Financial Value of Nature:
Coastal Housing Markets and Climate Resilience

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Abstract

Valuing the benefits of nature is a difficult task, often resulting in insufficient funding directed to nature preservation and restoration. As extreme weather events intensify due to climate change, one of the tangible benefits of nature is the protection it offers against resulting damages. Measuring the financial value of nature's climate adaptation benefits is key to attracting private investments. We propose a methodology for such valuation by assessing how mangroves, a common coastal wetland in Florida, mitigate the effects of hurricanes on home prices by reducing flood risks and their perception. Using property-level housing transaction data, we find that proximity to mangroves lowers home price decline and dispersion following major hurricanes. The probability of a 25% value loss following the hurricane is substantially lower for properties protected by the mangroves (by as much as 7 percentage points, or a 60,000-dollar benefit for a property worth 1 million dollars).

Keywords: climate adaptation, hurricanes, nature-based adaptation, housing, property values

JEL codes: Q54, G12, R31

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1 Introduction

The effects of climate change are no longer a future risk. The frequency and severity of climate-related disasters have increased in recent years and are expected to increase further (Hsiang and Kopp, 2018). This means that we need to think not only about climate change mitigation efforts, designed to reduce greenhouse gas (GHG) emissions, but also about adaptation efforts that would help protect nature, infrastructure, property, and people from the consequences of climate change. Nature-based solutions (NbS) such as protecting and restoring coastal wetlands are effective at reducing flood risks following hurricanes (Arkema et al., 2013; Menéndez et al., 2020; Beck et al., 2022). However, the benefits of such solutions are difficult to evaluate, which is a barrier to attracting private investments in such projects. Attracting private investment is key to preserving and restoring nature and biodiversity, because financial needs in this area exceed the means of governments and non-profit companies (Flammer et al., 2025).

In this paper we propose a methodology to evaluate private benefits of nature as protection against climate-related extreme weather events using market-based evidence. In particular, we measure the reduction of hurricane-related market value losses of properties thanks to the protection provided by mangrove forests. We account for the effects of mangroves on price dispersion, and compute the dollar value of private benefits from such protection. In prior studies, such as del Valle et al. (2019); Hochard et al. (2019); Menéndez et al. (2020); Sun and Carson (2020), the financial benefits of mangroves are derived from direct damage avoidance analysis based on construction costs data. Our analysis of market values of properties is designed to incorporate forward-looking differences between expected values of properties that are protected by nature and those that are not.

The state of Florida provides a relevant setting for our analysis. Multiple counties in the state have been hit by severe hurricanes in recent decades with substantial impacts on housing prices.[1] At the same time, parts of Florida's coastline are covered with mangroves, which are shown to be a natural protection against hurricane-induced flood damages (Thomas et al., 2020). In terms of the physical storm impact, studies such as Gijsman et al. (2021) and Mazda et al. (2006) find a linear effect of mangroves on flood risk reduction: wave energy and storm surge decay along a transect through mangroves, and wave and surge attenuation is a linear function of the distance inland of the mangrove forest. This impact translates into physical property damages, and Beck et al. (2022) and Menéndez et al. (2020) demonstrate that mangroves effectively reduce property damages from hurricane and flooding. Similar findings in economics studies are reported in del Valle et al. (2019), Hochard et al. (2019),

[1]See the list of continental U.S. hurricanes collected by NOAA at Last accessed in March 2025.

and Sun and Carson (2020).[2]

We combine geographic variation in flood protection provided by mangroves with over-time variation in the impact of hurricanes on housing prices. Property-level data allow us to analyze the full distribution of the effects, rather than focusing only on the average value losses. Moreover, we rely on transaction data, therefore only considering actual sale prices. We summarize the effects using the measure of probability value at risk (pVaR), frequently used in pricing the value of extreme events, which measures the probability of housing price values dropping by more than a threshold amount following a hurricane (we choose a 25% threshold as an example). We then translate the measured reduction in pVaR thanks to mangroves into the willingness to pay (WTP) for mangroves protection and restoration, as a share of pre-hurricane house value.

In addition to computing average effects of mangroves protection across all the hurricane years, we allow for the effects to differ across counties that were on the path of hurricanes and those that were off path. We find that on the hurricane path proximity to mangroves reduces the probability of the 25% value loss of residential properties by as much as 7 percentage points, which is a sizable decline in risk. When translated to willingness to pay, this corresponds to 40-80 thousand dollars value of mangroves protection per 1-million dollar property, depending on the initial risk of value loss, likely exceeding estimated direct damages or insurance premium differences. This risk reduction is also observed in off-path counties, but the effect is about half as large and is only apparent with about 1-year lag. This is likely due to the fact that perception of flood risk protection from mangroves increases following hurricanes as housing market participants learn from the experience of their neighbors.

We combine multiple data sets to conduct our analysis. Transaction prices of residential property sales, as well as property locations and characteristics, are sourced from Zillow's Transaction and Assessment Database (ZTRAX). For data on mangroves locations relative to properties, we rely on Global Mangrove Watch maps. The elevation of the properties is measured using the Topologically Integrated Geographic Encoding and Referencing database. The National Flood Hazard Layer from the Federal Emergency Management Agency (FEMA) is used to identify flood risk designation. All these data are merged using the geo-coordinates of the properties. We estimate the effects of a generalized hurricane variable (based on three major hurricane years: Ivan and Jeanne in 2004, Sandy in 2012, and Irma in 2017). Our benchmark analysis focuses on seven coastal counties affected either directly or indirectly by these hurricanes: Pinellas, Miami, Manatee, Lee, Hillsborough,

[2]In particular, Sun and Carson (2020) finds that coastal wetlands' protection is especially effective in areas with weaker disaster prevention building codes, and in general the average value of these protections (damage avoidance) is around $1.8 million per square kilometer annually.

Collier, and Charlotte.[3]

The statistical analysis is conducted at two levels of granularity. At the property level, we are able to evaluate property-specific price changes using repeated sales information and controlling for property and time fixed effects. Property fixed effects absorb any differences in flood exposures and amenities associated with specific properties,[4] while time fixed effects account for aggregate house price dynamics. This analysis provides us with estimates of the average housing price effect of hurricanes depending on the properties' proximity to the mangroves. To address the dispersion of the price effects, we also conduct the ZIP code-level analysis of the coefficient of variation of housing prices, controlling for aggregated values of properties' attributes in each ZIP code, as well as ZIP code and time fixed effects.

We apply the results of our statistical analysis to the observed distribution of housing price changes for the properties with repeated sales before and after hurricanes to evaluate the effect of proximity to mangroves on the pVaR of property values. We find that the effect varies by hurricane and county and can be as large as 7 percentage point reduction (from over 36% to nearly 29%) of the probability of 25% housing value loss, which is what we estimate for Collier County following Hurricane Irma. The willingness to pay for this risk reduction, and therefore for mangroves protection and restoration, corresponds to 60 thousand dollars per 1-million dollar house in this case, under standard assumptions.

We have to make a few important specification decisions for our analysis. First, we want to control for properties' inherent exposure to flood risk following a hurricane. This depends on the properties' elevation as well as their proximity to the coast. Not surprisingly, proximity to the coast is highly correlated with proximity to mangroves. We address this issue in three ways: first, in the regressions with property fixed effects, this issue does not arise as the distance to the coast is absorbed by property fixed effects and in the ZIP code level analysis, we control for the average elevation and distance to the coast of properties in the ZIP code; second, in our benchmark regressions, we discretize the distance to mangroves into five categories which reduces the multicollinearity problem; third we rely on FEMA flood maps to control for the properties' exposure to flood risk.[5] Importantly, properties in high

[3]The benchmark results focus on FEMA medium risk regions. Note that the FEMA Flood Map data do not always overlap with the ZTRAX sale transaction data. For example, In Collier County, while the FEMA flood risks are mapped comprehensively, only a small portion of the county is populated extensively and has housing transaction data. In the estimations that include all FEMA flood zones, the sample also includes Broward County.

[4]Daniel et al. (2009) show that not controlling for amenity values may create biased results when measuring the effects of floods on property prices. Doss and Taff (1996a) show that properties with open access to the coastline are generally valued higher than those with forested wetlands, such as mangroves. Atreya et al. (2016) show the importance of distance to amenities for housing prices.

[5]FEMA flood maps is a common source for such analysis. For example, Faticaa et al. (2023) use flood risk maps to simulate the gains for firms for adaptation in terms of reduced negative post-disaster performance.

flood-risk areas are subject to a number of financial and regulatory requirements as well as subsidized insurance premia, which distorts the response of their values to disasters such as hurricanes (Morgan, 2007).[6] In addition, property values in high flood risk areas are shown to be lower in general (David Harrison and Schwartz, 2001; Zhang, 2016), suggesting that some of the flood effects might be priced in. For these reasons, our benchmark analysis is limited to properties in the medium flood risk areas, which are subject to hazard, but not affected by distortions.[7]

Second, frequency of housing sales is affected by hurricanes. As we are relying on actual transaction data, we allow for up to three years for the measured effects of the hurricanes, including the hurricane year. Other studies have demonstrated that housing price effects of hurricanes might be even more persistent, up to 5-6 years (Bin and Landry, 2013; Ortega and Taşpınar, 2018). However, the high frequency of major hurricanes in Florida makes it impractical to include more than three years in the estimation. In addition, we verify that there are no pre-trends observed due to differences in distance to mangroves in our data, i.e. pre-hurricane price dynamics are not correlated with distance to mangroves.

Third, in the ZIP code level analysis, we control for property characteristics because we cannot control for property fixed effects. We include the following controls in our regressions, taking the median of them at the ZIP code level: distance to coast, elevation, property age, building area square footage. We compute price moments separately for different property types (single family house or condominium). In addition, we include ZIP code and time fixed effects.

We extend our analysis by allowing the effect of mangroves to vary as a function of the width of the mangrove forest at each location. We define "width" to be the cross-shore distance from water edge to back of the mangrove belt, band or forest. Studies have shown that mangroves flood protection effects are larger when mangrove forests are wider (Gijsman et al., 2021; Maza et al., 2021). Our results are consistent with this finding — the decline in property prices following hurricanes is substantially smaller when mangrove forest is wider in proximity to the properties in question: an additional 10 meters of mangroves (up to 30 meters) have as much protection effect as reducing distance to mangroves by 2 km.

Our study is not the first to estimate the effect of flood risks on housing prices. The negative effect has been found in a number of studies, including Bin and Landry (2013), Daniel et al. (2009), Graff Zivin et al. (2023), Bernstein et al. (2019), Baldauf et al. (2020), Hino and Burke (2021), and Keys and Mulder (2020). Bernstein et al. (2019) and Baldauf et

[6] A similar distortion is found in the aftermath of wildfires in California that received FEMA rescue funds, as shown by (Issler et al., 2020).

[7] In the Appendix we document the differences in the effects of mangroves by flood risk level.

al. (2020) show the climate effects on housing prices by measuring the climate belief effects, while Ortega and Taṣpınar (2018) attribute long-term reduction in New York property values following hurricane Sandy to change in climate beliefs. Our paper is also related to Benetton et al. (2022) and Kelly and Molina (2023) who estimate the value of "grey" infrastructure (seawalls) using house listing prices in Venice and transaction data in Miami-Dade County respectively. To our knowledge, our study is the first to measure the mitigating effect of mangroves or NbS more generally on flood risk-related housing value loss. Additionally, our analysis of price dispersion due to hurricane events is similar to studies such as Gete et al. (2024) showing that riskiest Florida counties could experience mortgage rate spread increase as high as 13% compared to before the landfall. Our paper also contributes to the literature on the financial value of wetlands preservation and conversely of wetland loss, as in Taylor and Druckenmiller (2022) and Rizzi (2022).

More generally, our analysis contributes to the literature on valuing nature, ecosystem, and biodiversity. In particular, Nolte (2020) uses housing data to estimate the costs of conservation in the United States. Most studies focus on the amenity values of the ecosystem rather than climate risk reduction (Atreya et al., 2016; Belcher and Chisholm, 2018; Cho et al., 2006; Doss and Taff, 1996b; Mahan et al., 2000). In contrast, our analysis contributes to the smaller literature on the costs and benefits of flood risk reduction measures, which includes studies by Brouwer and Schaafsma (2013); Corderi-Novoa et al. (2021); Lind (1967); Zhu et al. (2007), although very few of these studies focus on NbS. More recently, analytical models from Giglio et al. (2025) show that the marginal value of nature's adaptation effect increases as climate change intensifies, and as climate-related extreme events become more frequent.

To summarize, we find that the protection effects of mangroves can be large in terms of reducing potential residential property value losses after hurricanes, especially in the areas that are not currently designated as high flood risk. While we only measure the effects on the housing values, other benefits of NbS are many and need to be taken into consideration in a broader cost-benefit analysis.[8] Specifically to mangroves, in addition to flood protection of non-housing assets such as agricultural areas, public infrastructure, open spaces, and other properties, co-benefits include biodiversity protection through preservation and restoration of the habitats, and other ecological benefits. Moreover, further private benefits can be generated through carbon offset markets due to the potential of mangroves to sequester carbon.[9]

[8] Allaire (2018) surveys the literature on the broad impacts of extreme flooding that NbS may help reduce.

[9] Globally, mangroves are among the most carbon-rich tropical ecosystems, comprising 14% of global ocean carbon sequestration as both above ground biomass and soil organic matter, despite only covering about 0.5% of global coastal areas (Alongi (2012); Alongi (2014)).

There are two main takeaways from our analysis. First, to the extent that residential property values reflect present value of the future actual costs of hurricane-related damages, protection and restoration of mangroves could be an important part of the adaptation to climate change and an associated increase in hurricane frequency. Second, given that mangroves provide benefits to residential property owners as well as developers, insurance companies, and financial institutions, these private agents need to be contributing to the expenses associated with protection and restoration of mangroves. Designing financial instruments that would allow for such contributions will help alleviate climate adaptation costs for federal, state, and local governments while reaping the co-benefits in terms of ecosystem and biodiversity protection. Our analysis provides actual estimates as well as the methodology to quantify private benefits of nature that can be incorporated in such financial instruments.

2 Mangroves Biodiversity and Carbon Benefits

Before diving into our analysis of private value of climate adaptation benefits that mangroves provide, we briefly summarize the state of knowledge on mangroves biodiversity and carbon benefits. In this paper we do not quantify these benefits, but we acknowledge their foremost importance.

Mangroves are exceptionally productive tropical forests that thrive in the intertidal zones between land and sea (Figure A.1). These ecosystems have evolved to withstand the harsh conditions of saltwater exposure, shifting tides, and strong wave action (Bunting et al., 2018a). Their unique adaptations, including aerial root systems, enable them to mitigate wave energy and wind impacts while absorbing pollutants from surrounding waters.

