Summer 2022

Neighborhood Change on the Mississippi Coast After Hurricane Katrina (2006 – 2019)

Margot Habets

NEIGHBORHOOD CHANGE ON THE MISSISSIPPI COAST AFTER HURRICANE KATRINA (2006 – 2019)

by

Margot Habets

Bachelor of Science
Tulane University, 2017

Submitted in Partial Fulfillment of the Requirements

For the Degree of Master of Science in

Geography

College of Arts and Sciences

University of South Carolina

2022

Accepted by:

Susan Cutter, Director of Thesis

Jerry Mitchell, Reader

Zhenlong Li, Reader

Tracey L. Weldon, Vice Provost and Dean of the Graduate School

ACKNOWLEDGMENTS

I would like to acknowledge and thank my colleagues and friends in HVRI who have supported me throughout this thesis in both small and large ways. They have improved my work on this thesis and my work as a researcher. In addition, a large thank you must go to Dr. Cutter for her continuous dedication to my work, understanding of when curiosity leads me down rabbit holes that never made it in a draft, and support in bringing everything together in the end. I am grateful for Dr. Zhenlong Li and Dr. Jerry Mitchell's support over this project.

Lastly, I am so thankful for my parents Gaston and Ariane and my brother who have supported me in innumerable ways, the Soda City Volleyball Crew for giving me the best excuse to give my brain a break, and Tim for reading every draft along the way.

ABSTRACT

Hurricane Katrina was a historic event, forever changing many lives as well as altering impacted communities in the short and long term. In the fifteen years since the storm, patterns of damage, recovery programs and dollars, and existing neighborhood change have altered demographics in coastal Mississippi. This thesis investigates how population, median age, race, and education demographics have changed at the census tract level in the fourteen years since Hurricane Katrina (2006-2019) compared to pre-Katrina trends (1990-2000). A moving average using American Community Survey data as well as interval changes measure how different neighborhoods have been altered since the storm. Local Moran's I cluster and outlier analysis combined with a change concept test identified clusters of large and small change. Large changes were focused on the Gulf Coast and inland tracts where development has focused since the storm while small changes were less common and scattered throughout the tri-county study area.

The subsequent case study on coastal Mississippi considered damage, FEMA assistance recipients, and the growth of impervious areas before reviewing reports on Katrina recovery, city and county development, and regional plans for the future. The case study found that housing development was focused away from the coast, with many people priced out of rebuilding homes directly on the coast or opting away from future risk. For the most part, economic development remained focused on the coast, including tourism and multiple ports, which have been repeatedly impacted after Hurricane Katrina, including the 2010 BP oil spill.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

On August 29th, 2005, Hurricane Katrina made its final landfall near the Mississippi-Louisiana border as a Category 3 storm, impacting not only New Orleans and Southeast Louisiana, but also the entire Mississippi coast. Hurricane Katrina made history as the costliest storm to impact the U.S. and was responsible for 1,833 fatalities and about $108 billion in damage (2005 dollars) (NWS, 2016). The National Weather Service (NWS) reported the storm surge along the Mississippi coast and St. Louis Bay at 24 to 28 feet, enough to severely damage or destroy over 60,000 housing units and damage to some degree another 200,000 homes in Mississippi alone (Office of the Governor, 2015).

Initial studies after the storm show how the damage from Hurricane Katrina and pre-existing social inequalities have led to an uneven initial recovery in New Orleans and coastal Mississippi (Cutter et al., 2006; Elliot & Pais, 2006). By one estimate, Hurricane Katrina displaced an average of 15% of the population from coastal Mississippi (Frey & Singer, 2006) some of whom returned to their original homes immediately, while others returned after some time or permanently migrated elsewhere (Fussell et al., 2014).

In addition to the movement of those who originally lived in the study area, others moved into these counties from outside areas (Fussell et al., 2014). Human migration and neighborhood change are ongoing processes, but the magnitude to which hazards impact these patterns is not well understood (Lee, 2017). Further, damage from a natural hazard may cause changes in housing stock, infrastructure, public services, and investment from recovery programs, causing neighborhoods directly and indirectly impacted to change (Wyczalkowski et al., 2019).

