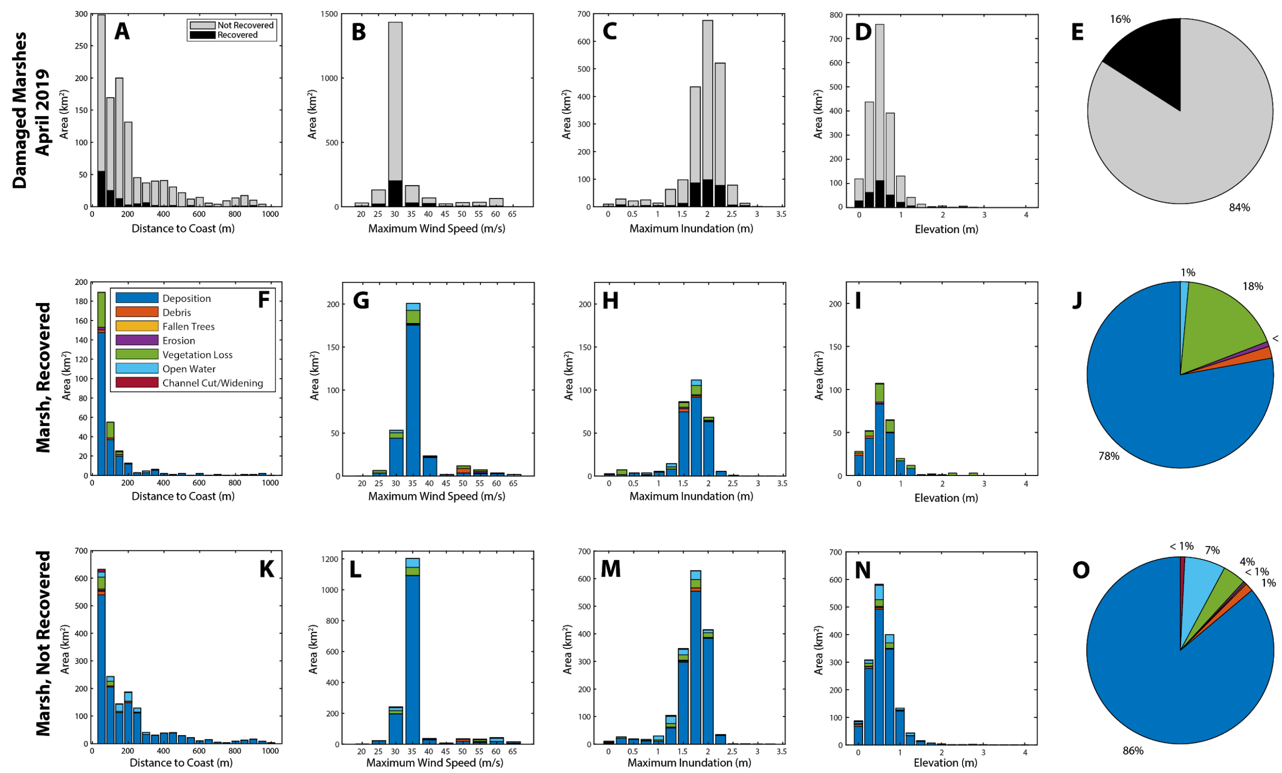

Figure 4.3. Analysis of recovery for damaged Panhandle marshes with aerial imagery from April 2016. Recovered and non-recovered marsh area as a function of distance to coast, maximum wind speed, maximum inundation, and elevation, respectively. *E)* Pie chart of ratio of recovered to non-recovered marshes. *F-I)* Original damage type of recovered marsh area as a function of distance to coast, maximum wind speed, maximum inundation, and elevation, respectively. *J)* Pie chart of distribution of original damage type of recovered marshes. *K-N)* Damage type of non-recovered marsh area as a function of distance to coast, maximum wind speed, maximum inundation, and elevation, respectively. *O)* Pie chart of distribution of damage type of non-recovered marshes.

Table 4.2. Area of marsh recovery study and percent recovered by damage type.

	Recovered (km^2)	***Not Recovered (km^2)***	***Percent Recovered by Damage Type***
All Damage	309.6	1633.5	15.9%
Deposition	241.2 (77.9%)	1406.7 (86.1%)	14.6%
Debris	6.3 (2%)	23.4 (1.4%)	21.2%
Fallen trees	0 (0%)	3.6 (0.2%)	0.0%
Lateral erosion	2.7 (0.9%)	6.3 (0.4%)	30.0%
Vegetation loss	54.9 (17.7%)	65.7 (4%)	45.5%
Conversion to open water	4.5 (1.5%)	115.2 (7.1%)	3.8%
Channel cut/widening	0 (0%)	12.6 (0.8%)	0.0%

Discussion and Conclusion

Visual assessments found that many homes and shorelines were either ranked as having no damage, or as being repaired and replaced about one year after Hurricane Michael. Vegetated shorelines either received a rank of low damage or as recovering well, given on-site assessments. Virtual marsh assessments found low levels of damage, but low recovery. On-site assessments found hardened shorelines were either majorly damaged or not damaged, when including bulkheads that had aspects of repair. Both methods (in person and virtual) showed that vegetated shorelines were resilient to the storm. Homes assessed were either repaired, or actively being repaired, with only small or slightly damaged aspects left.