These adaptations not only protect the mangrove ecosystem but also provide crucial benefits to nearby human communities. Mangroves serve as natural barriers against storm surges and coastal erosion and help maintain water quality (Das and Vincent, 2009; Hochard et al., 2021), as shown by Figure A.2. In addition to their protective functions, they bolster local economies by supporting ecotourism, recreational activities, and both commercial and subsistence fisheries. They also supply a range of forest products, from timber and medicinal plants to pollination services that sustain agricultural livelihoods (Tomlinson, 2016; Leal and Spalding, 2024; Barbier et al., 2011; Walters et al., 2008).

Mangroves play a vital ecological role by offering habitat that enhances biodiversity. They serve as breeding, feeding, and nursery grounds for a wide variety of species, including endemic fish, macroinvertebrates, birds, and mammals (Tomlinson, 2016; Naylor et al., 2000; Corte et al., 2021; Mohd-Azlan et al., 2015; Ng et al., 2021). Beyond their ecological and economic value, mangroves also contribute significant non-material benefits, such as cultural heritage, spiritual fulfillment, educational opportunities, aesthetic appeal, and a strong sense of place for local communities (Onyena and Sam, 2020; Friess, 2016; Walters et al., 2008).

On a global scale, mangroves are among the most carbon-dense ecosystems in the tropics, storing an average of 1,023 ± 88 megagrams of carbon per hectare (Donato et al., 2011). Despite covering just 0.5% of coastal areas worldwide, they are responsible for approximately 14% of global oceanic carbon sequestration through both aboveground biomass and soil carbon (Alongi, 2012, 2014). However, the actual amount of carbon stored can vary significantly. These differences depend on several environmental and ecological factors, such as soil salinity and composition (Jennerjahn, 2020; Song et al., 2023; Matsui et al., 2015), tree species diversity and functional traits (Rahman et al., 2021), forest maturity and spatial configuration (Wu et al., 2020; Tue et al., 2014), local climate conditions (Dobbs et al., 2014), and the geomorphic and hydrological setting (Chaikaew and Chavanich, 2017; Sasmito et al., 2020). Socio-political elements like land ownership and governance also play a role (Primavera and Esteban, 2008; Friess, 2016; Lovelock et al., 2022).

Despite their high carbon storage potential, the long-term durability of mangrove carbon sinks remains uncertain. Key knowledge gaps persist regarding ecological processes such as mineralization rates (Wu et al., 2020), the effects of climate change on mangrove metabolic activity (Alongi, 2014), and future changes in land use driven by human development (Sasmito et al., 2020).

3 Data Sources

We develop a novel dataset that combines high-resolution geospatial data with housing financial transactions. One key distinguishing feature of our dataset is that we are able to identify property-level variations of flood risks and the benefits provided by coastal wetlands.

We combine the datasets of Global Mangrove Watch and Zillow's Transaction and Assessment Database (ZTRAX) to assess the value of mangroves in flood risk reduction. The data merging process is based on the geo-coordinates of the properties (detail of the data merging process is in Appendix A.3). We supplement the data with additional geographic information system (GIS) data such as house elevation from U.S. Geological Survey and the U.S. Census.[10] We use the National Flood Hazard Layer (NFHL) from FEMA to identify the perceived flood risks.

[10] From the U.S. Census, we use TIGER (Topologically Integrated Geographic Encoding and Referencing database).

Housing Data

ZTRAX is a dataset of house final sales that provides a rich set of information on sale price, date of sale, square footage, and other key properties characteristics.[11] The scope of analysis is Florida due to mangroves mainly growing in tropical environments and the high frequencies of hurricanes in the state. Our study includes eight coastal counties: Pinellas, Hillsborough, Manatee, Charlotte, Lee, Collier, Broward, and Miami-Dade.[12] The time coverage of our data is 1993 to 2019. There are over 6.4 million records of transactions in our sample, in which there around 2.04 million unique properties. The majority, 68%, of these properties are single-family houses. All the sale price data have been converted to real terms (in terms of 2015 dollars).

Mangroves Data

We have collected mangroves data from Global Mangrove Watch, which is an online platform established by the Japan Aerospace Exploration Agency's Kyoto and Carbon Initiative. The initiative is an international collaboration among Aberystwyth University, solo Earth Observation, and the International Water Management Institute. The platform provides remote sensing data and tools for monitoring mangroves (Bunting et al., 2018b). Remotely sensed data are created from satellite radars that are able to detect mangroves extent across the entire world at 30-meter resolution (Bunting et al., 2022). This dataset additionally displays the change in mangroves coverage between select years during 1996 and 2020.[13] Unfortunately, there are no sufficient temporal variations in mangroves coverage in the counties we consider in proximity of the properties in our data (see Table A.2). Thus, we cannot use mangroves dynamics as a source of identification, therefore we use a time-invariant measure of the distance to mangroves and mangroves width.

Figure 1 shows the distribution of mangroves in our sample. While all eight counties in the sample have mangrove coverage, the southwestern Florida counties have higher density. To measure the effect of mangroves on flood risk reduction, we use property-specific distance to mangroves and the width of the mangrove forest. Property-specific distance is calculated as a geodesic (shortest distance) to the closest mangrove forest. We bin the distance measure into groups: 0-2km, 2-4km, 4-8km, 8-16km, and more than 16km.

[11] Importantly, these data are collected from county assessors' offices, and are not the listing prices from the Zillow website. As far as we know, ZTRAX does not provide information of the properties' listing dates.

[12] We are precluded from considering remaining coastal counties due to the limitations of the GIS data.

[13] Specifically, we use data from years 1996, 2007, 2008, 2009, 2010, 2015, 2016, 2017, 2018, 2019, and 2020. The average of these years' data is used as the mangroves distance measure.

For each property we also record the width of the mangrove forest that is closest to the property. We calculate the width of mangrove forest using the GIS data by generating transects between the boundaries of mangroves and location of properties, and by calculating the geodesic distances from the properties to the boundaries. Additional details are described in Appendix A.3.

Figure A.3 documents the distribution of hosing prices per square meter as a function of distance to mangroves controlling for Florida overall housing price index. We find that without considering the hurricane effects, housing price per square foot decreases the further away the properties are from mangroves.[14]

Hurricane Data

The dates and paths of hurricane landings are obtained from National Hurricane Center, National Oceanic and Atmospheric Administration (NOAA) and North Carolina Institute for Climate Studies. We select three main hurricane years during which major hurricanes affected Florida in our sample. While hurricanes Ivan and Jeanne as well as Irma passed through Florida (see Figure 4), Sandy did not. The choice to include hurricane Sandy in the analysis allows us to illustrate that the benefits of mangroves are not only due to direct flood risk reduction for those counties in the hurricane paths. Hurricane effects on housing markets in the counties that are not directly affected are likely due to changes in the perception of risks from future hurricanes stemming from observing their neighbors' experiences.

FEMA Data

Using National Flood Hazard Layer (NFHL), we categorize properties into three flood risk categories: low, medium, and high. More specifically, in line with the taxonomy of FEMA, an area is a medium (or moderate) risk zone if it is located in a 500-year floodplain, meaning that the damages to this areas are not likely unless the flood is of a size that only occurs once in 500 years.[15] When an area is designated as a high risk zone, also known as Special Flood Hazard Area (SFHA), or 100-year floodplain, it means that properties are likely to experience damages from a smaller-scale event, such as occurs once in a 100 years. Figure 2

[14]Ex ante, the price variation in this graph could be capturing the price premia of beachfront properties. However, the relative flatness of the slope between 1km and 10km suggests there are factors other than being close to the ocean driving the price difference.

[15]Data were obtained from FEMA "Flood Zones" at https://www.fema.gov/glossary/flood-zones in 2021-2024.

shows that substantial areas of the coastal counties are either in medium or high flood risk zones.

4 Empirical strategy

Following real estate economics literature including Mueller et al. (2009) and Graff Zivin et al. (2023), we use a hedonic regression model to estimate how housing prices, both in terms of level and dispersion, reflect the value of mangroves. To uncover the level effect, we rely on the variation arising from the repeated sales of properties. In other words, if a house is sold after a recent hurricane, its price should reflect how buyers and sellers perceive the risk exposure of the property and the potential value of mangroves in alleviating the risks.

We focus on three major hurricane years that fall in the time frame of the sample: Hurricanes Ivan and Jeanne in the year 2004; Hurricane Sandy in 2012; and Hurricane Irma in 2017.[16] Given that perception of the flood risk in Florida can be affected by the hurricanes that land in neighboring states along the Gulf of Mexico and eastern seaboard, some of the effects we find for Irma in 2017 could also be affected by hurricanes Harvey and Maria. Figure 4 shows the paths of these hurricanes across the six counties in our sample. We allow for differential effects of hurricanes on counties that are directly in the paths of hurricanes and those that are not. As the paths of hurricanes show, different hurricanes landed in different counties in our sample (and Sandy did not land in Florida) providing sufficient variation for identification of separate effects. To generalize the effects of these hurricanes, we combine three hurricane years into a single hurricane variable in the benchmark estimations while disaggregating the effects in the robustness tests section.

4.1 Identification and measurement of the mangroves effect

A major source of flood risk comes from buildings close to the coast, as ocean waters can travel inland during storms Gijsman et al. (2021). However, the risk is mitigated by natural barriers like mangroves when they are in between homes and their coastline (Das and Vincent (2009)). Everything else equal, even when faced with identical flood risks, properties closer to mangroves are less likely to be damaged by hurricanes and floods or, if affected, are likely to have smaller damages.

It is not straightforward to identify how housing prices would reflect the presence of man-

[16]Ivan and Jeanne occurred closely to each other (both within September 2004), and are considered as one single hurricane event in this study. Throughout the paper, we may use "Ivan" as abbreviation for "Ivan and Jeanne".

groves. There are at least two mechanisms at work. On the one hand, if people perceive that mangroves can reduce the impact of flooding, therefore protecting their home value, they would be willing to pay more for houses in closer proximity to mangroves. On the other hand, the presence of mangroves can potentially reduce value of the amenities that one would experience when living by the ocean, such as view and access to the waterfront, therefore pushing down the house price. Our identification strategy relies on the assumption that risk reduction can be affected by the flooding events, such as those associated with major hurricanes, while the amenity value is not.

Our benchmark specification relies on differential changes in house prices in the aftermath of the hurricanes depending on the proximity of the property to mangroves. We include year-month fixed effects to absorb any price trends common to our sample, as well as average impact of hurricanes on housing prices. We include property fixed effects to account for distance to the coast, elevation, amenity values resulting from mangroves, as well as all other property characteristics. The variable of interest is an interaction of a post-hurricane indicator, which only varies over time but not across properties, and our measure of property proximity to mangroves, which only varies across properties but not over time. Main effects of these variables are absorbed by fixed effects. We also include 1 and 2 years before the hurricane to capture any pre-trends.

One important identification issue remains — since mangroves grow at the water edge, proximity to mangroves is highly correlated with proximity to water edge and therefore with the exposure to flood damages. Even though we can measure proximity to water edge directly, we cannot control for its interaction with post-hurricane indicator because of resulting near-multicollinearity with distance to mangroves. In the robustness tests we make sure that our results of distance to mangroves are not spuriously driven by the distance to the coast. In addition, we focus our benchmark specification on NFHL "medium flood risk" areas, thus excluding properties that are not at the risk of flooding at all, or those that are at an extreme risk of flooding. Importantly, NFHL risk designations combine information on proximity to the water edge, elevation, and any existing grey flood protection measures. In our pre-testing we find that the properties in the medium flood risk are most likely to benefit from proximity to mangroves.[17]

One more potential confounding factor is the presence of man-made, or grey, flood protection infrastructure. To the extent that it does not vary much over time, property or ZIP code level fixed effects are likely to capture it. Unfortunately, no systematic public data are available for us to control for grey infrastructure directly, thus, any time-varying effects of its presence on housing prices will appear in the error term. Potential bias can arise if the

[17] Details are in Appendix A.5.

presence of grey infrastructure is correlated with mangroves. To the extent that the most likely correlation is negative, because grey infrastructure tends to be present where mangroves are not, the likely bias will be against us finding larger price declines for properties that are further away from the mangroves following hurricanes.

4.2 Baseline Econometric Specification

We estimate the effect of mangroves on flood risk-related effects on the level and the dispersion of properties' sale prices. The baseline specification of the hedonic regression is the following:

$$log(P_{it}) = \beta'(m_i \times H_t) + \delta_i + \delta_t + \epsilon_{it}, \tag{1}$$

where $log(P_{it})$ is the logarithm of sale price of property i in month t. H_t is a vector of indicators of whether house i is sold 1 or 2 years before, the year of, or 1 or 2 years after a hurricane. For example, Hurricane Irma occurred in August-September of 2017, if a property is sold in October 2017, the "year of hurricane" indicator for that particular observation is 1. m_i indicates mangroves distance group in which the property is located. The baseline group is within 2km of mangroves presence, and there are 4 additional groups: 2-4km, 4-8km, 8-16km, and more than 16km. The specification includes property fixed effects δ_i to obtain estimates of within-property variation, identified by repeated sales. We also control for year-month fixed effects δ_t to account for common housing price dynamics and seasonality. Note that in this specification the main effect of mangroves distance group is absorbed by property fixed effects since it does not vary over time, while main effect of the components of H_t is absorbed by the time fixed effects. Standard errors are clustered on time to allow for correlation across properties.

4.3 Price dispersion

To estimate the probability value at risk (pVaR) impact of mangroves, we need to also obtain a measure of price dispersion as a function of proximity to the mangroves in the aftermath of the hurricanes. To do so, we aggregate the property data to the ZIP code level and estimate the following regression of the price dispersion measure σ_{zt}/μ_{zt}, measured as the coefficient of variation of the sales price within a particular ZIP code (where σ_{zt} is the standard deviation and μ_{zt} is the average sales price of properties in ZIP code z in month t).

$$\frac{\sigma_{zt}}{\mu_{zt}} = \xi m_z + \beta'(m_z \times H_t) + \gamma' X_z + \delta_z + \delta_t + \epsilon_{zt}, \tag{2}$$

where m_z now represents median distance group of properties in ZIP code z to mangroves. In this regression, since we cannot include property fixed effects, we include ZIP code fixed effects δ_z and a vector of ZIP code level control variables X_z that includes average distance to coast, elevation, property age, building area square footage, dummy variables whether the property is a family house or a condominium. We continue to include time fixed effects δ_t which absorb the main effect of the hurricane indicators. Standard errors are also clustered on time.