Mississippi has experienced large hurricanes and coastal flooding before Katrina. The National Hurricane Center historical tracks database lists 81 storms that reached at least tropical storm strength directly impacting Mississippi since 1852 (National Hurricane Center, 2021). The recovery and neighborhood change due to these and other events must be understood within a historical context. Homeownership has generally increased on the Mississippi coast and the median value of their homes was higher than the state's average, but the lasting impacts of segregation meant that these improvements were not accessible to everyone (Cutter et al., 2014). Social inequalities coupled with variable damage resulted in a differential recovery across the three coastal Mississippi counties in the aftermath of Hurricane Katrina.

Recovery from natural hazards is difficult to define, with no linear timeline or established endpoint (Chang, 2010). Recovery follows some general stages: emergency, recovery, reconstruction, and betterment reconstruction where each stage takes approximately ten times as long as the previous one (Kates et al., 2006). Using this model, the Mississippi coast is predicted to take nineteen years to fully recover and has been in the betterment reconstruction stage for years. Various studies on reconstruction and demographic trends show that this recovery is uneven, is partially but not completely explained by patterns of higher and lower damage, and is further explained and contextualized by pre-hazard vulnerabilities and social inequities (Burton et al., 2011; Cutter et al., 2014).

1.1 RESEARCH QUESTIONS AND PURPOSE

This thesis focuses on the long-term changes experienced by the coastal Mississippi region after Hurricane Katrina. Work of this nature can help identify what communities are likely to be displaced in a post-disaster context. Examining this data at the census tract level provides insight into how recovery is variable at a small scale and manifests differently due to the uniqueness of place, especially communities. The relatively long timescale of this analysis (15 years) will help show whether the Kates et al. estimation for time to recovery is visible in demographic changes and whether any initial changes caused by Katrina persist over time. This combination of spatial and time scales is unique to this study and will add greater depth to the field's understanding of the long-term impacts of Hurricane Katrina.

Using the 1990-2000 county and census tract demographic data as a baseline, the research questions examined are as follows:

- Has there been a significant change in population, race, age, and education demographics in the study area over the years 2006-2019?
- Are these changes or lack of changes geographically clustered, isolated, or random?
- What accounts for these patterns of change?

This thesis begins with a literature review discussing geographic theories of recovery and neighborhood change as well as summarizing current and past research on Hurricane Katrina recovery. Chapter 3 explains the study area and the data and methods used in the first two research questions, the statistical and conceptual tools used to identify case study areas with results discussed in Chapter 4. Chapter 5 contains the case study of Coastal Mississippi including the documents and data used, spatial analysis conducted, and case study results. Results from Chapters 4 and 5 are discussed further in Chapter 6, including major takeaways and conclusions from the research questions, the contributions of this thesis, limitations of the study, and further research.

CHAPTER 2

LITERATURE REVIEW

Smith and Wegner (2007) define recovery as "the process of restoring, rebuilding, and reshaping the physical, social, economic, and natural environment through pre-event planning and post-event actions," (p. 237). The capacity of different places to recover depends on the level of damage an area receives, pre-existing vulnerability, and how well the impacted community can cope and access recovery assistance (Finch et al., 2010). Recovery is an unequal process where those with their own financial resources tend to recover first, while others may have to wait for outside assistance (Olshansky, 2005). The different phases of recovery, however defined, are nonlinear, can overlap, and are not experienced at the same time or level equally across impacted communities (Kates et al., 2006; National Research Council, 2006).

Data availability and consistency are a large barrier to long-term recovery research, especially at the local scale. Further, disaster recovery can be a ten-year or longer process, while most research funding grants only last for three to five years, limiting research timelines and data collection. Long-term recovery is a scarcely studied topic and is complicated by overlapping recovery periods from multiple hazards, as well as other shocks a region may experience. There is value in planning for long-term recovery, especially when recovery is planned in such a way that it makes a community more resilient and less vulnerable, leading to smaller impacts from future hazards.