Marshes in the three counties were largely undamaged by Hurricane Michael (98%), suggesting that the majority of marshes can withstand the effects of a category 5 hurricane and continue to provide coastal protection. Highest hurricane wind speeds were associated with the front-right quadrant of the storm. This area was expected to have more damages for both shorelines and homes. The majority of damaged marshes (4.3%) were in Gulf County and east of the storm (2.1%). The Gulf County area, which was directly southeast of landfall, had some of the highest winds speeds and inundation values. This shows how storm characteristics were a predictor of marsh impacts. The majority of damage was caused by deposition of sediment or vegetation (79.5%). Of this damage type, 14.6% of marshes recovered. Previous studies show that this type of damage may actually increase the total marsh elevation (Castagno et al. 2018), though too much deposition may cause irreparable vegetation loss. However, post-storm removal of deposition is a tangible, low-cost method to increase marsh recovery.

These findings suggest that marshes may be largely resistant to storm impacts without human involvement, but not particularly resilient, at least within the first six months of disturbance. Other studies also show the resilience of marshes, and other vegetated shorelines (Radabaugh et al. 2019). Radabaugh (et al. 2019) goes further to discuss the potential for vegetation (mangroves specifically) to recover without human input. Privately owned shorelines are often reported to be the "bottom of the repair list" (local insite and survey responses), and therefore their ability to recover without human input is important. However, given the trend of increased recovery of marshes on public land, post-storm management action may be key to increasing marsh resilience after a storm. Efforts to remove the thick layers of wrack buildup can prevent vegetation death and build the marsh's resilience against future storms. Given the potential for more intense hurricane landfalls as the climate changes, ensuring marsh resilience and resistance provides coastal communities natural barriers to storm damage.

Visual assessments show homes were mostly recovered one year after the storm. However, locals talked about the lasting psychological damage that was still apparent, stating "It's hard to be happy with a blue roof". Psychological stress can occur for a variety of reasons, stemming from a variety of storm impacts (Lane et al. 2013). Marsh recovery 6 months after the storm was challenging, and only 16% of originally damaged marshes recovered. Many acres of forests were also severely damaged, changing the landscape of the Florida Panhandle (Florida Forest Service 2018). With the surrounding landscape changing so drastically, a person's sense of place can be negatively impacted, causing additional psychological stress (Pais and Elliott 2008, Bullard and Wright 2009). This additional psychological stress is often overlooked within engineering assessments of structural home damages. Further studies on psychological health and impacts are needed to fully understand storm recovery.

Study 4: Effects of Green Space on Storm Impacts and Recovery

Overview - With sea level rising, oceans warming, and coastal populations increasing, natural hazards are increasingly impacting both the landscape and the communities situated there (O'Keefe et al. 1976, Emanuel 2005, Donnelly and Woodruff 2007, Pielke et al. 2008). Waterfront residents are choosing to live along the coast, with high land value and personal benefits, at the cost of high hazard exposure (Collins et al. 2018). When studying these hazards and the impacts they have on coastal communities, both the social and environmental aspects need to be understood. Variations in the social landscape can lead to areas of vulnerable populations (limited English proficiency, elderly, low income, etc.) who are at greater risk when a disaster occurs (Harlan et al. 2006, Emrich and Cutter 2011). Many attributes of local to regional landscapes such as elevation, shoreline archetypes, density of houses, natural and nature-based features (NNBF), and other surrounding environments affect disaster outcomes. (Syvitski et al. 2009, Gittman et al. 2015, Neumann et al. 2015, Munoz et al. 2018). Understanding what happens to both the natural and human communities during and after a disaster, such as Hurricane Michael, facilitates a better understanding of complex social and ecological systems (SES). Much less is known about how these diverse factors affect post-disaster recovery. Therefore, damage and recovery data from the Hurricane Michael impact survey was analyzed along various social and environmental factors found throughout the Florida Panhandle. Responses were mapped and linked to exposure characteristics using ArcGIS. Responses and various landscape variables were analyzed using ordinal logistic regressions (OLR). We found that surrounding green space was beneficial for physical home and psychological recovery.

Methods
<u>Exposure:</u> Initial spatial analysis was completed by summarizing the survey responses along a 10m by 10m grid across the study region. Maps were created using recovery, damage, and surrounding environments in ArcGIS. Individual buffers of 0.1km, 1km and 10km were created for each survey respondent, and the landscape characteristics were summarized for the

surrounding buffer (Figure 5.1). Land cover collected from Florida Fish and Wildlife (FWC) was categorized into Blue, Green, and Built environments. An individual household's surrounding environment was calculated by the percent cover of all three categories for each buffer. A variable representing the ratio of built to green environment within each buffer was created by subtracting the percent of the built environment by the percent of the green space of each buffer. A positive Built to Green ratio resulted in a higher proportion of built environment, while a negative Built to Green ratio resulted in a higher proportion of Green environment. Values close to 0 were areas where the percent of Built and the percent of Green, within the buffer were almost equal. The landscape was further divided into the location of marsh and tree forests/plots. Distance to the closest cell and the percent cover in each level of buffer were found for both marshes and trees.