4.4 Direct and Indirect Effects (Learning)

After establishing average effects of the mangroves distance, we allow for heterogeneous effects depending on whether a given county is in the path of hurricane or not. To do so, we create an indicator θ_{ct} for whether a hurricane that landed in a given year t, moved through county c. We extend this definition to indicators of "before" and "after" the hurricane. We also create an "off path" indicator for counties that were not hit by a given hurricane, $1-\theta_{ct}$. We then split the interaction term in our regression 1 into two separate variables: one for "on path" properties and one for "off path" properties.

For the property-level regression with thus estimate

$$log(P_{it}) = \beta_1'(\theta_{ct} \times m_i \times H_t) + \beta_2'((1-\theta_{ct}) \times m_i \times H_t) + \delta_i + \delta_t + \epsilon_{it}, \tag{3}$$

similarly, for ZIP code level coefficient of variation equations we estimate

$$\frac{\sigma_{zt}}{\mu_{zt}} = \xi m_z + \beta_1'(\theta_{ct} \times m_z \times H_t) + \beta_2'((1-\theta_{ct}) \times m_z \times H_t) + \gamma' X_z + \delta_c + \delta_t + \epsilon_{zt}. \tag{4}$$

4.5 Price Level and Width of the Mangrove Forest

As Gijsman et al. (2021) point out, forest width is an important factor in mangroves' functionality in reducing flood risks.[18] Thus, we estimate

$$log(P_{it}) = \beta'(m_i \times H_{it}) + \gamma'(\omega_i \times H_{it}) + \rho'(\omega_i \times H_{it} \times m_i) + \delta_i + \delta_t + \epsilon_{it}, \tag{5}$$

where as before the main effects of the width of the mangrove forest ω_i and distance group as well as their interaction are absorbed by the property fixed effects δ_i.

[18] The importance of examining the width of the mangrove forest is supported by additional studies: del Valle et al. (2019) examines the impact of the width of the mangrove forest on economic activities; while Maza et al. (2021) shows that in conditions characterized by short waves, mangrove forest widths exceeding 300 meters are necessary to diminish incoming waves and surge by over 50%.

We measure forest width by discretizing it in three ways: 1) whether the observed width falls in the threshold value of 300 meters; 2) 4 bins of mangroves widths ranging from less than 100 meters to greater than 500 meters;[19] and 3) the inverse of the mangroves width in meters. In the main results, we use measure of inverse of the width.[20]

5 Results

We first show the estimation results of mangroves effects on the level and dispersion of property sale prices, distinguishing between the properties located in the counties on and off the hurricane paths in the aftermath of the hurricanes. We use point estimates to calculate the probability of losing 25% or more of property value following a hurricane as a function of property distance to the mangroves, and translate the results into the willingness to pay for mangroves protection and restoration. We then extend our analysis to account for the intensive margin of the effect as measured by the width of the mangrove forest.

Throughout our analysis we focus exclusively on properties located in medium flood risk zone shown on Figure 2. As described in Appendix A.5, the effect of mangroves on prices of high flood risk properties in the aftermath of hurricanes is less clear. This is likely due to the effect of special policies and insurance rules that apply to such properties.

5.1 Benchmark Results: price levels, hurricane paths and price dispersion

We begin by reporting our benchmark results which will contribute to our calculations of the pVaR and willingness to pay (WTP) for mangroves protection.

Effect on the price level: property-level analysis

Table 1 reports the results of our benchmark estimation of the effects of mangroves on the level of property prices following hurricanes (equation 1). All regressions include year-month time fixed effects as well as property fixed effects. To test for the pre-trends we include separately an indicator of 1-24 months before each hurricane. To allow for different effects

[19] More specifically, the 4 bins are: less than 100m; between 100m and 200m; between 200m and 500m; and greater than or equal to 500m. The choices for these bin sizes are based on the empirical distribution of the width data in our data, and with support from experimental results in Figure 3 of Maza et al. (2021).

[20] The main reason for this choice is the ease of interpretation. The results for the other two measurements are similar and available upon request.

in the first year following the hurricane (before insurance is normally paid), we separate an indicator of 0-12 months following hurricane from 12-36 months after the hurricane. We first include these indicator individually and then together, all interacted with the index of distance to mangroves (the main effect of the time period indicator is absorbed by the time fixed effects). The main effect of distance to mangroves as well as all property-specific characteristics are absorbed by property fixed effects. The identification comes from price changes between repeated sales of the same property, relative to monthly trend. In the last column we also allow for annual trend to vary by distance to mangroves.[21] The mangroves distance groups are labeled so that the larger the number, the more distant an individual property is from mangroves. Therefore, a negative coefficient on this measure means that the further the mangroves, the lower the house sale price is.

In the year of the hurricane and the two years that follow we observe that the price decline increases with distance to mangroves. We illustrate this effect in Figure 3 using our benchmark specification in column (4) of Table 1. We find that there are no pre-trends, except when we include mangroves distance-specific trends when we observe a positive pre-trend: that is, in pre-hurricane years prices are higher for properties that are further away from mangroves. When allowing for trends to vary with mangroves distance, we find that prices grow slower for properties that are further away from mangroves. It is possible that persistent negative effects of hurricanes, which are more substantial for properties further away from the mangroves contribute to these differential trends, as property owners and insurance providers learn about the disaster-protection value of mangroves. Thus, while our results show that trends in house prices differ with distance to mangroves, these differences might be reflecting actual effects we are trying to measure, and therefore we do not include them as controls in the rest of our analysis.

Properties in counties on and off the hurricane path: property-level analysis

We separate the properties into two groups: those located in counties through which the hurricanes in question (Ivan, Jeanne, or Irma) passed directly, and the rest, as shown in Figure 4. We allow for the effect of the distance to mangroves following the hurricanes to be different for these sets of counties. Since we did not find pre-trends, we do not include them in the analysis.[22] Note that, as before, the main effect of hurricanes on property prices

[21]The results are similar if we allow for different trends for different mangroves distance bins rather than an interaction of trend with the categorical mangroves distance measure. These results are available upon request.

[22]Including pre-trends does not affect our results.

are absorbed by time fixed effects.[23] The results are reported in Table 2. Following the hurricanes, we find that the effects of mangroves protection are substantially larger for the properties located in hurricane-path counties, both immediately following hurricanes and in the following two years. The effects are illustrated in Figure 5. The magnitude of the effect on prices of properties in off-path counties is about 30% smaller in the year of the hurricane and 2.5 times smaller in the following two years than that for properties in on-path counties. These findings indicate that housing market participants learn about the protective nature of mangroves when their neighbors are affected by the hurricanes and the damages are much more contained and prices hold up much better for the properties that benefit from mangroves protection.

We use the estimated coefficients for the years 2-3 after the hurricane from column (3) in Table 2 to predict the shift of the empirical distribution of price changes due to the presence of mangroves for our pVaR and willingness to pay (WTP) analysis, separately for each hurricane and each county, to allow for the effect to vary based on the hurricane path.

Effect on price dispersion: ZIP code level analysis

Next, we estimate our ZIP code level regressions in equation (2) to obtain estimates of the effect of mangroves on price dispersion following hurricanes. We aggregate our data to ZIP code level for each month taking mean, standard deviation, and median of sale prices for each month and ZIP code, separately for single-family homes and condos. We calculate median distances to mangroves and to the coastline, median elevation, median property size and mean values of building code indicators in each ZIP code. We include these values as controls in the regressions along with time fixed effects and ZIP code fixed effects. We continue to cluster standard errors on time.

Our dependent variable is the unit-free coefficient of variation of house sale prices in a given month in a given ZIP code. The results are reported in Table 3. In all specifications, we find a positive and significant effect of higher distance to mangroves on the coefficient of variation in the aftermath of the hurricanes. That is, the proximity to mangroves attenuates price dispersion after hurricanes (shorter distance to mangroves means lower price dispersion).

When we break down the effect of hurricanes by counties that are on and off the hurricane path, we find that the increase in price dispersion for properties further away from mangroves is larger for the counties that are off the hurricane path but is also positive and significant for the counties on the hurricane path in the year of the hurricane. In the two years that follow,

[23] Including a separate set of time fixed effects for counties on and off hurricane paths for specific hurricanes does not make any difference in the estimates. These results are available upon request.

the effect of mangroves on price dispersion is about the same in the counties on and off the hurricane path. We find that without controls or ZIP code fixed effects, higher distance to mangroves on average is associated with lower price dispersion, but the sign flips once we include controls, and the coefficient becomes essentially zero once we also include ZIP code fixed effects. Note that the effects of controls also drop when we include ZIP code fixed effects, suggesting these do not vary much over time.

We will use the estimates for the years 2-3 after the hurricane from this last regression (column(4)) to predict the increase in dispersion of the price changes due to the presence of mangroves for our pVaR and WTP analysis. As a robustness tests we also estimated our benchmark price level regression at the ZIP code level and found results that are similar to the property-level regressions (See Table A.9 and A.10).

To help interpret the results, we visualize the mangroves effects across space in Figure 6 of southern Florida, on which our data sample is based. The results from the regressions of the price level and dispersion reported in Tables 1 and 3, without differentiation by the hurricane path, provide the *relative* effects across mangroves distance groups: 0-2km, 2-4km, and so on.[24] When an individual property is located between 2 and 4km to mangroves, the reduction of house sale price is higher on average by 3.25 percentage points (relative to properties right next to mangroves), but this reduction becomes greater if the property is further from mangrove. Similarly, there is an increase in price dispersion as the distance to mangroves increases. Thus the map shows that mangroves proximity has a price level as well as stabilization effects.

5.2 Heterogenity across the width of the mangrove forest

We have shown that the overall effect of mangroves is to stabilize housing price following hurricanes. We now explore it further by focusing on one dimension of heterogeneity: conditional on the same distance of properties from mangroves, how does the width of the mangrove forest affect price declines following hurricanes? This dimension of heterogeneity is of particular interest because it has been demonstrated that mangroves width is important in providing protection from flooding and wind damage. To evaluate the effect, we are focusing on the interaction terms between the width of the mangrove forest and other key variables.

[24]Each hexagon represents an area with 5km of diameter, in which there are housing transactions as reported by the ZTRAX dataset. We interpolate the effects of distance to mangroves into 1km grid to calculate average effect on price level and dispersion for each hexagon.

Estimating equation (5) with additional interaction terms for the flood risk indicators, we compute marginal effect of different groups of mangrove forest width on the price level properties in medium flood risk areas 2 years following hurricanes, controlling for distance to the mangroves. Figure 7 presents a heat map of the effects of both mangroves distance and width 2 years after a hurricane for properties in the medium flood risk areas.[25] We select width groups of mangrove forest to report based on the empirical distribution of the width of Florida mangroves in the sample. We find that properties near thinner banks of mangroves, such as those less than 20 meters wide do experience larger reduction of sale price after a hurricane. Such relative reduction of sale prices dwindles as the width of mangrove forest increases.

In general, the closer properties were to mangroves and the wider are the belts of mangroves, the more sale price benefits a property experiences. In terms of magnitudes, when a property is located within 0-2km from mangroves, and such mangrove forest is between 20-30 meters wide, this property could be sold up to 10% higher in the aftermath of a hurricane than if the distance were 2-4km and the forest width were 10-20 meters. In fact, properties in close proximity to mangroves that are 30 or more meters wide did not experience decline in housing prices 2 years following hurricane Ivan. As the heatmap shows, the effect of every 10 meters of reduction in mangrove forest width is equivalent in magnitude to the effect of an increase in distance to mangroves by 2km.

5.3 Probability Value at Risk

To make further sense of magnitudes and to account for potential benefits of mangroves protection and restoration in terms of the dispersion of housing prices, which is essential to evaluating a private financial benefit of mangroves protection, we turn to the concept of value at risk, which is standard in evaluating risk properties of assets.

To illustrate the concept, we compute a change in the sale price of each property from the last transaction before a given hurricane to the first transaction in the 2nd year following the hurricane. Figure 8 shows the distribution of percentage price changes from before to after each hurricane across properties, by county. Given important housing market dynamics during our sample, including rapid increase prior to 2007 followed by the price collapse in 2008-09, we adjust these price changes by Florida-specific Case-Shiller U.S. National Home Price Index. For illustrative purposes, we select a 25% property loss value as a threshold for the value at risk. Red areas indicate the probability of a loss exceeding this 25% threshold, which is known as probability value at risk, or pVaR. For instance, for

[25] Full regression results are available upon request.

Charlotte county following hurricane Sandy, which did not even pass through Florida, there was a 41% probability of losing more than 25% of house value relative to trend.

Next, we ask how this measure varies with the distance to mangroves. We already have the estimates for how the mean of distribution is affected by the distance to mangroves for counties on and off the hurricane path (column (3) Table 2) and also the effect on the second moment, measured by the coefficient of variation (column (4) of Table 3). Thus we can adjust this empirical distribution of price changes for each hurricane and each county. We calibrate the distribution of price changes based for properties that are are more than 16km from mangroves and for properties that are closer than 2km to mangroves. We then compare the difference in the probability of 25% value loss between properties with and without close mangroves protection.

Figure 9 shows the results by counties and hurricanes. It is evident that the presence of mangroves makes a difference in reducing the probability value at risk of property sale prices. In general, because of the flood risk reduction benefits of mangroves, the regions of significant property value losses (25% or more) are smaller for properties near mangroves than for those far away. In the most prominent cases of Collier or Hillsborough counties after Irma, the decline in pVaR is 7 percentage points. Notably, the effects are observed not only in the counties directly hit by the hurricanes but also in counties where perceived flood risk and perceived benefits of mangroves are affected by experience in the neighboring regions. Not surprisingly, these effects are smaller in magnitude.

5.4 Willingness to Pay

How do we translate pVaR estimated in the previous section to the amount of money those who benefit from mangroves protection should be willing to invest in it? We have to make some parametric assumptions.

Assume a Constant Relative Risk Aversion (CRRA) utility function

$$u(x) = \begin{cases} \frac{x^{1-\gamma}}{1-\gamma}, & \text{if } \gamma \neq 1, \\ \ln(x), & \text{if } \gamma = 1. \end{cases}$$

A homeowner that faces a choice of protecting and not protecting mangroves is essentially facing potential hurricane effects that bring the same losses but with different probabilities (lower probability in case of mangroves). We can simplify our analysis by assuming binary lottery (no loss vs. 25% loss of value) and use our empirical estimates to calculate willingness to pay for the reduction in the probability of a 25% loss.

Thus, without mangroves, the expected utility will be

$$\mathbb{E}[u(W_N)] = (1 - p_N)u(W) + p_N\, u(0.75\, W)$$

W is the value of the property before the hurricane, and p_N is a probability of losing 25% of this value as a result of the hurricane in the absence of mangroves.