This review covers the current and prevailing geographic theories of recovery which consider how and why recovery from hazards varies from place to place. This is followed by a summary of research focused on hazards and neighborhood change, which complements theories of recovery. Lastly, this review summarizes selected examples of the many case studies of New Orleans and coastal Mississippi after Hurricane Katrina, including how the two areas compare in major findings.

2.1 GEOGRAPHIC THEORIES OF RECOVERY

Pre-disaster actions and inherent vulnerabilities of a community expand the Kates et al. (2006) timeline to include planning and social context of recovery. Some recovery conceptualizations involve stage models or phase timelines (Haas et al., 1977; Kates et al., 2006), while others identify factors that seek to measure damage and recovery based on housing and economic status (Comerio, 1998). Recovery has also been related to urban scale and interdependencies between the social and physical environment. As urban areas grow, their critical services become more efficient which are essential for community recovery, but this also leads to a reduced level of self-reliance which can reduce resilience to future hazards (Yabe et al., 2021).

Some conceptualizations and models do not investigate recovery specifically, but factors that influence recovery for an impacted area. Inherent characteristics of a community, such as vulnerability and resilience, impact how different areas can recover from a disaster. The disaster resilience of place (DROP) model, for example, outlines how variation in place-specific characteristics before a hazard event, post-hazard processes, as well as the conditions of the hazard itself result in spatially variable resilience, and through that resilience, variable recovery (Cutter et al., 2008). The DROP model (Figure 2.1) joins spatial differences among the interaction of natural systems, social systems, and the built environment as antecedent conditions that in turn interact with the spatial nature of event characteristics, coping responses, absorptive capacity, and adaptive resilience to shape the degree of recovery in impacted areas.

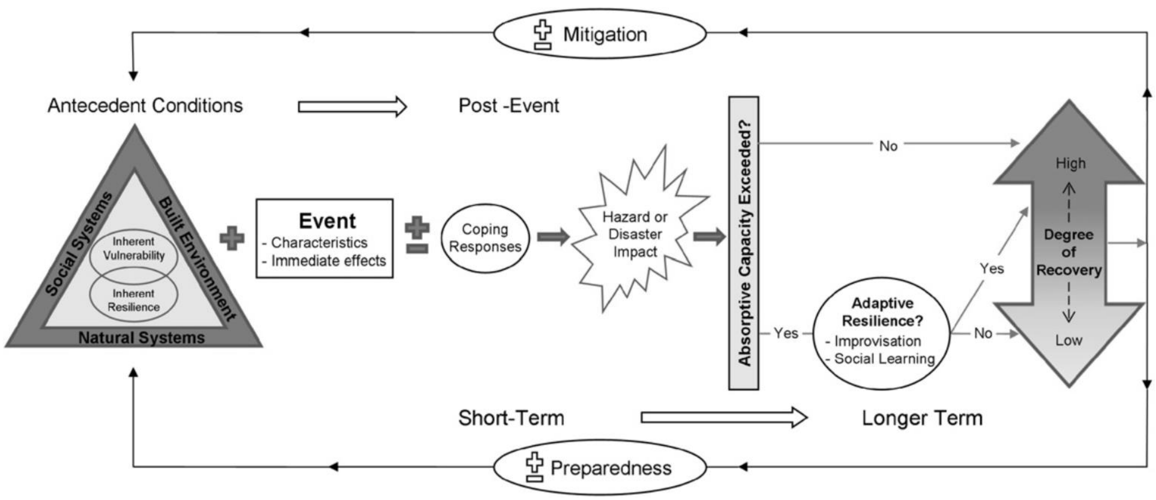

Figure 2.1 The DROP model (Cutter et al., 2008).