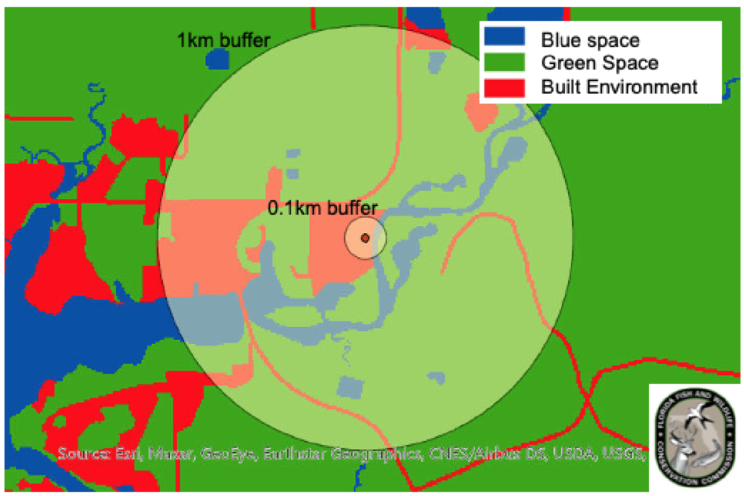

Figure 5.1. The above shows example buffers used to calculate the percent cover of landscapes for individual residents. FWC land cover values are displayed by blue for water, green for green spaces, and red for built environments.

Surrounding storm characteristics were collected from the Coastal Emergency Risk Assessment (CERA) web map, where best track ADCIRC models for Hurricane Michael were available for download ("Coastal Emergency Risk Assessment" n.d.). The maximum winds, maximum inundation, maximum wave heights, and the storm track were downloaded. The surrounding winds, inundation, and wave heights within the residents' buffers were collected to represent the storm. The variables found within the 0.1km buffer best represented the storm characteristics directly affecting respondents' homes. The shoreline type and distance to the coast were determined using NOAA's ESI lines.

<u>Statistics:</u> Using survey responses from Study 2, along with surrounding environmental and storm characteristics, this sub-study looked at the factors influencing higher home damage states, and lower recovery, using an ordinal logistic regression (OLR). Influence categories tested in the full model were: Social characteristics (*Age, Gender, Race, Out of State residents, Employment*

Status, Income, Risk Knowledge, Fairness outcomes, and *Connection to neighbors*), Location characteristics (*County, Distance to Coast,* and *Distance to Marsh*), Storm characteristics (*Max winds, Max inundation, Max wave height,* and *Distance to Hurricane Track*), and Environmental characteristics (*Shoreline archetype, % Built - % Green,* and *%Trees*). The variables were used to understand their influence on 3 different dependent variables; Overall Home Damage State (n=320), Property Recovery (n=310), and Psychological recovery (n=277). A selection process of potential variables using previous studies, theoretical information, correlation matrices (Appendix: Figure 1), and corresponding AIC values limited the independent variables down to 7. Spearman-rank correlation and Kruskal-Wallis tests were used to find the independence and distribution of variables. Variables were selected to explain the social (*Income* [low income as reference]), locational (*Waterfront* and *Distance to Coast*), storm (*Max winds in 0.1km buffer* and *Max Inundation in 0.1km buffer*), and environmental characteristics (*%Built - %Green 0.1km,* and *%Trees*) for each respondent within the survey. Once the variables selection process was complete, OLRs were run using the selected variables, and the Odds ratios were found for each dependent variable.

Further OLR tests were run to summarize the surrounding environmental characteristics of residents at each increasing buffer. Therefore, each model predicting (1) Home Damage State, (2) Property recovery, and (3) Psychological recovery were run 3 times (at the 0.1km, 1km, and 10km buffer). Constant variables in each model were; *Income, Waterfront, Distance to Coast, Max winds in 0.1km buffer,* and *Max Inundation in 0.1km buffer*. The variables *%Built - %Green* were changed per model, depending on which buffer size was being tested (0.1km, 1km, or 10km).

Results

When summarizing the respondents by a 10m by 10m grid, the grids where high home damages occurred, but residents were recovering, had 60% or more green space surrounding them (Figure 5.2). However, the three grids with the lowest percent of green space (<17%) had both high home damage and not recovered responses (Figure 5.2). The ratio of surrounding Built to Green space was not significantly different by Home Damage state (0.1km buffer $\chi^2 = 3.946$, $p = 0.413$; 1km buffer $\chi^2 = 0.355$, $p = 0.986$; 10km buffer $\chi^2 = 5.618$, $p = 0.230$). This was similar for both property recovery (0.1km $\chi^2 = 0.911$, $p = 0.634$; 1km $\chi^2 = 3.493$, $p = 0.174$; 10km $\chi^2 = 3.282$, $p = 0.194$), and psychological recovery (0.1km $\chi^2 = 1.100$, $p = 0.634$; 1km $\chi^2 = 0.6851$, $p = 0.710$; 10km $\chi^2 = 0.440$, $p = 0.803$). However, green space and the surrounding environment was found to be significant for recovery when controlling for social and hurricane factors using OLR.