Certainty equivalent of this lottery is

$$CE_N = \begin{cases} ((1 - p_N)W^{1-\gamma} + p_N(0.75\, W)^{1-\gamma})^{\frac{1}{1-\gamma}}, & \text{if } \gamma \neq 1, \\ W^{1-p_N}(0.75\, W)^{p_N}, & \text{if } \gamma = 1. \end{cases}$$

Similarly for the case with mangroves protection,

$$\mathbb{E}[u(W_M)] = (1 - p_M)u(W) + p_M\, u(0.75\, W)$$

where $p_M < p_N$ is the pVaR with mangroves protection.

$$CE_M = \begin{cases} ((1 - p_M)W^{1-\gamma} + p_M(0.75\, W)^{1-\gamma})^{\frac{1}{1-\gamma}}, & \text{if } \gamma \neq 1, \\ W^{1-p_M}(0.75\, W)^{p_M}, & \text{if } \gamma = 1. \end{cases}$$

The willingness to pay for mangroves protection will then be

$$WTP = CE_M - CE_N.$$

The results of these calculations are reported in Figure 10. We can see that for cases such as Collier county following hurricane Irma, where the probability of losing 25% of house value is 36 percent for properties not protected by the mangroves, and drops by 7 percentage points for properties near mangroves, the owner (or the insurer) of the 1-million-dollar property should be willing to pay about 60 thousand dollars for mangroves protection and restoration.

6 Robustness Tests

We have conducted analysis of alternative specifications to check for robustness of the headline estimation that exploits property-level fixed effects.

Disaggregation by hurricane and year. In the benchmark we use the measure of generalized major hurricane events. As robustness check, we repeat the estimation in equation (1), but with indicator variables of Ivan, Sandy, and Irma included (instead of the aggregate hurricane variable). The results are consistent with Table 1. Tables A.5 and A.6 show the estimations in which each hurricane is included separately and we also use 1-year intervals following hurricanes. We see that there is almost no differences with the benchmark results.

Distance to the coast. One potential concern of the baseline specification is that we do not explicitly account for distance to coast, and the mangroves distance measure used potentially captures coastal distance—in other words, the price benefit shown in the baseline regression could in fact be showing amenity value of proximity to the coast.[26] To assuage such concerns, we use an alternative specification: instead of linear measure, we use an indicator variable of mangroves presence. Additionally, we include the linear distance of properties to coast, in addition to property-level co-variates such as property age and square footage to account for property characteristics.

In this specification, the mangroves indicator variable is equal to 1 if a property is located within 500 meters of mangroves. Table A.7 shows the results of the estimation. Similar to what results in Table 1 suggest, the results here show that mangroves proximity by itself increases the property sale price. Additionally, in majority of the cases, when taking into account hurricane shocks, the price stabilizing effect of mangroves continue to be true, which are consistent with results in our main specification. In terms of magnitude of effects, the coefficients in Table A.7 are larger, which makes sense as here we are comparing properties close to mangroves with all other properties (as opposed to effects of relative mangroves distance in Table 1).

Price per square foot. Another concern is with potential heterogeneity of property sizes. So far we have only considered the effects of mangroves on the overall sale prices of properties. In our benchmark specification, the direct effect of property size on price is absorbed by the property fixed effects and in the aggregate regressions we control for the property square footage. That said, it is worth verifying property heterogeneity is not affecting our results. Table A.8 shows the results of mangroves effect on the price per square foot. The signs of coefficients are fully consistent with the specification in which the dependent variable is the overall price.

[26] Potential multicollinearity is the main reason of not including both mangroves distance and coast distance interactions with hurricane indicators in the same regression.

Specification and subsample. The benchmark results are also robust to alternative specifications and to analysis of different subsamples. Tables A.11 and A.12 show the results that use property sale volume as analytical weights in the estimation. There are almost no differences with the benchmark. Additionally, since our sample covers years that include the 2008 Financial Crisis, there could be concerns about the sensitivity of the results. To address this, we repeated the benchmark estimation by excluding observations for years 2007 to 2009, and the results are shown in Table A.13. There are no meaningful differences with the benchmark.

Additional controls: insurance and climate beliefs. We also test whether the baseline results may change if we include controls that are not captured by property fixed effect or time fixed effect. We collected data from FEMA's National Flood Insurance Program (NFIP) and from Yale Climate Belief data.

Ex ante, it is unclear whether flood insurance, as a tool for climate adaptation, may offset or amplify the effect of mangroves. We have included the variable of ZIP code-level flood insurance coverage (lagged by 1 year) into the benchmark regressions.[27] Table A.14 and Table A.15 show that the inclusion does not change the benchmark results, and the coefficients of NFIP insurance coverage are generally null. The more interesting part is the interaction term between insurance coverage and on-path mangroves distance variable: the magnitudes are extremely small but significant; the interaction terms for after the hurricanes are negative. This means when insurance coverage is high, being further from the mangroves reduces housing prices even more. Thus after hurricanes, insurance coverage does not substitute for mangroves proximity. In fact, insurance coverage may serve as a mechanism of flood risks to increase awareness of the importance of being near mangroves for new home buyers.

From the Yale Climate Belief data, we have chosen the variable measuring the degree to which people in a county believe that climate change will harm them personally. It is important to note that the belief data we have access to starts from 2014, and the resulting sample is a subset of the benchmark sample. The results are reported in Table A.16. In terms of the mangrove-related coefficients, we do not find significant differences in terms of the direction of impact with the benchmark results. In relation to the belief variable, it does not appear significant in Table A.16. In short, climate beliefs heterogeneity does not affect the relationship between mangroves and housing prices.

[27] We cannot merge the NFIP data to our sample at property level, since the public version of NFIP does not identify specific properties.

7 Conclusion

Preserving nature and biodiversity is now one of the foremost concerns of the policymakers worldwide. The problem with financing the preservation and restoration of nature and biodiversity, however, is their quintessential public good nature. Unfortunately, governmental and non-profit resources are not sufficient for the needed investments. Thus, it is key to attract private capital to finance preservation of these resources. Attracting private capital requires quantification of private benefits of natural resources so that a case can be made for structured financial instruments and public-private partnerships. One such benefit of nature is its contribution to reducing climate-related risks.

While nature-based climate adaptation solutions have been shown in natural sciences and engineering literature to have flood risk reduction benefits, there are limited studies that explicitly measure the financial value of such benefits with market-based evidence. In this paper, we help fill the gap by demonstrating the financial benefits of mangroves in stabilizing property values following hurricanes. Using the Florida housing market as the study setting, we identify the mangroves effect by comparing the effect of hurricanes on sale prices of properties close to mangroves versus those that are not. We find that on average, after a major hurricane, properties 2-4km away from mangroves experience an additional loss of around 3.3% of value relative to properties near mangroves. The price effect difference increases even more (to over 15%) when properties are further than 16km away from mangroves. Moreover, mangroves protection reduces prices dispersion following hurricanes. These changes result in as much as 7 percentage points reduction in the probability of losing more than 25% of the property value following a hurricane. This is a substantial benefit of mangroves presence to property owners and insurers. An owner or insurer of a 1-million dollar property in this case would be willing to pay 40-80 thousand dollars, depending on the initial risk of value loss, for preserving or restoring mangroves nearby.

Additionally, we take into consideration how the effect can vary by the width of the mangrove forest. In coastal engineering studies, wider belts of mangroves have been found to be important in reducing wave and surge impact. Unsurprisingly, our analysis finds that properties close to wider mangrove forest experience greater price stabilization benefits after hurricanes. The results demonstrate the financial benefits of restoring mangroves on the intensive margin.

These private financial benefits of mangroves are only one component of their overall benefits to flood reduction, ecosystem services, and biodiversity. We do not conduct a full cost-benefit analysis of mangroves protection and restoration, but our results are important in demonstrating private benefits that may help secure private funding of mangroves protection and restoration efforts as well as inform policy decisions on how funding of such efforts can be structured.

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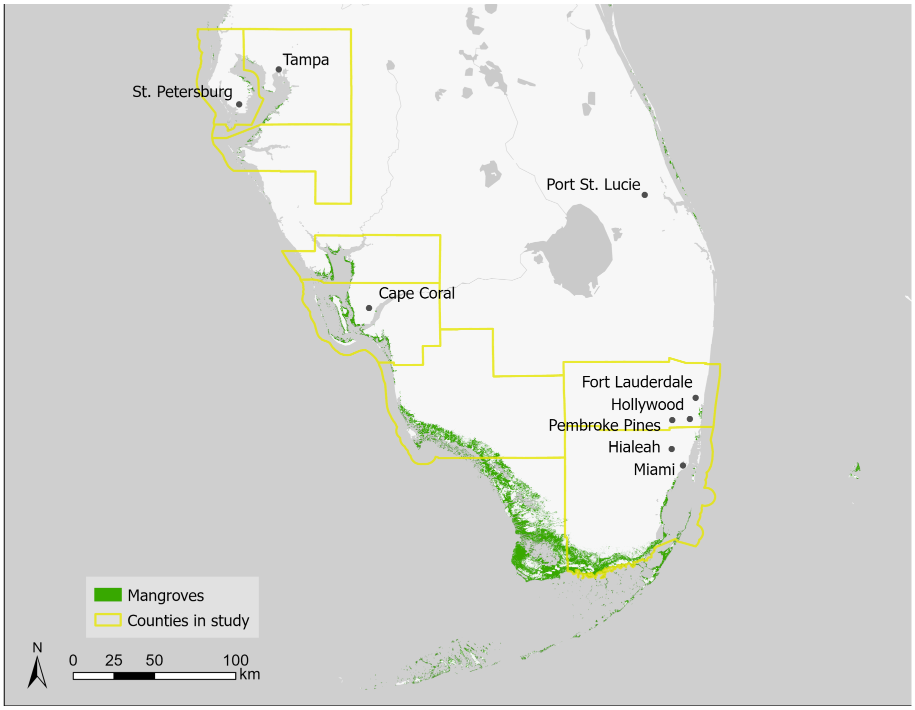
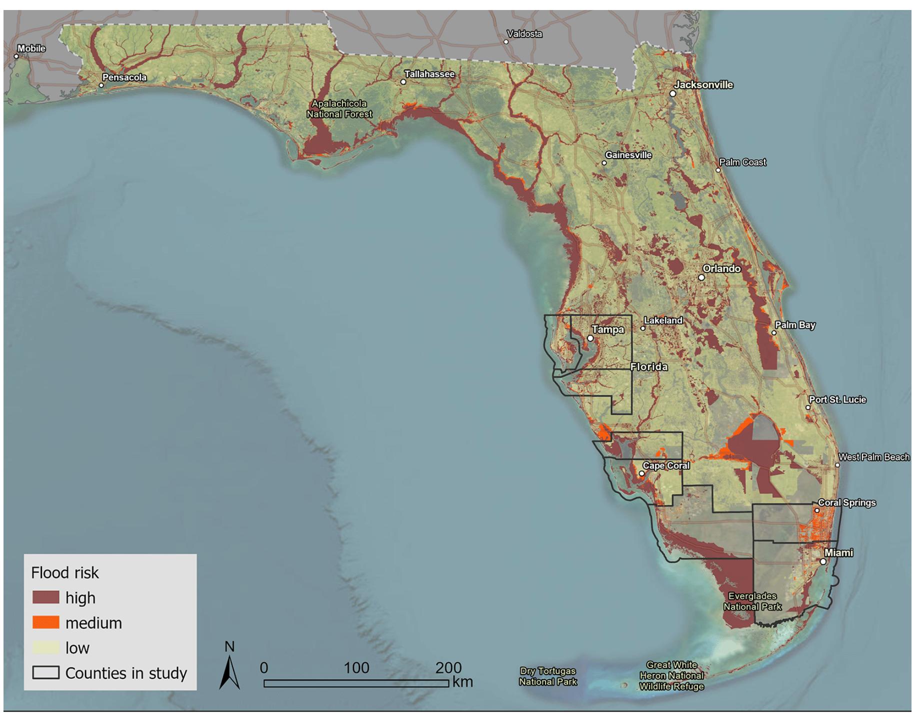
Figure 1: Mangroves Distribution in Florida: Select counties in 2020



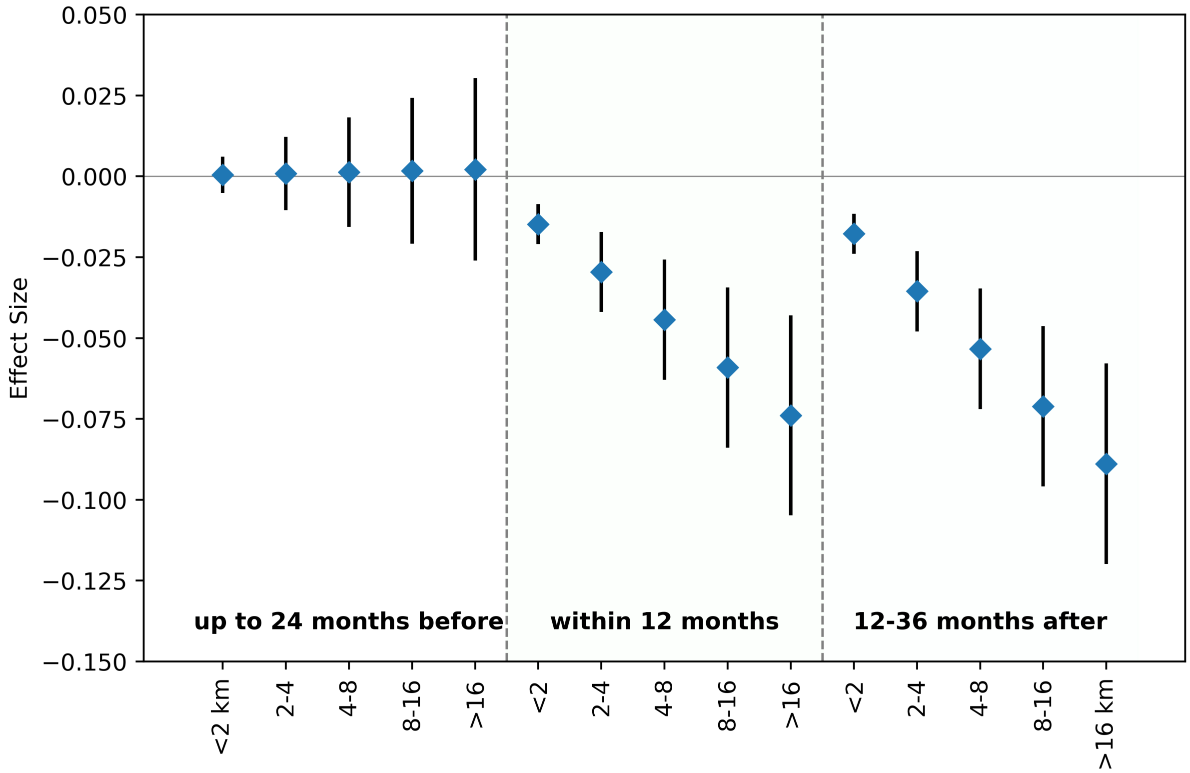
Source: Global Mangrove Watch.