The recovery process itself is complex and community recovery depends on local leadership, the community's ability to act, and community knowledge of emergency management and available resources (Rubin et al., 1985). The inputs and interactions occurring at the local level shape the recovery process in each area, which results in variable recovery across an impacted area (Rubin et al., 1985).

Each section of the DROP model can be considered specifically to examine how each component may impact recovery within a community. Models of social vulnerability specifically have been used to understand how inherent community vulnerabilities interact with exposure to produce inequities in recovery (Cutter, 2003; Finch et al., 2010). Population characteristics such as the number of people displaced, demographics (age, race, gender), and median income all help researchers understand how recovery may differ spatially and among different groups (Chang, 2010; Cutter et al., 2014). Certain demographics and housing types, namely minority status and renting, may extend the time it takes for recovery, with multifamily homes and duplexes the least likely to be restored after a disaster (Peacock et al., 2014).

In addition, the degree of recovery examined in the DROP model may refer to any number of variables, as Smith and Wegener (2007) list four different aspects of recovery in their definition. Housing and population demographics are often used as indicators for recovery and are considered proxies for both social and physical recovery (Cheng et al., 2015; Schultz & Elliott, 2013). Parts of the DROP model and the recovery process are still poorly understood or difficult to measure, including the degree to which pre-planning and mitigation actions lessen hazard impacts and subsequent recovery (Cutter et al., 2008; Olshansky, 2005).

Complementary to the DROP model, the Composite of Post-Event Well-Being (COPEWELL) model focuses on community functioning and well-being, relating these concepts to resilience and contextualizing them within a hazard setting (Kendra et al., 2021). Developed for the CDC, this model uses a systems approach to focus on the loss of community function after a disaster and posits that recovery is experienced through the return of community functions. Pre-event functioning, recovery functions including social cohesion and external resources, population factors such as vulnerability and inequality, and lastly mitigation factors such as the natural and engineered systems of an area all lead to varied community functioning over time (Kendra et al., 2021).

2.2 HAZARD IMPACTS ON NEIGHBORHOOD CHANGE

Cheng et al. (2015) explained the two main perspectives on what recovery works towards – either bouncing back or reaching a counterfactual state. The first is the more traditional viewpoint of recovery, a return to the status quo that existed pre-disaster. This viewpoint does not consider long-term trends that would have impacted the hazard-struck area regardless, failing to contextualize the disaster recovery in the economic and political influences occurring at the same time (Chang, 2010). In contrast, recovery as reaching a counterfactual state asks what economic drivers were impacting the community's recovery outside of the disaster and how they influenced the recovery of the community in question (Cheng et al., 2015).

Neighborhood change is a continuous process, characterized by in- or out-migration, development, upgrades, or maintenance, which lead to changes in who lives where, subsequently leading to larger changes in an area as a whole (Lee, 2017). A variety of interrelated factors including the quality of housing available, socioeconomic status of those in the community, and historical and current political economy influence neighborhood change (Lee, 2017). Hazards may shift a neighborhood from its pre-existing trends, altering its trajectory by causing migration, displacement, and immobility (Black et al., 2013; Lee, 2017). Spatial variation in neighborhoods and neighborhood change is impacted by inequalities in financial, educational, social, and cultural systems (Barnshaw & Trainor, 2010).

The physical damage or threat of damage caused by a natural hazard causes individuals to evacuate immediately before or after an event, as was well documented after Hurricane Katrina (Frey & Singer, 2006). The decision to return after an evacuation is influenced by access to transportation, costs of continued residence in the impacted area, and access to recovery resources (Fussell, 2015). For some, the benefits of living in a disaster-prone area may outweigh the costs and they may return and remain, while other residents may have a desire to relocate after a disaster but are unable to do so (Hunter, 2005). The recovery process can be stressful, and in some cases depressing, in all stages from evacuation, to returning to a damaged home, and navigating the recovery process (Koslov et al., 2019; Siebeneck et al., 2020).