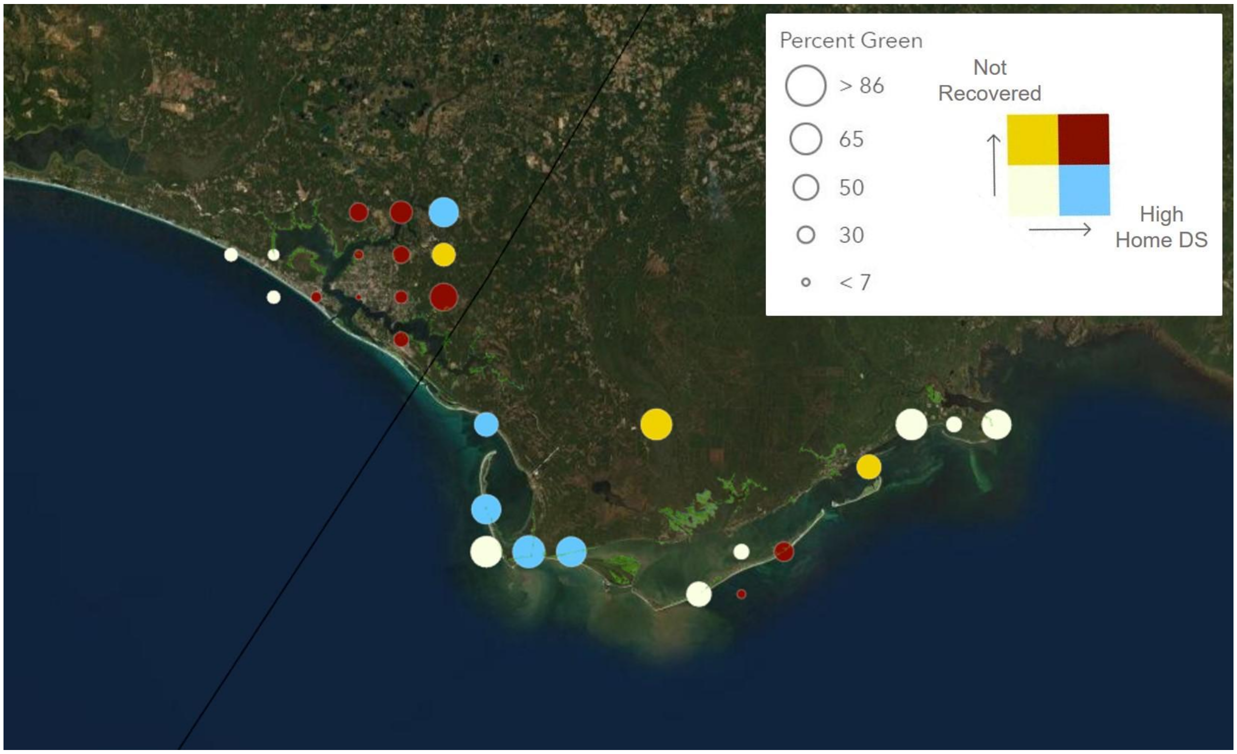

Figure 5.2. Above is a bivariate map summarizing residents' home damage, property recovery, and surrounding green space. These key variables were averaged together using a 10 by 10 kilometer grid across the study region. A single grid is represented by a circle. Circles are colored using the relationship between property recovery and home damage, then sized by the amount of surrounding green space. Red dots are grids that, on average, have high home damage and are less recovered, and blue dots are grids that have higher home damage and are more recovered. White dots are grids that, on average, have lower home damage and are more recovered, and yellow dots are grids that have lower home damage and are less recovered.

The two variables that were found to be significant in predicting home damage states were winds (OR = 1.033, $p = 0.004$) and distance a home was situated from the coastline (OR = 0.998, $p = 0.018$) (Table 5.1). The surrounding environment of %Built - %Green was not found to be significant (OR = 1.004, $p = 0.492$). The %Trees variable was also not found to be significant (OR = 1.025, $p = 0.236$). Although the distance to the coast was significant, the binary location of waterfront versus inland was not (OR = 1.243, $p = 0.821$). The income of respondents was binned into low ($50,000 or less), medium ($50,001 - $150,000) and high (more than $150,000). Low income was used as the reference variable within the model. Neither an income increase from low to medium (OR = 0.662, $p = 0.395$), nor from low to high (OR = 1.278, $p = 0.500$) were significant.

Many variables were significant in the property recovery model (Table 5.1). Specifically, the surrounding environment of %Built - %Green had a significant influence on property recovery within a 90% confidence interval (OR = 1.012, $p = 0.058$). If the surrounding environment was more built, the probability of a respondent being less recovered with their property increased (Figure 5.3). The percent of trees within a 0.1km buffer was not significant and had a positive relationship with decreased recovery (OR = 1.030, p = 0.137). Waterfront was a strong and significant predictor, where if a resident was waterfront (instead of inland) they had an odds of 7.122 times of being less recovered (OR = 7.122, p = 0.048). The distance to the coast was not significant in this model, and hardly had an effect on the recovery (OR = 0.999, p = 0.303). Both the winds and inundation were significant in this model. However, they oppositely affected recovery. High wind had a negative effect on recovery (OR = 1.031, p = 0.014), and high inundation had a positive effect on recovery (OR = 0.760, p = 0.023). Income had a parabolic effect on property recovery. The increase from low to middle income was not significant, but had a negative influence (OR = 0.873, p = 0.785), while the increase from low to high income had a strong positive effect on recovery (OR = 2.300, p = 0.036).

When psychological recovery was tested, the only variable found to be significant at a 95% confidence level was the neighboring environment (OR = 1.020, p = 0.010) (Table 5.1). An increase in built space, increased the odds that respondents were not recovered by 1.020 times. The other environment, location, storm, and social variables followed the same trend as property recovery with differing levels of significance. At a 90% confidence level the variable of winds was found to increase the probability of respondents reporting not psychologically recovered (OR = 1.025, p = 0.083) (Table 5.1). Although the three models produce different results, they were all influenced by winds and green space in some form.

Since both property and psychological recovery were significantly improved by more surrounding green space directly around a resident (0.1km buffer), the other two buffers of the surrounding environment were tested. The ratio between built to green space was only significant for the residents' recovery within a 0.1km buffer (Property Recovery: OR = 1.015, p = 0.028; Psychological Recovery: OR = 1.020, p = 0.016), and both increased the probability of slower recovery with increasing built space (Table 5.2).