Figure 2: Flood Risk Map: 2020



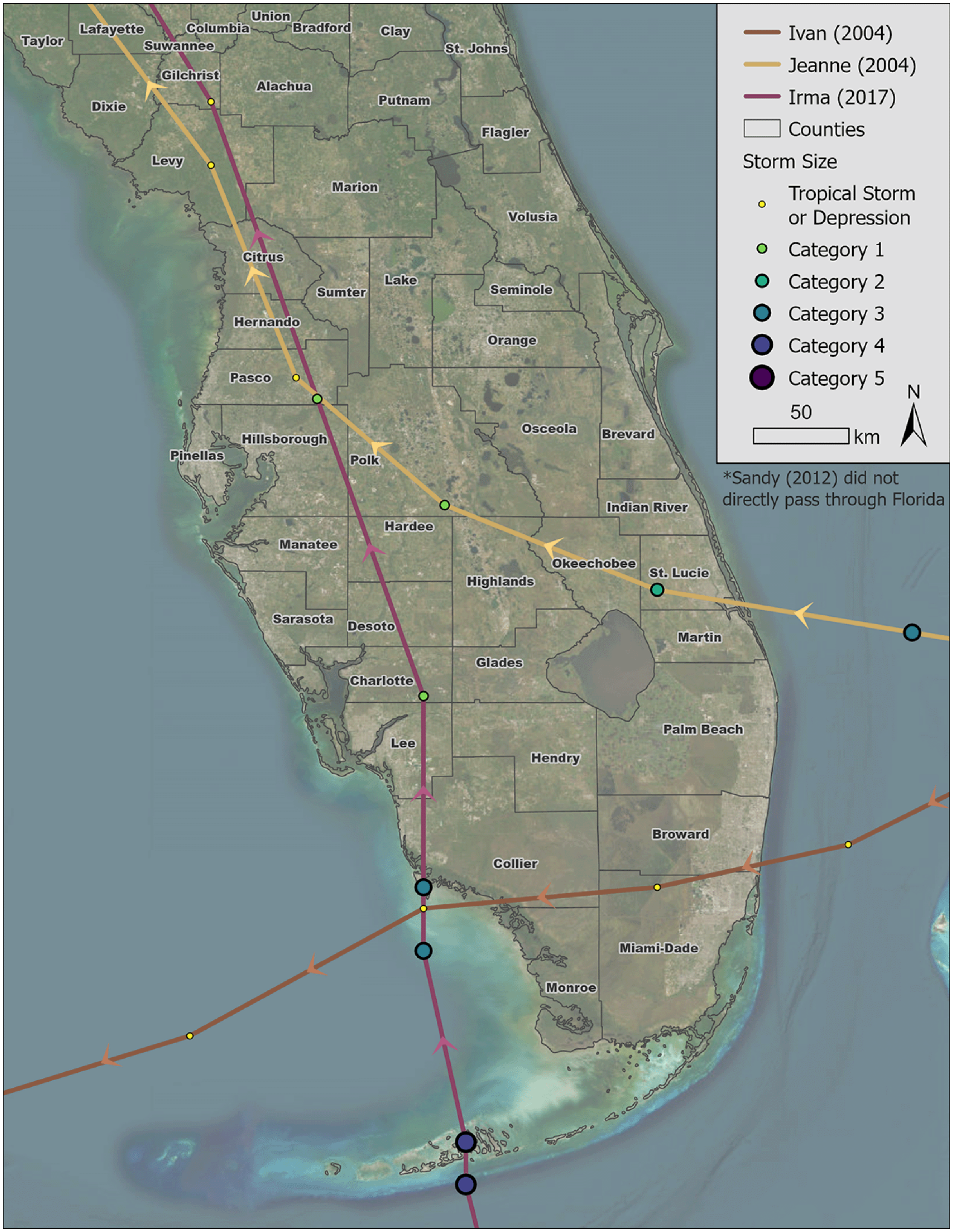
Notes: Risk from the associated flood zones from FEMA Flood Hazard Layer.

Figure 3: Mangroves Effects on Housing Sale Prices Following Hurricanes



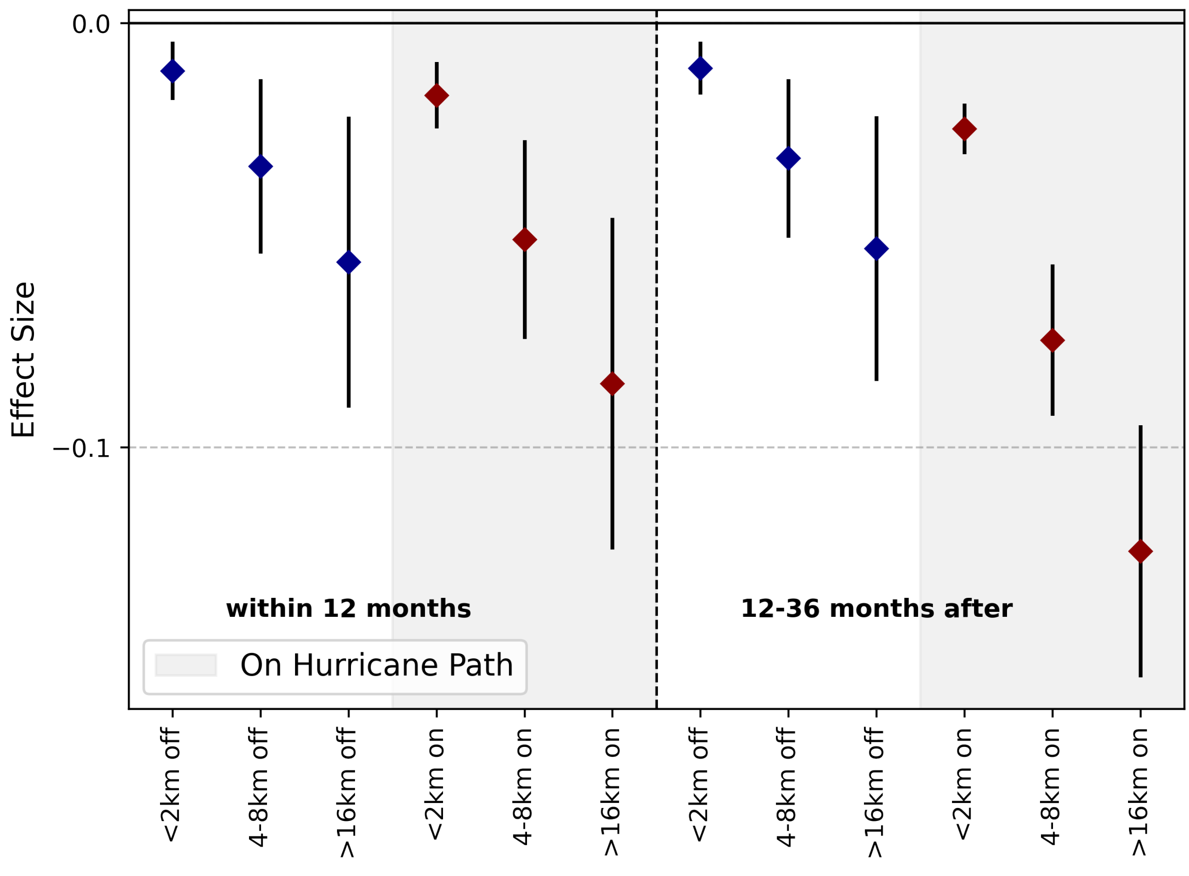
Notes: The horizontal axis shows the distance (in kilometers) between properties and mangroves. Plotted are coefficients and standard errors from column (4) of Table 1 that estimates equation 1.

Figure 4: Hurricane Paths



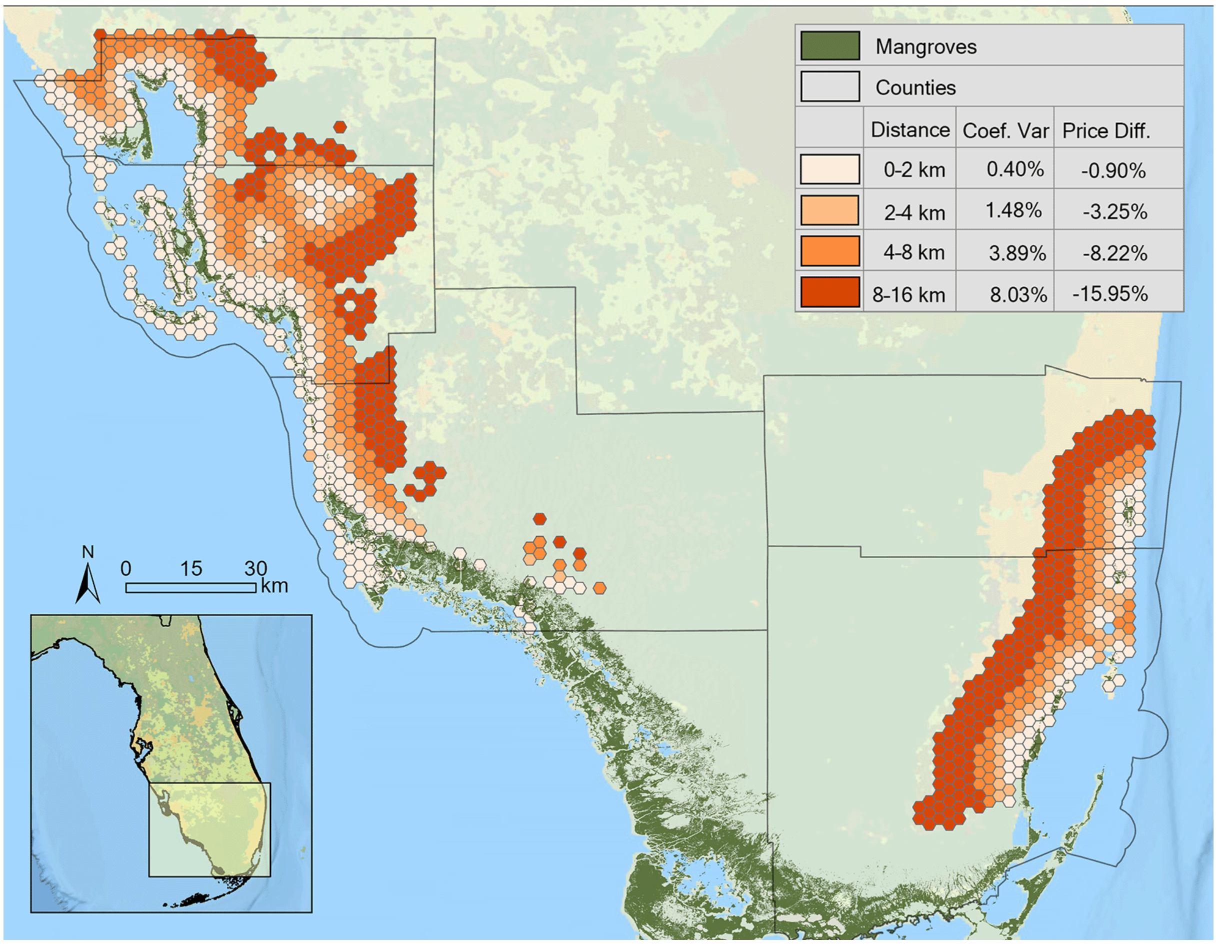
Notes: The graph illustrates the paths of hurricanes examined in this paper. Sources: National Hurricane Center, NOAA; North Carolina Institute for Climate Studies.

Figure 5: Mangroves Effects on Housing Sale Prices Following Hurricanes, Accounting for on or off Path



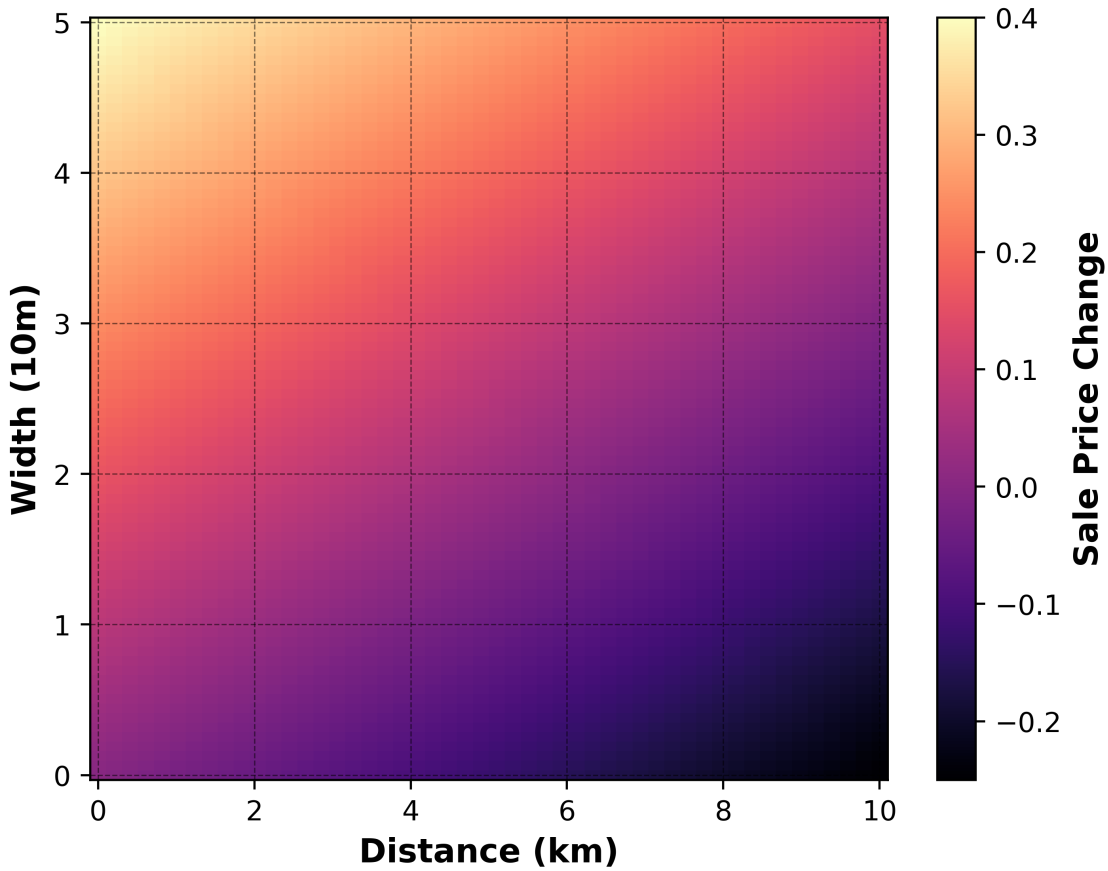
Notes: The horizontal axis shows the distance (in kilometers) between properties and mangroves. Plotted are coefficients and standard errors from column (3) of Table 2 that is estimates equation 3 and differentiates between counties on and off the hurricane paths.