There are contrasting views of who is most likely to permanently relocate after a hazard. Black et al. (2013) found that while the poor are more likely to be vulnerable to disaster, they are less able to move away from disaster-prone areas. Alternatively, more socioeconomically advantaged groups have the resources to rebuild their homes when severely damaged, while more disadvantaged groups are forced to move elsewhere, resulting in wealthier neighborhoods retaining their populations (Cross, 2014; Raker, 2020). Different neighborhoods also have different opportunities in recovery, with some slated for buyout programs from local mitigation programs, others may want buyouts and cannot receive them, while even others may prefer to rebuild in place (Koslov et al., 2019).

Wyczalkowski et al. (2019) identify two opposing concepts of neighborhood change after a hazard event. These are the "recovery machine" (Pais & Elliott, 2008) and the "rent gap" (Smith, 1979) concepts, which have opposing predictions for neighborhood change after a disaster. The recovery machine idea posits that the pre-hazard inequalities are reinforced after an event since low socioeconomic populations are less likely to have access to and take advantage of any programs aimed to restore a community, entrenching that neighborhood in further neglect. The rent gap concept states that areas of lower socioeconomic status, in this case once damaged by a natural hazard, are more likely to be slated for rebuilding by developers because their potential profit will be higher (Smith, 1979). Instead of this rebuilding targeting the current population of the neighborhood, rehab inputs are likely to spur gentrification and displace original residents (Figure 2.2) (Lee, 2017).

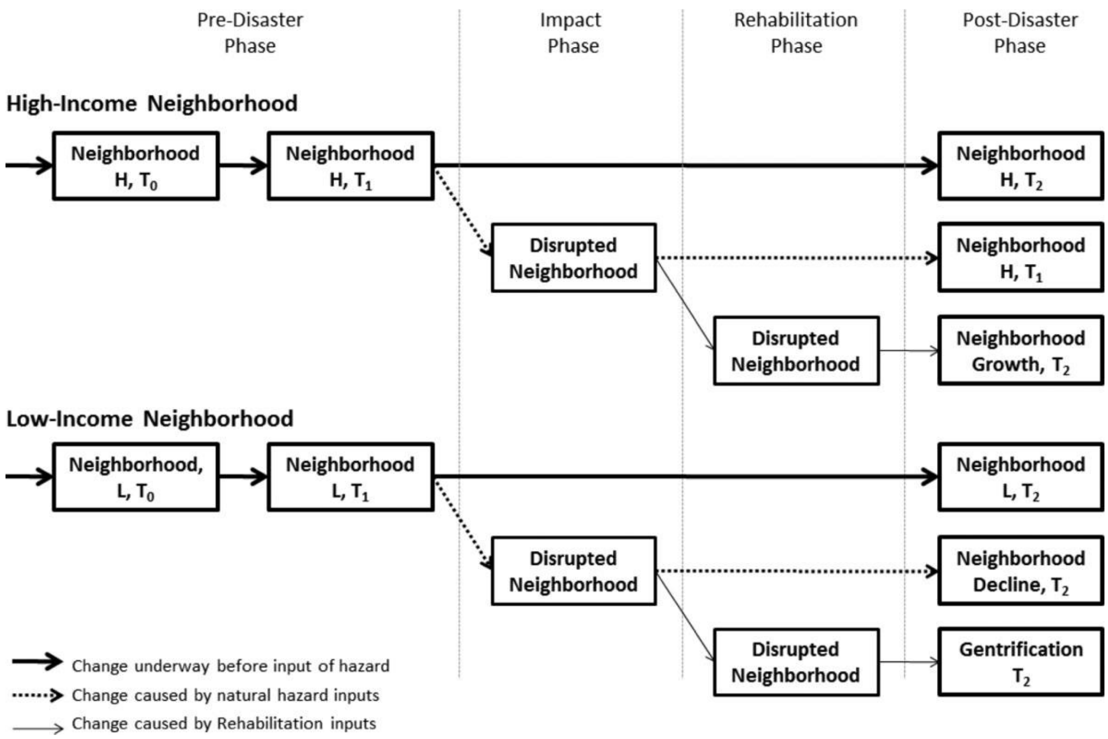

Figure 2.2 Lee's (2017) model of neighborhood change after a disaster.