Table 5.1. The odds ratio for the coefficients used to predict (1) Home Damage State, (2) Property Recovery, and (3) Psychological Recovery. Summarising buffers are 0.1 km for all the spatial environmental coefficients. The corresponding AIC values for the models are displayed underneath the respective dependent variable tested. Significance of independent variables are marked as ** p-value <0.01, * p-value <0.05, and + p-value <0.1

Models run through Ordinal Logistic Regression						
Model	**(1)Home Damage State AIC = 502.42**		**(2)Property Recovery AIC = 182.35**		**(3)Psychological Recovery AIC = 155.66**	
Coefficients	*OR*	*p-value*	*OR*	*p-value*	*OR*	*p-value*
%Built - %Green	1.004	0.492	1.012	0.058+	1.020	0.010*

Trees	1.025	0.236	1.030	0.137	1.012	0.624
Waterfront	1.243	0.821	7.122	0.048*	5.440	0.150
Shoreline Distance	0.998	0.018*	0.999	0.303	0.999	0.136
Max winds	1.033	0.004**	1.031	0.014*	1.025	0.083+
Max inundation	0.929	0.052 .	0.760	0.023*	0.998	0.987
Income Mid	0.662	0.395	0.873	0.785	0.618	0.368
Income High	1.278	0.500	2.300	0.036*	1.469	0.333

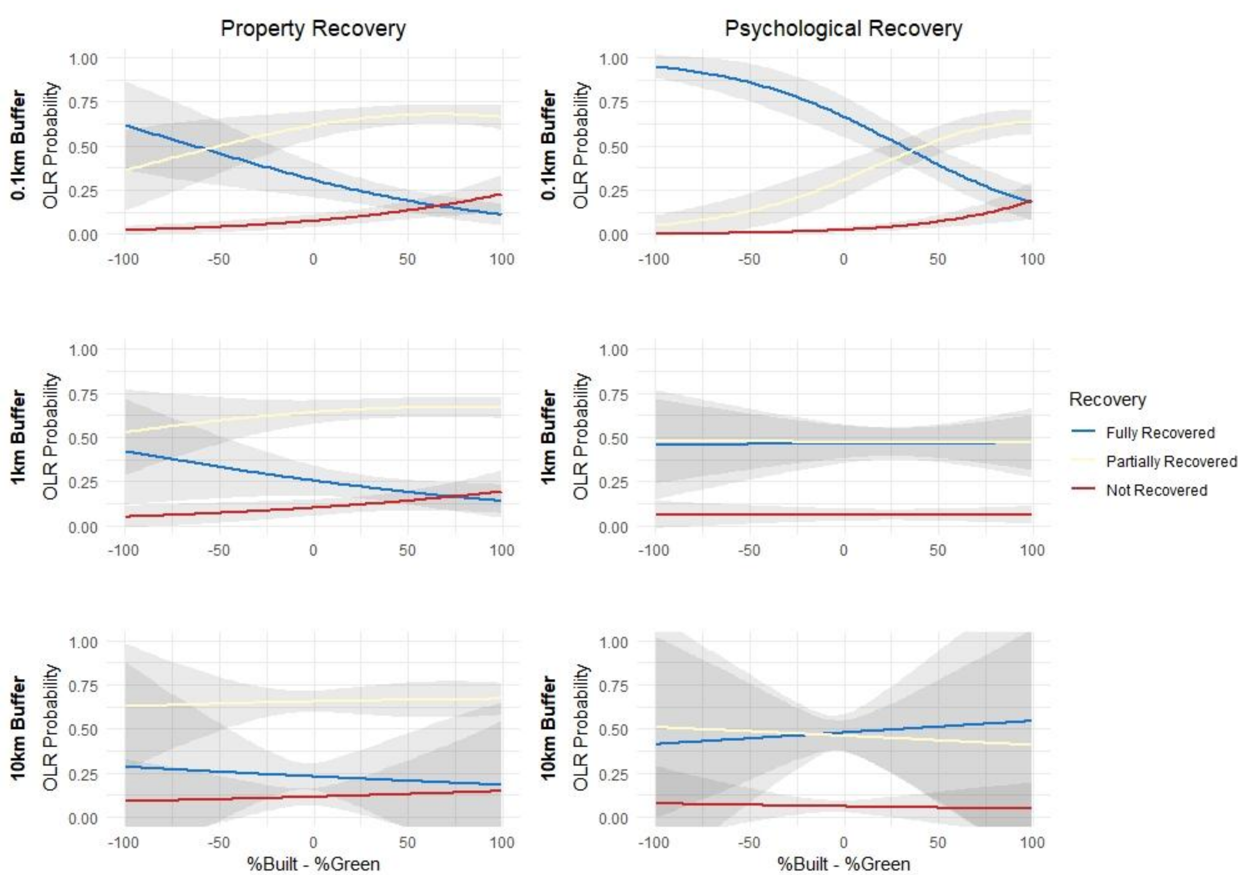

Figure 5.3. The probability of a respondent reporting a recovery state for property recovery and psychological recovery, given the ordinal logistic regression (OLR) models run prior. Each buffer (0.1km, 1km, and 10km) of land cover is tested, creating three models for each type of recovery. The probability (y-axis) for each level of recovery is plotted by the respective %Built - %Green buffer directly around a

home (x-axis). Each probability curve is colored for the corresponding recovery being predicted. The standard error of the probabilities are plotted along the curves using the grey area. The variable of %Built - %Green was significant for the 0.1km buffer model in both recovery models.

Table 5.2. The Odds Ratio (OR) and p-value of the coefficient *%Built - % Green* are displayed for each corresponding model run. The three models predicting property recovery, and three models predicting psychological recovery. The environmental buffers of 0.1km, 1km, and 10km are used to summarise surrounding land cover and create the fluctuation in each model.