Figure 6: Map—Mangroves Stabilize Housing Sale Prices Following Hurricanes



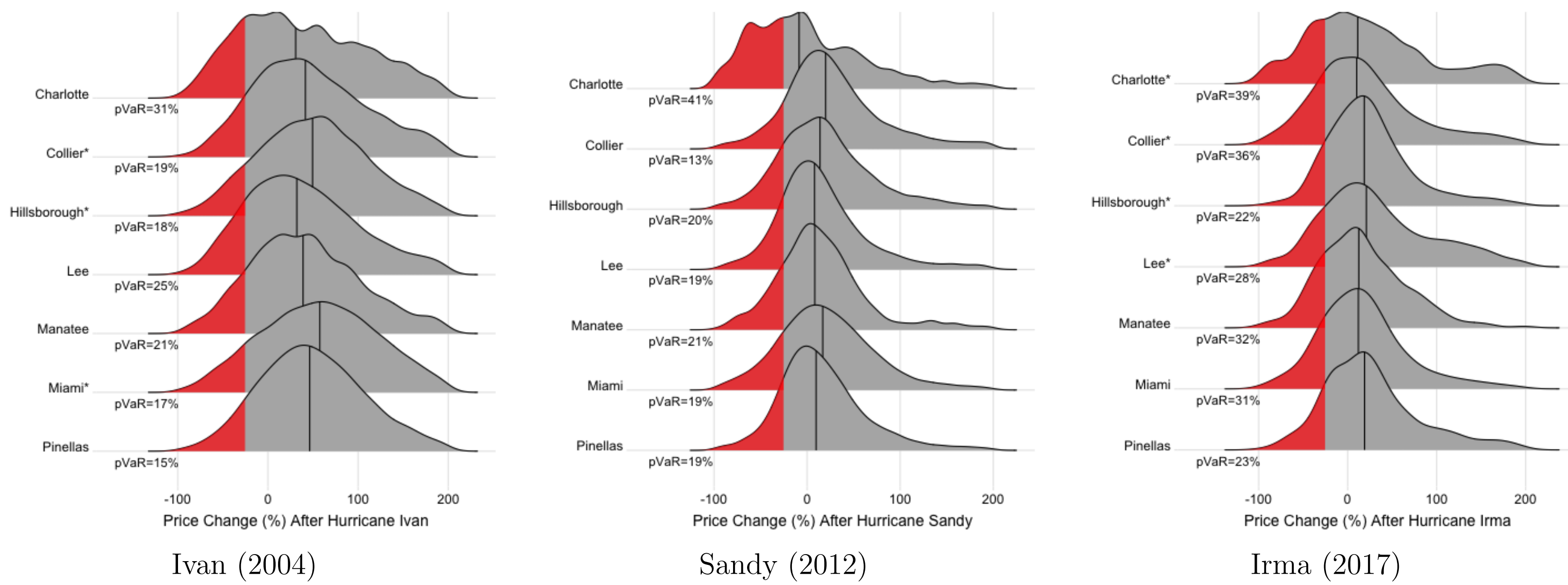
Notes: The numbers are computed from estimates reported in Table 1 column (4) and Table 3 column (3). "Price Diff." refers to the relative difference of prices between properties by mangroves proximity after a hurricane hit. Closer proximity to mangroves results in smaller sale price reductions following a hurricane. "Coef. Var" refers the price dispersion reduction effect of mangroves. Closer proximity to mangroves results in smaller sale price volatility following a hurricane. The results reported are relative percentage differences between distances. The reference baseline case is a property with nearly 0km distance to mangroves.

Figure 7: Effect of Mangroves Distance and Width on Sale Price, Medium Risk Areas



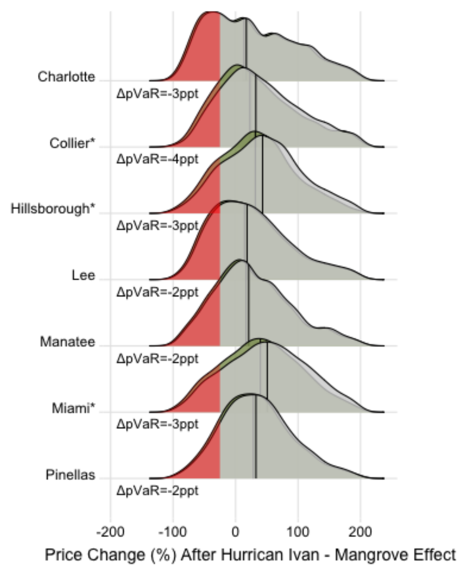
Notes: Proximity to mangroves in combination with greater mangroves width generally result in more positive sale price changes following hurricanes. Results are based on estimation for Hurricane (year 2) for counties on the path in medium risk areas, and a linear combination of mangroves distance (interact with hurricane) coefficient and mangroves width 10m coefficient. We choose coefficient for mangroves with 10 meter width because it is at the lower end of mangroves width empirical distribution, namely a lower threshold to meet in order for the width benefits to take effect. The unit of measurement of effect here is the log of sale price.

Figure 8: Probability Value at Risk after Hurricanes

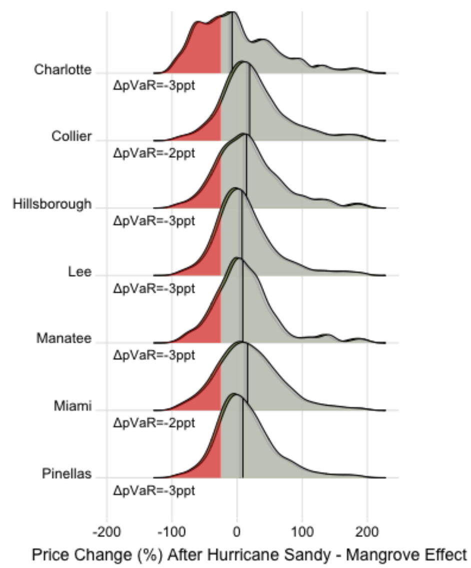


Notes: County names with asterisks refer to those on the hurricane path. Price changes of properties in FEMA-designated medium flood risk zones, adjusted using Florida-specific Case-Shiller U.S. National Home Price Index. The effect refers to the 2nd year after the hurricanes, in this case Sandy. The red region refers to a loss of 25% or more, and $pVaR$ refers to the cumulative density of this region.

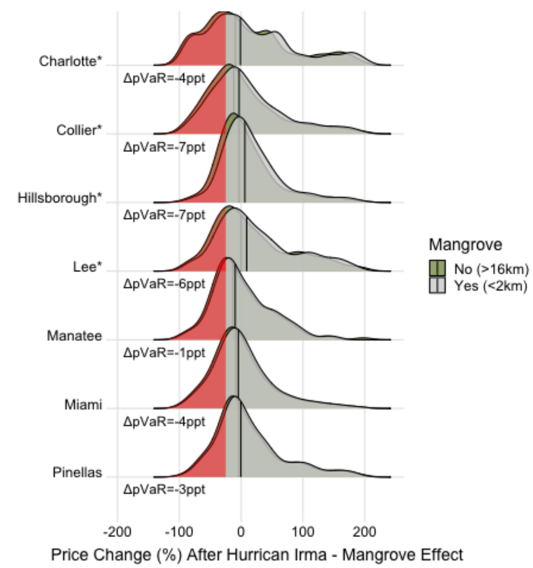
Figure 9: Mangroves Reduce Probability Value at Risk after Hurricanes



Ivan (2004)



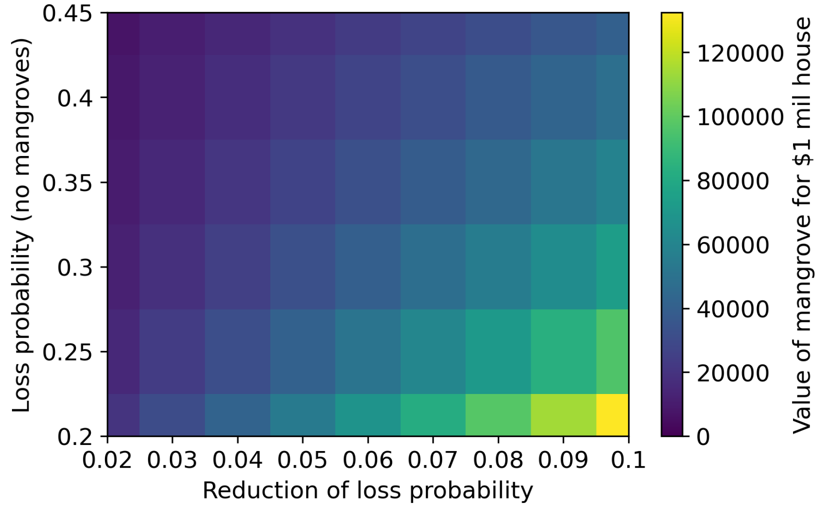
Sandy (2012)



Irma (2017)

Notes: County names with asterisks refer to those on the hurricane path. Price changes of properties in FEMA-designated medium flood risk zones, adjusted using Florida-specific Case-Shiller U.S. National Home Price Index. The red region refers to a loss of 25% or more. ΔpVaR represents the differential of the cumulative density between mangroves and no mangroves case–a negative value means pVaR is reduced because of mangroves presence.

Figure 10: Willingness to pay for mangrove risk reduction



Notes: Willingness to pay for reducing the probability of losing 25% of housing value following hurricanes. Calculations assume CRRA untility function with $\gamma = 3$. For instance, if the pVaR of a $1 million dollar property is over 38% (vertical axis), and mangroves reduce the probability of loss (horizontal axis) by 7 percentage points, then the willingness to pay for mangrove protection is $60,000.

Table 1: Effect of Mangroves on House Sale Prices after Hurricanes

	Dependent variable is Log(Sale Price)				
	(1)	(2)	(3)	(4)	(5)
Mangrove Distance ×	0.001			0.000	0.013***
I(2 years before hurricane)	(0.002)			(0.003)	(0.003)
Mangrove Distance ×		-0.009***		-0.015***	-0.013***
I(1 year after hurricane)		(0.002)		(0.003)	(0.003)
Mangrove Distance ×			-0.014***	-0.018***	-0.003
I(2-3 years after hurricane)			(0.003)	(0.003)	(0.003)
Trend × Mangrove Distance					-0.002***
					(0.000)
R^2	0.714	0.714	0.714	0.714	0.714

Note: Equation (1) estimation results for medium flood risk properties in the data. Time and property fixed effects are included in all regressions. Robust standard errors clustered on time are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 1171460.

Table 2: Effect of Mangroves on Prices after Hurricanes: Accounting for Hurricane Path

	Dependent variable is Log(Sale Price)		
	(1)	(2)	(3)
Mangrove Distance × I(1 year after hurricane)			
On hurricane path	-0.011***		-0.017***
	(0.003)		(0.004)
Off path	-0.006*		-0.011***
	(0.003)		(0.003)
Mangrove Distance × I(2-3 years after hurricane)			
On hurricane path		-0.021***	-0.025***
		(0.003)	(0.003)
Off path		-0.007**	-0.011***
		(0.003)	(0.003)
R^2	0.714	0.714	0.714

Note: Equation (3) estimated for medium flood risk properties in the data. Time and property fixed effects are included in all regressions. Robust standard errors clustered on time are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 1171676.

Table 3: Effect of Mangroves on Price Dispersion after Hurricanes

	Dependent variable is coef. of variation of sales price			
	(1)	(2)	(3)	(4)
Mangrove Distance ×	0.009***	0.003	-0.001	
I(2 years before hurricane)	(0.002)	(0.003)	(0.003)	
Mangrove Distance	0.006*	0.010**	0.010**	
I(1 year after hurricane)	(0.002)	(0.003)	(0.003)	
Mangrove Distance	0.011***	0.009**	0.008*	
I(2-3 years after hurricane)	(0.003)	(0.003)	(0.003)	
Mangrove Distance × I(1 year after hurricane)				
On hurricane path				0.005
				(0.004)
Off path				0.013*
				(0.004)
Mangrove Distance × I(2-3 years after hurricane)				
On hurricane path				0.008**
				(0.003)
Off path				0.007**
				(0.003)
Mangrove Distance	-0.010***	0.005**	0.002	0.003
	(0.002)	(0.002)	(0.005)	(0.005)
Median distance to the coast		-0.004***	0.002	0.002
Median elevation		0.022***	-0.002	-0.002
Median property age		0.001***	0.000*	0.000*
Median property size		0.000	0.000	0.000
Residence type indicators	YES	YES	YES	YES
Zipcode Fixed Effect	NO	NO	YES	YES
R^2	0.023	0.139	0.226	0.227
Observations	76559	45063	45060	45060

Note: Dependent variables: Coefficient of variation of sale prices at ZIP code level. Results estimated from Equation (2) and include controls for ZIP code level averages of property characteristics: $\sigma_{zt}/\mu_{zt} = \xi m_z + \beta'(m_z \times H_{zt}) + \gamma' X_z + \delta_c + \delta_t + \epsilon_{zt}$. Robust standard errors clustered on time are in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

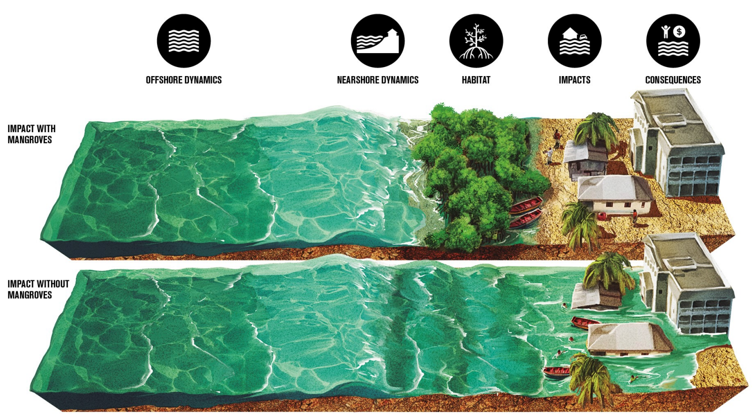
A Appendix

Appendix A.1 Mangroves Illustrations

Figure A.1: Mangrove Forest

Notes: A typical coastal mangrove forest. Photo used is under CCL and sourced from wikimedia.