The size of a community impacted and its distance to the nearest metro area also has an impact on the long-term changes in that community (Cross, 2014). One study found that on a county level, areas that were further away from metro areas or already losing population pre-hazard were almost three times more likely to lose a third of their population after a hazard, whereas counties growing in population or closer to metros were less likely to lose population over the long-term (Cross, 2014). A separate study of hazard impacted counties in the 11990sfound a positive relationship between at least $1 million of disaster-related property damage and population growth (Schultz & Elliott, 2013). The median income of the same study area grew over the 1990s but the poverty level remained the same, meaning that income increases were not equally distributed (Schultz & Elliott, 2013).

2.3 RECOVERY CASE STUDIES ON HURRICANE KATRINA

Initial studies on New Orleans after Hurricane Katrina observed the most population loss occurred in socioeconomically disadvantaged areas (Wang et al., 2014) and followed patterns of damage (Elliott et al., 2009). Population recovery was greatest towards the central business district and the suburbs (Wang et al., 2014) with white homeowners experiencing less flooding, allowing them to return sooner and absorb displaced residents from other parts of the city, generally of the same race (Elliott et al., 2009).

The interaction of pre-existing vulnerabilities and Hurricane Katrina's impact meant that those with the most damage also tended to be the least able to take advantage of any opportunities for recovery (Finch et al., 2010; Fussell, 2015). After ten years, Van Holm and Wyczalkowski (2019) found that, in New Orleans, damage correlated with the likelihood that a neighborhood would be gentrified, resulting in a whiter, more educated, and higher-income neighborhood over the long term, displacing original residents.

The pre- and post-Katrina demographics and pre-existing trends of coastal Mississippi differ greatly from New Orleans. The three coastal Mississippi counties studied here were whiter in 2000 and remained predominately white in 2010, though the African American and Hispanic populations have grown (Cutter et al., 2014). Frey and Singer (2006) found that, unlike New Orleans, many of the residents that evacuated coastal Mississippi were white homeowners, with the share of minority residents increasing and the proportion of those living below the poverty staying stable in early 2006 compared to July 2005.

On the Mississippi coast, Katrina damage was the highest predictor of time to housing recovery, but social and economic resilience also had an impact on who was able to recover from the storm, however, the pattern of recovery was inconsistent (Burton, 2015; Cutter et al., 2014). The three impacted counties along the coast have different rates of population recovery, with Jackson County, the furthest from Katrina's track, being the only to return to pre-Katrina population levels by 2012 (Cutter et al., 2014). Within each county, different cities with similar damage have different rates of housing reconstruction and growth, indicating that socioeconomic and political factors have influenced their timelines for recovery (Burton et al., 2011; Stevenson et al., 2010). Rebuilding patterns have shifted over time, first focusing on less damaged areas, and then shifting to impacted areas, though tending to still avoid the most severely damaged locations (Cutter et al., 2014; Stevenson et al., 2010). In some locations, such as Biloxi, Mississippi, rebuilding had moved away from damaged areas to limit future risk (Trivedi, 2020).

While Hurricane Katrina is a common case study for hazard recovery, a large portion of the literature focuses on either the city of New Orleans (Elliott et al., 2009; Finch et al., 2010; Fussell et al., 2014) or a county level analysis of impacted areas (Cross, 2014; Schultz & Elliott, 2013). The local context of disaster vulnerability, resilience, and recovery means that the conclusions drawn from New Orleans based studies may not apply to coastal Mississippi. Long-term studies of disaster recovery are often studied at the county level and cover multiple hazards, but this aggregation may not provide the place-specific information that would be helpful to county and state emergency management offices to create a better mitigation and recovery strategy.