Coefficient %Built - % Green		
Models	*OR*	*p-value*
Home Damage State		
0.1km buffer (AIC = 215.94)	1.004	0.492
1km buffer (AIC = 215.36)	0.991	0.213
10km buffer (AIC = 191.05)	0.988	0.633
Property Recovery		
0.1km buffer (AIC = 182.35)	1.012	0.058+
1km buffer (AIC = 185.45)	1.008	0.353
10km buffer (AIC = 185.73)	1.003	0.911
Psychological Recovery		
0.1km buffer (AIC = 155.66)	1.020	0.010*
1km buffer (AIC = 163.09)	0.999	0.989
10km buffer (AIC = 165.06)	0.997	0.917

Discussion and Conclusion

This study took predicting storm impacts and recovery further by including green space, and the potential green spaces have at protecting from storm impacts. Many studies focus on one area of storm protection, or recovery (i.e. storm intensity, economic damage, social factors, environmental impacts, etc.). However, including all of these factors when predicting storm damages and recovery was found to be important. Winds were the primary predictor for high home damages, while the surrounding ratio between Built and Green space were key predictors for both property and psychological recovery. This influence of recovery was not present when using buffers at larger distances from residents, instead, the environment directly around a resident has the potential to help aid in recovery.

The positive effect of surrounding green space has its limitations, and specific types of green space could help residents differently (Czembrowski and Kronenberg 2016). For instance, the amount of trees within a buffer had negative impacts on recovery, meaning that more trees directly surrounding residents caused them to have slower property recovery. The large timber industry, along with general forests in the Florida Panhandle, were hit hard by the storm. The Florida Forest Service estimates that 2,808,645 acres of forest land area was damaged by Hurricane Michael (Florida Forest Service 2018). This much destruction potentially causes additional direct and indirect damages to residents. Downed trees can further harm a home and important infrastructure like roads and power lines (Lane et al. 2013). The impacts of the neighboring forests can also cause psychological stress. Living in a place so visually different from before the storm, can hinder people's feeling of being recovered (Pais and Elliott 2008). This may impact the property recovery responses, since they were self-assessed, and some survey bias may be present. Even though the green space of trees hindered property recovery, controlling for this variable showed that, overall, having more green space than built environment helped both property and psychological recovery from the storm.

Home Damage States were influenced by the maximum winds residents experienced directly around their home. An increase in wind speed increased the probability of having a higher home damage state. This agrees with most modeling of storms and their damages. Predicting initial home damage often uses the hurricane-force winds (Dinan 2017). This storm was a wind-driven storm with wind intensities causing a category 5 hurricane. Most damages were caused by winds during this storm. When controlling for exposure variables, such as distance to the coast, or if a home was located on the waterfront, winds were still significant predictors of home damage. Using distance to the coast as a linear variable, instead of just the binary variable of waterfront, found that residents who lived further away from the coast decreased the odds of reporting higher damage states. None of the income levels with reference to yearly income of < $25k were significant. This category 5 storm impacted the area similarly across the study area. The initial damage received from the storm was not dependent on a residents income, but on their exposure and location instead. The initial damages affected all residents within the track of the storm. However, secondary hazards and recovery from these damages were not evenly distributed across communities, therefore social and environmental characteristics played a larger part in recovery (Bullard and Wright 2009, Lane et al. 2013).

Recovery from a major hurricane is a complicated process that can take years for a community to recover fully (Kates et al. 2006). The OLR for property recovery revealed that the social, environmental, and hurricane factors were significant predictors of property recovery. High values of winds (ie. closer to the storm) caused higher damages and slower recovery, while higher inundation (although not significant within the Home Damage model) reduced the odds of having a higher home damage state and slower property recovery. Winds caused damage along the path of the storm, while areas outside of the hurricane-force winds had higher inundation (Apalachicola and Apalachee Bay). The damage caused by winds can be different then the damage caused by inundation, therefore resulting in different observations reported (Mohammad et al. 2017). Additionally, residents experiencing high inundation values were often situated along the coastlines, who typically had higher incomes and potentially more flexible spending to pay for increased construction costs. Including income showed an effect on property recovery from the storm.

Similar to other hurricane studies looking at social factors, high income had a significant effect on one's ability to recover their property from the storm (Pais and Elliott 2008, Bullard and Wright 2009, Mitsova et al. 2019). Income affecting recovery could account for the interesting flip of high inundation promoting recovery. Since most waterfront homes are valued at a higher cost than inland homes, and the risk of high inundation was directly connected to these higher valued homes, residents who have higher income and more flexibility in their spending are often found along the coast (Collins et al. 2018). So, even though a waterfront home, with a closer distance to the coast, predicts slower recovery due to their exposure, the higher inundation along the coast does not.

Next Steps in the Hurricane Michael Region

The Hurricane Michael Study demonstrates the practicality, efficacy, and even the cost-effectiveness of nature-based resilience solutions. In particular, living shorelines offered similar protection to that of hardened shorelines, but were significantly cheaper to repair and maintain.

Marshes proved incredibly resistant to the direct impacts of a category 5 storm. This suggests that they are more resistant than most other coastal defenses—particularly the bulkheads that are commonly used for shoreline protection. Marshes were more likely to fail on private lands than public lands and were slower to recover, which points to the need to create better incentives for marsh management on private lands. This reiterates the benefits and best practices of marsh management on public lands.

While nature-based solutions offer a range of resilience-benefits for such hazard-prone areas, local governments do not always have the capacity to plan and implement nature-based solutions to build resilience in these hazard-prone areas. Furthermore, solutions that can improve regional resilience are difficult to plan—limited capacity, funding streams, and incentives also impede cross-jurisdictional coordination.