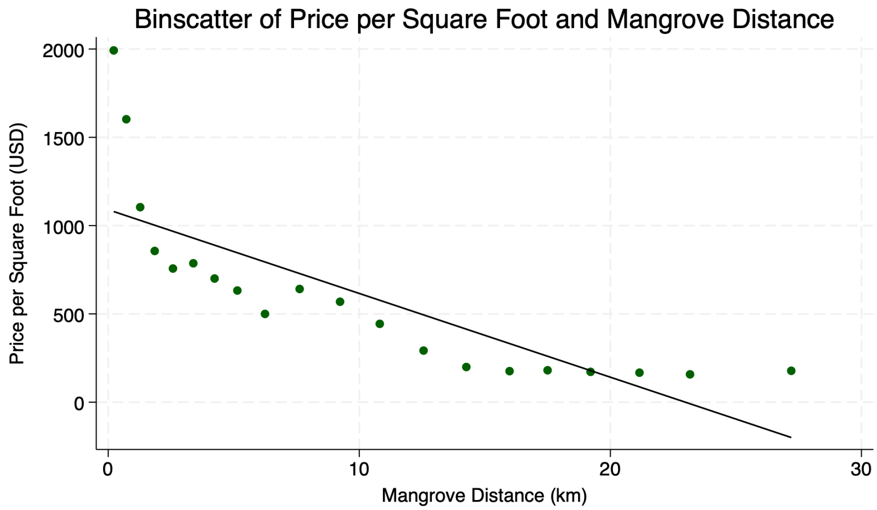
Figure A.2: Illustration of the protective effect of mangroves



Notes: The graph illustrates how mangroves reduce flood risks. Photo used is under CCL and published in "Forces of Nature: Coastal Resilience Benefits of Mangroves in Jamaica" (source link)

Appendix A.2 Descriptive Results

Figure A.3: Scatterplot of Housing Price and Mangroves Distance



Notes: Controlling for Florida-specific housing price index.

Appendix A.3 Data Details

Table A.1: Data source table

Data type	Scale or Resolution	Coverage	Years	Source
Houses	Interpolated property address	Florida	1993-2022	ZTRAX
County lines	7.6 foot accuracy	National	2016	TIGER
Elevation map	10 meter cells	Florida	2022	USGS
Coastline	167 foot accuracy	National	2018	USGS
Mangroves	30 meter cells	Global	1996-2020	GMW
Flood risk zones	60 foot accuracy	National	2020	FEMA
Mangroves width	2.22e-4 degree cells	National	2020	GMW

We have used a variety of GIS data to evaluate the effects of mangroves distance and width on housing transaction prices. More specifically, as shown by Table A.1, there are 3 main types of data: 1. housing; 2. mangroves distance and width; 3. flood risk zones. All geo-processes are completed in ArcGIS Pro (v3.1.0) using Python. The process is a batch run spatial analysis that adds landscape attributes to each Zillow housing transaction in this study. The attributes gathered include housing elevation, distance to mangroves, and distance to coastlines. The ArcPy library (v3.1) provides functions to convert a table of the transaction data into spatially explicit points based on their latitude and longitude, spatially join these points to landscape attributes, and export the tabulated results.

Housing Zillow transactions tables contain sale details and locations for the sold homes in the study area from 1993 to 2019. County geographic data are from the 2020 year Census, and enable us to group transactions by county U.S. Census Bureau (2022). Elevation data from the USGS 3D Digital Elevation Program was from U.S. Geological Survey (2020). Housing data was converted into mapped points using the display X, Y data function using their latitude and longitude fields (WGS84). These houses were intersected with county linework using a spatial join between houses that are within a county polygon U.S. Census Bureau (2022). Elevation data was joined with the transactions using the raster to points function.

Mangroves Distance Global Mangrove Watch data included 30-meter resolution mangroves coverage for select years between 1996 and 2020 Bunting et al. (2022). This mangroves feature describes presence and absence to help researchers identify coverage changes. The National Hydrography Dataset contains detailedinformation for all records where the parent feature is coastline ($PARENT_FEA =$ Coastline) U.S. Geological Survey (2018). The distances between each housing transaction and landscape level attributes was calculated with a spatial join. These spatial joins recorded the geodetic distance between a housing feature and the closest mangroves and coastline feature. All this information was exported as a table for subsequent analysis outside ArcGIS Pro using the export table function. An overview of the complete workflow (in diagrams) is available upon request.

Mangroves Width Our approach focuses on the mangroves closest to a property, rather than calculating what is between houses and the coastlines. Engineering studies use mangroves width measures between communities and coastline because it predicts storm surge and inundation mitigation De Dominicis et al. (2023). In the literature, these widths have been calculated as either the length of mangroves covering the shortest distance from a community to the coastline Del Valle et al. (2020); Das and Vincent (2009), the mangroves area normalized by coastline length Hochard et al. (2021), or the mean cross-shore mangroves width Heatherington and Bishop (2012); Montgomery et al. (2018). An overview of the complete workflow (in diagrams) is available upon request.

Flood Zones Flood zones are collected from the FEMA Flood Hazard Layer,Federal Emergency Management Agency (2020). Properties in this study are classified into three categories of flood risk, low, medium, high, based on their flood zone and its subtypes (as defined by FEMA's flood zone data table). High risk category is indicated by a flood zone of AE or VE, low risk areas is designated as a zone of "Area of Minimal Flood Hazard".

Medium areas contain all other flood zones.

Appendix A.4 Temporal Variation of Mangroves

Table A.2: Summary Statistics: Change (%) in Property-Mangroves Distance (1996 through 2020)

Percentile	Max year to year change (%)	Longitudinal Change (%)
5th Percentile	0	0
25th Percentile	0	0
50th Percentile (Median)	0	0
75th Percentile	0.08	0.02
95th Percentile	2.5	1.9
Mean	1.1	1

Appendix A.5 Effect of Flood Risk

We account for the *ex ante* flood risk using National Flood Hazard Layer (NFHL) data.[28] The NFHL flood risk data not only provides information on the underlying flood risks, but it is likely to affect housing sale prices due to variety of regulatory implications. For instance, one key pricing mechanism that arise would be the insurance requirement: if properties are located in the high risk zone and if they have federally-backed mortgages or are financed by federally regulated lenders, they are required to have at least federal flood insurance.[29]

While such mandatory insurance policy has potentials of protecting homeowners against losses, it is also likely to distort property prices. There is a small but growing literature that document such unintended consequences on housing affordability, when areas become designated as high flood risk zones. For example, Blickle and Santos (2022) show that becoming designated as high risk potentially reduce mortgage originations, especially for lower-income borrowers. Additionally, Sastry (2022) documents that banks are incentivized to shift the burden of risks to federal agencies. More importantly, banks optimize their risk exposure by rationing credit through reducing loan-to-value (LTV) ratio of mortgage, which results in the composition of borrowers shifting towards groups with higher credit scores or higher income.

With this institutional context, we show the results of estimation from Equation (1), disaggregated by the flood risk zones and by the major hurricane events we examine. The

[28]See Appendix A.3 for the detailed discussion of the floodzone definitions we use.

[29]https://www.benefits.gov/benefit/435

Table A.3: Effect of Mangroves on Prices by Flood Risk

	Low flood risk			Medium flood risk			High flood risk		
	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ivan*Distance	-0.01***	0.02***	0.01***	-0.01**	-0.04***	-0.04***	-0.02***	-0.04***	-0.02*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Sandy*Distance	0.01**	0.01***	-0.02***	-0.01*	-0.01*	0.00	-0.04***	-0.04***	-0.02**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Irma*Distance	-0.05***	-0.04***	-0.03***	0.01***	-0.03***	-0.04*	0.02***	0.01	-0.04
	(0.00)	(0.00)	(0.01)	(0.00)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)
Flood risk			–			-0.26			-0.52*
			–			(0.16)			(0.21)
Property FE									Yes
Year-Month FE									Yes
R-squared									0.79
N									4048657

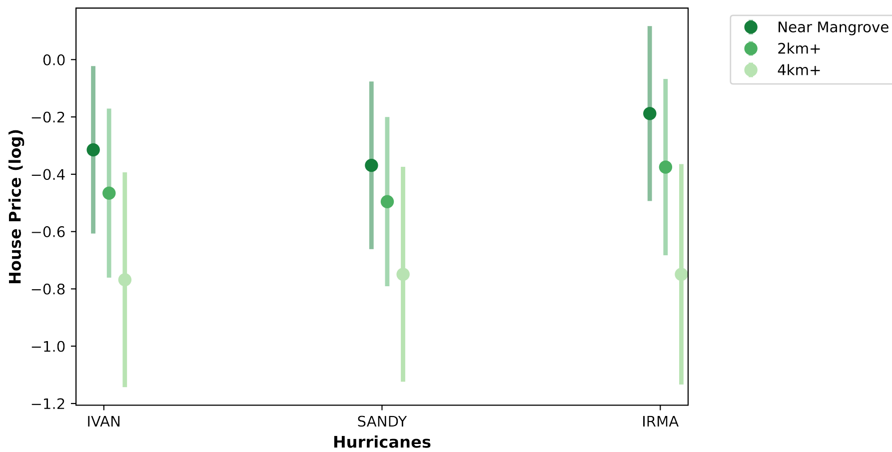
Note: Dependent variables: log of sale prices. Results estimated from the following equation for all properties in the data: $log(P_{it}) = \beta'(m_i \times H_{it}) + \lambda'_1(H_{it} \times High_i) + \lambda'_2(H_{it} \times Med_i) + \eta'_1(m_i \times H_{it} \times High_i) + \eta'_2(m_i \times H_{it} \times Med_i) + \delta_i + \delta_t + \epsilon_{it}$, where $High_i$ and Med_i are indicator variables of whether a property is located in a high or medium risk area, respectively. Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

results are reported in Table A.3. It helps to visualize them as shown in Figures A.4 and A.5. We can see evidence of reduction in price of the medium flood risk properties that are further away from compared to similar properties with proximity to mangroves. For instance, after Hurricane Ivan, the averted value loss of properties near mangroves is almost 10 percentage points compared to those over 2 kilometers away from mangroves. This pattern is consistent across different hurricane incidents.

In contrast, for high-risk flood zones there is no discernible effect of the distance to mangroves. One possible explanation is that in high flood-risk areas, the insurance requirement and the actual insurance coverage already cover potential losses or rebuilding costs and therefore hurricanes realizations have little effect on property prices. While mangroves protects these properties in the first place from damages, financial support from insurance payouts may have aided the reconstruction of these properties—both may have resulted in almost equivalent outcomes and potentially housing valuation after a natural disaster. Another potential mechanism at work is that because of the additional financing and insurance burden, the bidding intensity for properties is lower than it otherwise would be in high-risk areas. So the closing or final sale prices of such properties are lower than they otherwise would be. In this case, the expected financial benefits of mangroves presence in flood risk reduction is outweighed or crowded out by the overall financial costs.

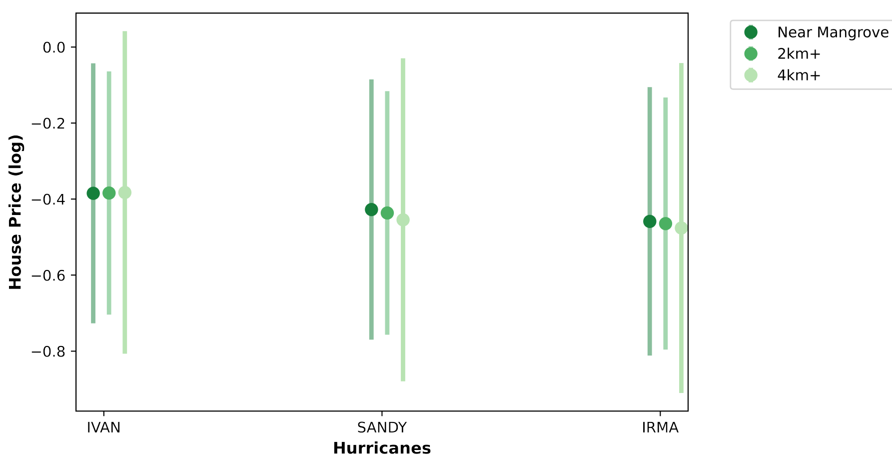
For these reasons, in our analysis, we rely on the estimates for medium flood risk properties. Table A.4 presents results disaggregated by hurricanes and interacted with each flood risk level, estimated on the full sample of our data.

Figure A.4: Mangroves and Price, Moderate Flood Risk Zone



Notes: Results are a linear combination of hurricane effect, mangroves distance effect, and their interaction terms. The results are from coefficients in Table A.3. Specifically, when calculating the medium-risk results, we estimate the linear combination of the triple interaction term of mangroves distance (adjusted for the distance examined), hurricane, and flood risk zone variables, plus the double interaction terms among these variables, and their main effect terms.

Figure A.5: Mangroves and Price, High Flood Risk Zone



Notes: Results are a linear combination of hurricane effect, mangroves distance effect, and their interaction terms. The results are from coefficients in Table A.3. Specifically, when calculating the high-risk results, we estimate the linear combination of the triple interaction term of mangroves distance (adjusted for the distance examined), hurricane, and flood risk zone variables, plus the double interaction terms among these variables, and their main effect terms.

Table A.4: Effect of Mangroves by Flood Risk, Hurricane, and Year

	Low flood risk			Medium flood risk			High flood risk		
	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ivan*Distance	-0.01***	0.01***	0.01***	-0.01***	-0.04***	-0.04***	-0.02***	-0.04***	-0.02***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Sandy*Distance	0.00	0.00	-0.01***	-0.01**	-0.00	0.00	-0.04***	-0.04***	-0.02**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Irma*Distance	-0.05***	-0.04***	-0.04***	0.00	-0.03***	-0.03*	0.01**	0.01	-0.04
	(0.00)	(0.00)	(0.01)	(0.00)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)
Ivan			–	0.07***	0.11***	0.11	0.22***	0.15***	0.06***
			–	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Sandy			–	0.07***	0.06***	0.07***	0.15***	0.15***	0.12***
			–	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Irma			–	0.02	0.15***	0.14*	-0.06***	-0.06**	-0.02
			–	(0.02)	(0.02)	(0.06)	(0.01)	(0.02)	(0.05)
Flood risk			–			0.11			-0.04
			–			(0.14)			(0.18)
Property FE									Yes
Year-Month FE									Yes
R-squared									0.79
N									4048657

Note: Dependent variables: log of sale prices. Closer proximity to mangroves results in smaller sale price reduction following a hurricane. A larger value in variable "distance" indicates further distance from mangrove. Results estimated for all properties in the data from equation: $log(P_{it}) = \beta'(m_i \times H_{it}) + \lambda_1'(H_{it} \times High_i) + \lambda_2'(H_{it} \times Med_i) + \eta_1'(m_i \times H_{it} \times High_i) + \eta_2'(m_i \times H_{it} \times Med_i) + \delta_i + \delta_t + \epsilon_{it}$. Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Appendix A.6 Robustness test tables and analysis disaggregated by hurricanes and years

Table A.5: Effect of Mangroves on Prices after Hurricanes by Year

	(1) Sale Price (log)	(2) Sale Price (log)	(3) Sale Price (log)	(4) Sale Price (log)
Mangrove Distance ×	0.000			0.005
I(2 year before hurricane)	(0.002)			(0.003)
Mangrove Distance ×	0.001			-0.011**
I(1 year before hurricane)	(0.003)			(0.004)
Mangrove Distance ×		-0.009***		-0.021***
I(1 year after hurricane)		(0.002)		(0.004)
Mangrove Distance ×			-0.015***	-0.020***
I(2 year after hurricane)			(0.003)	(0.004)
Mangrove Distance ×			-0.013***	-0.016***
I(3 year after hurricane)			(0.003)	(0.004)
R^2	0.714	0.714	0.714	0.714

Note: The negative coefficients of the interaction variables means that closer proximity to mangroves results in smaller sale price reduction following a hurricane. Results estimated from Equation (1) $log(P_{it}) = \beta'(m_i \times H_t) + \delta_i + \delta_t + \epsilon_{it}$ for medium flood risk properties in the data. Time and property fixed effects are included in all regressions. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 1171460.