Two notable exceptions are two books discussing the Mississippi Coast before and after Hurricane Katrina: Cutter et. al (2014) *Hurricane Katrina and the Forgotten Coast of Mississippi*, which focuses on pre-existing conditions and recovery on the entire Mississippi Coast, and Trivedi's (2020) book, *Mississippi After Katrina*, which is a case study of pre-existing conditions and systems and how they impact long-term Katrina recovery efforts specifically in Biloxi, Mississippi. These two works discuss the socioeconomic systems that existed in coastal Mississippi pre-Katrina and how these systems may have impacted recovery for different groups in the short and long term. This study seeks to combine methods used in smaller scale and longer-term studies to achieve a more complete picture of the full timeline of recovery on the Mississippi coast.

CHAPTER 3

DATA AND METHODOLOGY

This chapter describes the study area including the difference between the three counties examined, as well as the five variables studied. The data downloaded for the base period and post-Katrina period are described including their download process and how variables were converted for analysis. The four steps in the analysis before the case study are then explained including the approach to descriptive statistics, a paired t-test, cluster and outlier analyses using GIS, and a novel conceptual approach to comparing changes across time periods.

3.1 STUDY AREA

Hurricane Katrina became a tropical depression on August 24th, 2005, and intensified to make landfall over Florida on August 25th as a Category 1 hurricane. It continued into the Gulf of Mexico and intensified to a Category 5 hurricane before weakening to Category 3 before making its final landfall near the Louisiana-Mississippi border on August 29th (NWS, 2016). At the time of landfall, the storm had hurricane force winds extending up to 90 nautical miles (nmi) from the center and tropical storm-force winds extending up to 200 nmi. The strongest winds occurred to the east of the storm (Knabb et al., 2005).

In addition to destructive winds, Hurricane Katrina's storm surge extended along the entire Mississippi coast into Alabama and Florida. The eastern half of Hancock County through the western half of Harrison County experienced anywhere from 24 to 28 ft of storm surge and the rest of the state experienced 17 to 22 feet of storm surge. In many areas water inundated areas up to six miles inland, even crossing Interstate 10 (Knabb et al., 2005).

This study examines Hancock, Harrison, and Jackson Counties at the 2010 census tract level, removing census tracts with little to no population for analysis (n=79). While the majority of Mississippi was included under the FEMA (Federal Emergency Management Agency) disaster declaration for Hurricane Katrina, which is the official declaration of the areas impacted that requires federal assistance, this study focuses on the state's three coastal counties which were directly impacted by the most intense hurricane wind and storm surge. Figure 3.1 depicts the three counties and their census tracts, the track of Hurricane Katrina, and Interstate 10 which runs through or slightly north of the major cities of the study area and is a common dividing line when discussing the geography of the region.