The Nature Conservancy (TNC) has partnered with regional, local, and university partners and received funding from the National Fish and Wildlife Foundation to conduct a two-year planning project in Bay, Gulf, and Franklin Counties. The first portion of this project is dedicated to information gathering and research; TNC, Northeastern University, and the United States Naval Academy will begin by studying the effects of Hurricane Michael, the advantages and suitability of nature-based solutions in the Panhandle, and the local challenges for community planning.

Using results of this study, TNC will work with the Northwest Florida Water Management District, as well as local governments, regional planning councils, and state agencies, to create a portfolio of nature-based solution projects for coastal resilience in Franklin, Gulf, and Bay counties. The resulting regional resilience planning framework will guide investments in restoring, strengthening, and creating natural features to advance hazard mitigation, climate adaptation, post-hazard redevelopment, and conservation of the exceptional natural resources of the project area.

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Appendices

a. Comprehensive list of products (Available upon Request)

Product/ Projects	Date Of Presentation	Title
TNC Slide Deck - Study 1	February 2020	Collecting and Synthesizing Existing Data about Hurricane Michael
TNC Slide Deck - Study 3	May 2020	Storm Impacts on Nature-based Features
TNC-NU-Hurricane Michael Overview	September 2020	Measuring and Mapping the Impacts of Hurricane Michael in the Florida Panhandle to Better Understand the Role that Nature Plays in Coastal Resilience - preliminary findings
ODonnellASBPApres_narration	October 2020	Impacts and Recovery from Hurricane Michael: a survey of coastal residents
CastagnoASBPApres_narration	October 2020	Quantification of salt marsh damage in the Florida Panhandle from Hurricane Michael: Implications for recovery and resilience
Castagno et al. Manuscript	NA	Resistance, resilience, and recovery of salt marshes in the Florida Panhandle following Hurricane Michael
O'Donnell et al. Manuscript	NA	Exploring Patterns of Residential Outcomes Following Hurricane Michael in the Florida Panhandle
Hurricane Michael Story Map	NA	Hurricane Michael Story Map

b. Supplemental Tables & Figures

Table A1. Data sets available for Hurricane Michael damages and their respective organization.

Category	Outcome	Organization	Short Title/ Data Collected	Scale / Resolution	Assessment
Environmental	Beaches	Florida DEP	Post-Storm Beach Conditions and Coastal Impact Report	County	Onsite
	Land Change	Northeastern / TNC	Lidar Elevation Change	Neighborhood	Remote Sensing
	Aerial Imagery	NASA	Multiple Satellite imagery	Towns	Remote Sensing
	Aerial Imagery	ESRI	Before and after imagery of select locations	Neighborhood	Remote Sensing
	Beaches	USGS	Before and After: Coastal Change post-Hurricane Michael	Neighborhood	Remote Sensing
	Beaches	USGS	USGS Coastal Change Hazard Portal	Counties	Modeled
	Land Change	NOAA	Aerial Imagery	Towns	Remote Sensing
Socioeconomic	Infrastructure	FEMA	Hurricane Michael Debris Detection	Streets	Remote Sensing
	Forest	Florida Forest Service	Value Estimate of Timber	County	Modeled
	Structures	StEER	Early Access Reconnocence Report	Buildings	Onsite
	Structures	StEER	Preliminary Virtual Assessment Team Report	Buildings	Remote Sensing
	Infrastructure	FEMA	Historical Damage Assessment Database	Buildings	Remote Sensing
	Claims	FEMA	Application and approval tracking	County	Online
	Claims	Florida OIR	Application and approval of insurance claims	County	Online

Table A2. Summary of available damage assessments completed by other organizations by county.

	Bay	Calhoun	Decatur	Franklin	Gadsden	Gulf	Hamilton	Holmes	Jackson	Jefferson	Leon	Liberty	Madison	Miller	Mitchell	Seminole	Taylor	Wakulla	Washington	Other
FEMA																				
Assessed	21,459	269	366		140	658			2,287			32		80	8	463			86	
Affected	20,738	260	366		140	575			2,255			30		78	8	441			83	
Destroyed	721	9	-		-	83			32			2		2	-	22			3	
StEEF																				
Affected	131	14				15			5											
Destroyed	7	-				-			2											
Florida DEP																				
CZ Structures Damaged	1,570			165		984												6		
Coast Line (mi.)	41			55		29												240		
Armoring Damage (ft.)	1,460			4,670		1,870												100		
Critically Eroded (mi.)	20			12		8												1		
Non- Critically Eroded (mi.)	10			20		9												0		
Florida Forest Service																				
Forested Acres catastrophic	71,422	150,983		-	-	124,507		-	-		-	-						-	-	
Forested Acres severe	118,616	172,828		-	59,311	141,168		-	295,628		-	255,388						-	-	
Forested Acres Moderate	90,870	-		283,386	184,888	-		29,241	98,501		154,245	261,285						203,140	113,240	
Florida OIR																				
Number of Claims	88,303	4,030		2,291	6,298	8,794	158	1,028	14,168	243	10,269	1,187	53				59	1,475	3,522	7,937
Open/Closed claims with payment	78,346	3,704		1,405	5,088	7,361	139	794	12,802	180	7,225	1,064	39				41	1,022	3,011	5,269
Open/Closed claims without payment	9,957	326		886	1,210	1,433	19	234	1,366	63	3,044	123	14				18	453	511	2,668