Table A.6: Effect of Mangroves on Prices after Hurricanes: hurricane path effects by year

	(1) Sale Price (log)	(2) Sale Price (log)	(3) Sale Price (log)	(4) Sale Price (log)
Mangrove Distance × I(1 year after hurricane)				
On hurricane path		-0.011***		-0.046***
		(0.003)		(0.004)
Off path		-0.006		0.004
		(0.003)		(0.005)
Mangrove Distance × I(2 year after hurricane)				
On hurricane path			-0.024***	-0.028***
			(0.004)	(0.004)
Off path			-0.005	-0.010*
			(0.004)	(0.005)
Mangrove Distance × I(3 year after hurricane)				
On hurricane path			-0.017***	-0.022***
			(0.004)	(0.004)
Off path			-0.009**	-0.007*
			(0.003)	(0.003)
R^2	0.714	0.714	0.714	0.714

Note: The negative coefficients of the interaction variables means that closer proximity to mangroves results in smaller sale price reduction following a hurricane. Results estimated from Equation (3) $log(P_{it}) = \beta_1'(\theta_{ct} m_i \times H_t) + \beta_2'((1-\theta_{ct}) m_i \times H_t) + \delta_i + \delta_t + \epsilon_{it}$ for medium flood risk properties in the data. Time and property fixed effects are included in all regressions. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 1171676.

Table A.7: Effect of Mangroves: proximity indicator, by hurricane and year

	(1) 1st Year	(2) 2nd Year	(3) 3rd Year
Mangrove Proximity (<0.5km)			0.29***
			(0.00)
Distance to Coast (km)			-0.02***
			(0.00)
Ivan*Mangrove	0.12***	0.01	-0.04
	(0.01)	(0.02)	(0.02)
Sandy*Mangrove	0.01	0.04***	0.03*
	(0.01)	(0.01)	(0.01)
Irma*Mangrove	-0.06**	-0.14***	0.06
	(0.02)	(0.03)	(0.07)
Zipcode FE			Yes
Year-Month FE			Yes
R-squared			0.35
N			2050807

Note: Dependent variables: log of sale prices. Since the mangrove variable is a dummy variable (=1 if mangrove is present), a positive coefficient implies price benefits. Results estimated from Equation (1) and include property data in high, medium, and low flood risk areas designated by FEMA. Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.8: Level Effect of Mangroves on Price per Square Foot, by hurricane and year

	(1) 1st Year	(2) 2nd Year	(3) 3rd Year
Mangrove Distance			-0.12
			(0.10)
Ivan*Mangrove	-0.05***	-0.02***	-0.03***
	(0.00)	(0.00)	(0.00)
Sandy*Mangrove	-0.03***	-0.02***	-0.03***
	(0.00)	(0.00)	(0.00)
Irma*Mangrove	-0.05***	-0.08***	-0.05***
	(0.00)	(0.00)	(0.00)
Property FE			Yes
Year-Month FE			Yes
R-squared			0.69
N			1803920

Note: Dependent variables: log of sale price per square foot. Results estimated from Equation (1) and include property data in high, medium, and low flood risk areas designated by FEMA. Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.9: Effect of Mangroves on Prices after Hurricanes at ZIP code level

	(1) Sale Price (mean)	(2) Sale Price (median)
Mangrove Distance ×	0.001	-0.001
I(2 years before hurricane) (max)	(0.005)	(0.005)
Mangrove Distance ×	0.002	-0.004
I(1 year after hurricane) (max)	(0.006)	(0.006)
Mangrove Distance ×	-0.002	-0.006
I(2-3 years after hurricane) (max)	(0.005)	(0.005)
Mangrove distance group (median)	0.021*	0.019
	(0.009)	(0.010)
Distance to coast (median)	-0.035***	-0.040***
	(0.003)	(0.003)
Elevation meters (median)	0.012	0.011
	(0.007)	(0.008)
Property Age (median)	-0.010***	-0.010***
	(0.000)	(0.000)
Property Square Footage (median)	0.000**	0.000**
	(0.000)	(0.000)
Single family house (=1)	0.129***	0.176***
	(0.008)	(0.008)
Condo (=1)	-0.532***	-0.425***
	(0.009)	(0.009)
R^2	0.502	0.497

Note: The negative coefficients of the interaction variables means that closer proximity to mangroves results in smaller sale price reduction following a hurricane. Results estimated from Equation (1) $log(P_{it}) = \beta'(m_i \times H_t) + \delta_i + \delta_t + \epsilon_{it}$ for medium flood risk properties in the data. This estimation is at ZIP code level. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 56868.

Table A.10: Effect of Mangroves on Prices after Hurricanes: hurricane path effects at ZIP code level

	(1) Sale Price (mean)	(2) Sale Price (median)
Mangrove Distance × I(1 year after hurricane)		
On hurricane path (max)	-0.022**	-0.030***
	(0.007)	(0.007)
Off path (max)	0.015*	0.010
	(0.007)	(0.007)
Mangrove Distance × I(2-3 years after hurricane)		
On hurricane path (max)	-0.010	-0.012*
	(0.006)	(0.006)
Off path (max)	0.008	0.003
	(0.005)	(0.005)
Mangrove distance group (median)	0.019*	0.016
	(0.009)	(0.010)
Distance to coast (median)	-0.035***	-0.040***
	(0.003)	(0.003)
Elevation meters (median)	0.011	0.009
	(0.007)	(0.008)
Property Age (median)	-0.010***	-0.010***
	(0.000)	(0.000)
Property Square Footage (median)	0.000**	0.000**
	(0.000)	(0.000)
Single family house (=1)	0.128***	0.175***
	(0.008)	(0.008)
Condo (=1)	-0.532***	-0.425***
	(0.009)	(0.009)
R^2	0.503	0.499

Note: The negative coefficients of the interaction variables means that closer proximity to mangroves results in smaller sale price reduction following a hurricane. Results estimated from Equation (3) $log(P_{it}) = \beta_1'(\theta_{ct}m_i \times H_t) + \beta_2'((1-\theta_{ct})m_i \times H_t) + \delta_i + \delta_t + \epsilon_{it}$ for medium flood risk properties in the data. This estimation is at ZIP code level and includes time and ZIP code fixed effects. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 58868.

Table A.11: Effect of Mangroves on Prices after Hurricanes: Weighted Regression

	Dependent variable is Log(Sale Price)				
	(1)	(2)	(3)	(4)	(5)
Mangrove Distance ×	-0.002			-0.003	0.012***
I(2 years before hurricane)	(0.002)			(0.003)	(0.003)
Mangrove Distance ×		-0.011***		-0.016***	-0.014***
I(1 year after hurricane)		(0.002)		(0.003)	(0.003)
Mangrove Distance ×			-0.016***	-0.022***	-0.005
I(2-3 years after hurricane)			(0.003)	(0.003)	(0.003)
Trend × Mangrove Distance					-0.002***
					(0.000)
R^2	0.739	0.739	0.739	0.739	0.739

Note: Observations are weighted by the inverse of the number of sales for each property so that each property has the same weight in the regression. Results estimated from Equation (1) for medium flood risk properties in the data awith time and ZIP code fixed effects. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 1171460.

Table A.12: Effect of Mangroves on Prices after Hurricanes by Hurricane Path: Weighted Regression

	Dependent variable is Log(Sale Price)		
	(1)	(2)	(3)
Mangrove Distance × I(1 year after hurricane)			
On hurricane path	-0.014***		-0.036***
	(0.003)		(0.005)
Off path	-0.008*		0.006
	(0.004)		(0.005)
Mangrove Distance × I(2-3 years after hurricane)			
On hurricane path		-0.023***	-0.028***
		(0.003)	(0.003)
Off path		-0.010**	-0.013***
		(0.003)	(0.004)
R^2	0.739	0.739	0.739

Note: Observations are weighted by the inverse of the number of sales for each property so that each property has the same weight in the regression. Results estimated from Equation (3) for medium flood risk properties in the data. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 1171676.

Table A.13: Effect of Mangroves on Prices after Hurricanes: hurricane main and path effects, excluding Lehmann Crisis

	Dependent variable is Log(Sale Price)		
	(1)	(2)	(3)
Mangrove Distance ×	-0.001		
I(2 years before hurricane)	(0.003)		
Mangrove Distance ×	-0.015***		
I(1 year after hurricane)	(0.003)		
Mangrove Distance ×	-0.018***		
I(2-3 years after hurricane)	(0.004)		
Mangrove Distance × I(1 year after hurricane)			
On hurricane path		-0.037***	-0.035***
		(0.005)	(0.005)
Off path		0.008	0.007
		(0.004)	(0.006)
Mangrove Distance × I(2-3 years after hurricane)			
On hurricane path		-0.028***	-0.024***
		(0.004)	(0.003)
Off path		-0.009*	-0.010
		(0.004)	(0.006)
R^2	0.717	0.718	0.714
N	1066842	1066842	1171676

Note: Columns (1) and (2) include estimations excluding observations from years 2007 through 2009. Column (3) excludes Sandy as a hurricane in the estimation, but not dropping observations. The negative coefficients of the interaction variables means that closer proximity to mangroves results in smaller sale price reduction following a hurricane. Results estimated from Equation (1) $log(P_{it}) = \beta'(m_i \times H_t) + \delta_i + \delta_t + \epsilon_{it}$ and from Equation (3) $log(P_{it}) = \beta'_1(\theta_{ct} m_i \times H_t) + \beta'_2((1-\theta_{ct}) m_i \times H_t) + \delta_i + \delta_t + \epsilon_{it}$ for medium flood risk properties in the data. This estimation is at ZIP code level. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Appendix A.7 Robustness test: Insurance Coverage

Table A.14: Effect of Mangroves on Prices after Hurricanes, Controlling for Insurance Coverage

	(1)	(2)	(3)	(4)	(5)
	Sale Price (log)	Sale Price (log)	Sale Price (log)	Sale Price (log)	Sale Price (log)
Mangrove Distance ×	0.001			0.001	0.013***
I(2 years before hurricane)	(0.002)			(0.003)	(0.003)
Mangrove Distance ×		-0.009***		-0.015***	-0.013***
I(1 year after hurricane)		(0.002)		(0.003)	(0.003)
Mangrove Distance ×			-0.014***	-0.018***	-0.003
I(2-3 years after hurricane)			(0.003)	(0.003)	(0.003)
Trend × Mangrove Distance					-0.002***
					(0.000)
NFIP Insurance Coverage	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.714	0.714	0.714	0.714	0.714

Note: The negative coefficients of the interaction variables means that closer proximity to mangroves results in smaller sale price reduction following a hurricane. Results estimated from Equation (1) $log(P_{it}) = \beta'(m_i \times H_t) + \delta_i + \delta_t + \epsilon_{it}$ for medium flood risk properties in the data. Time and property fixed effects are included in all regressions. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 1171460.

Table A.15: Effect of Mangroves on Prices after Hurricanes: hurricane path effects, Controlling for Insurance Coverage

	(1)	(2)	(3)	(4)
	Sale Price (log)	Sale Price (log)	Sale Price (log)	Sale Price (log)
Mangrove Distance × I(1 year after hurricane)				
On hurricane path		-0.011**		-0.034***
		(0.003)		(0.005)
Off path		-0.006		0.008
		(0.003)		(0.004)
Mangrove Distance × I(1 year after hurricane)				
On hurricane path × NFIP Insurance		-0.000		-0.000*
		(0.000)		(0.000)
Mangrove Distance × I(2-3 years after hurricane)				
On hurricane path			-0.016***	-0.020***
			(0.003)	(0.003)
Off path			-0.007*	-0.008*
			(0.003)	(0.003)
Mangrove Distance × I(2-3 years after hurricane)				
On hurricane path × NFIP Insurance			-0.000***	-0.000***
			(0.000)	(0.000)
NFIP Insurance Coverage	0.000	0.000	0.000*	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.714	0.714	0.714	0.714

Note: The negative coefficients of the interaction variables means that closer proximity to mangroves results in smaller sale price reduction following a hurricane. Results estimated from Equation (3) $log(P_{it}) = \beta_1'(\theta_{ct} m_i \times H_t) + \beta_2'((1-\theta_{ct}) m_i \times H_t) + \delta_i + \delta_t + \epsilon_{it}$ for medium flood risk properties in the data. Time and property fixed effects are included in all regressions. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 1171676.

Appendix A.8 Robustness test: Climate Beliefs

Table A.16: Effect of Mangroves on Prices after Hurricanes, , Controlling for Climate Belief

	(1) Sale Price (log)	(2) Sale Price (log)	(3) Sale Price (log)	(4) Sale Price (log)	(5) Sale Price (log)
Mangrove Distance × I(2 years before hurricane)	-0.003			-0.253	-0.042
	(0.006)			(0.248)	(0.260)
Mangrove Distance × I(1 year after hurricane)		-0.025**		-0.032***	-0.019*
		(0.008)		(0.009)	(0.008)
Mangrove Distance × I(2-3 years after hurricane)			0.002	-0.263	-0.053
			(0.006)	(0.248)	(0.259)
Trend × Mangrove Distance					-0.009***
					(0.002)
Belief about climate damages	0.001	0.004	0.001	0.002	0.010
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
R^2	0.822	0.822	0.822	0.822	0.823

Note: The negative coefficients of the interaction variables means that closer proximity to mangroves results in smaller sale price reduction following a hurricane. Results estimated from Equation (1) $log(P_{it}) = \beta'(m_i \times H_t) + \delta_i + \delta_t + \epsilon_{it}$ for medium flood risk properties in the data. Time and property fixed effects are included in all regressions. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 53374.