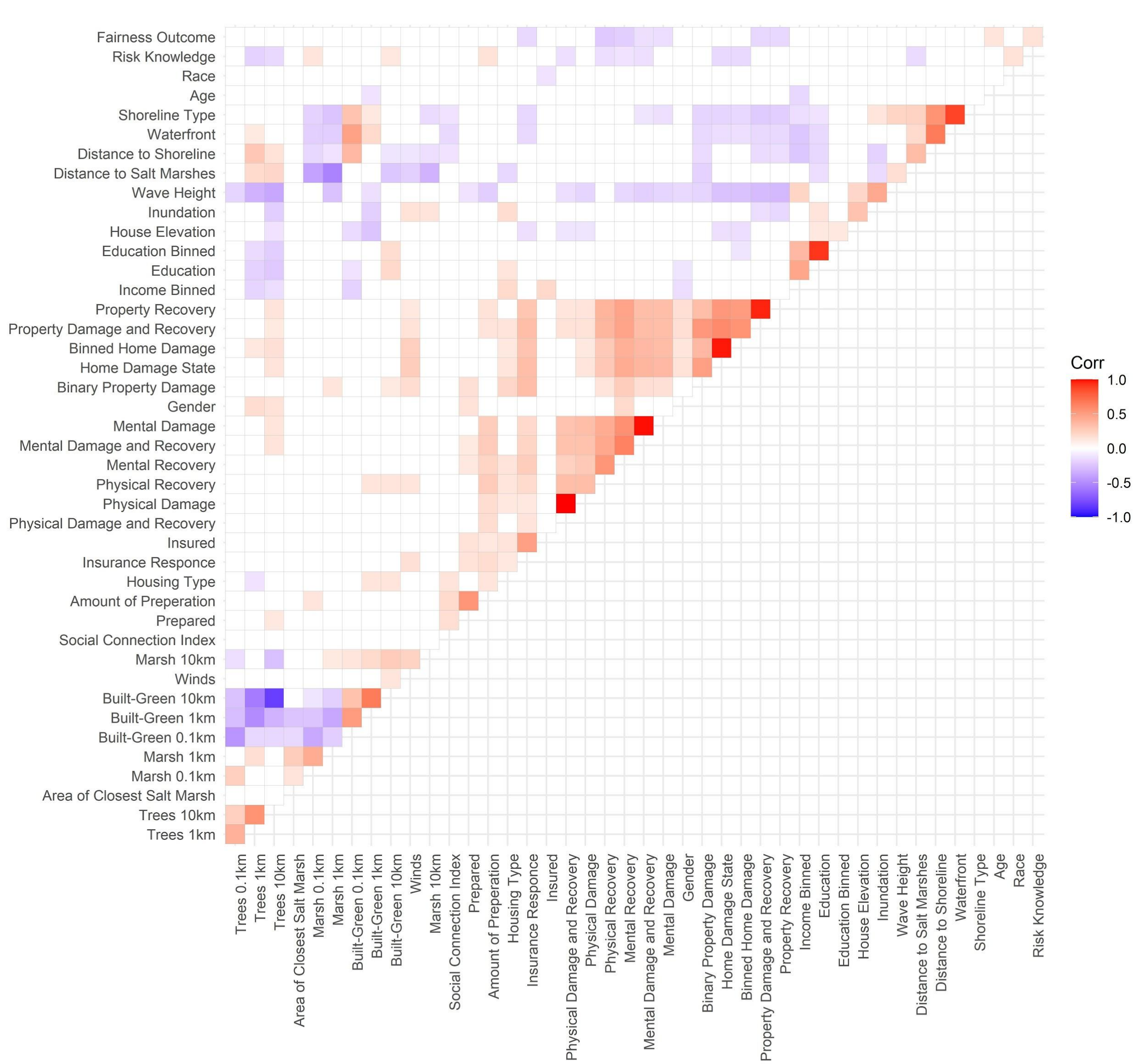

Figure A1. Correlation table of all potentially included variables within the ordinal logistic regressions ran. Correlations tests are done using a two-tailed spearman's rank correlation. Boxes are colored based on the direction of the correlation; red for positive and blue for negative correlation coefficients. White boxes are non-significant correlations using a p-value of 0.05.

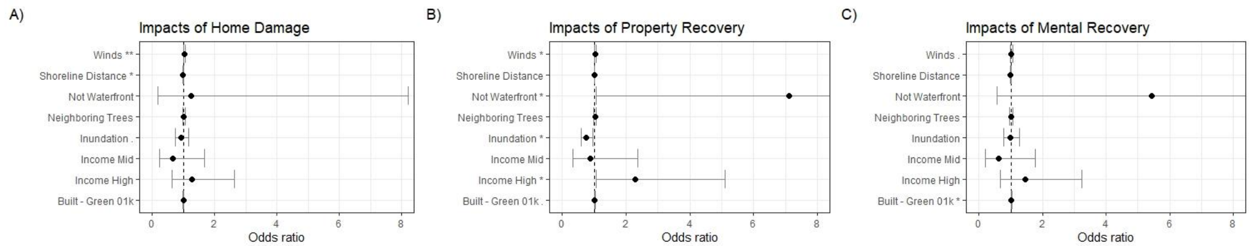

Figure A2. Odds ratios plotted for each variable used within the ordinal logistic regressions. A) is the odds for variables on the impact of home damage, B) is the odds for variables on the impact of property recovery, and C) is the odds for variables on the impacts of mental recovery. Each variable's significance is marked to signify the p-value using: . <0.1, * < 0.05, and ** <0.01.