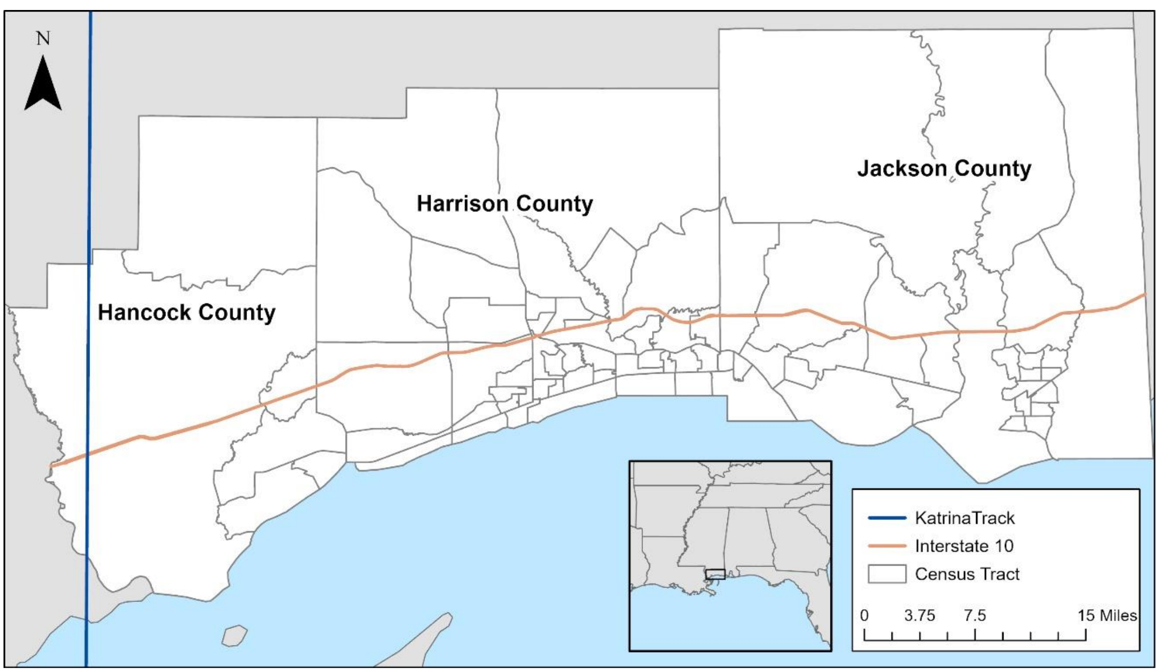

Figure 3.1 Study Area.

Hancock, Harrison, and Jackson Counties all have their main cities, and thus the majority of their populations, situated on the Gulf Coast. Harrison County is the most populous of the three and in 2020 was the second most populated county in the state, with 208,621 residents (U.S. Census Bureau, 2020). All three counties have a 2020 median income between $47,000 and $52,000 which is higher than the state average. Median housing cost is also comparable across the three counties, but Harrison County has the lowest 2020 owner-occupied housing rate (56.6%) and the higher number of building permits (1,703) compared to Hancock and Jackson Counties (75.5%/717 and 69.8%/546 respectively) (U.S. Census Bureau, 2020). Table 3.1 summarizes the population of the tri-county area both pre- and post- Katrina using census counts and intercensal estimates, highlighting some of the initial population changes that were in the area and remained for years following the storm. The population estimate for 2005 was completed in July, before Hurricane Katrina's impact at the end of August.

Table 3.1 County Population Counts/Estimates for 2000, 2005, 2008, 2010 and 2020.

County	2000 Census Population	2005 Population Estimate	2008 Population Estimate	2010 Census Population	2020 Census Population
Hancock	42,945	47,715	42,764	43,929	46,053
Harrison	189,577	197,784	182,735	187,105	208,621
Jackson	131,439	137,913	137,791	139,668	143,252

These three counties made up about 22.5% of the state's population in 2010 when only Jackson County had recovered to its pre-Katrina population (2005 in Table 3.1). In 2020, when all but Hancock County had recovered to its pre-Katrina 2005 population the three counties made up 13.4% of the state's population. Growth in population does not describe the details and demographics of the people living in coastal Mississippi, and where in each county they reside. This thesis looks closer at sub-county population, race, age, and education, to better understand where neighborhood change has occurred in this tri-county area.

3.2 CENSUS AND ACS DATA

The main data source used for the quantitative analysis is the United States Decennial Census and ACS (American Community Survey) 5-year estimates. The five variables used in this study are:

1. Population
2. Percent of the population that is not white
3. Median age
4. Percent of the population above 25 with at least a high school diploma, and
5. Percent of the population above 25 with at least a bachelor's degree.

The Decennial Census is taken every ten years with the goal to count the population of the United States and collect more detailed information on the population covering race, education, age, housing, and employment, among other topics. Methods on surveying the population, statistically sampling more detailed data, and how questions are asked on the census have changed over the years. For example, the 2000 census was the first year that anyone could mark more than one race option, rather than be limited to one category.

To create a baseline trend for each census tract and county to which post-Katrina trends will be compared, the 1990 and 2000 decennial census surveys were downloaded. Census data for 1990 was downloaded from the census FTP which is a direct upload of what was included on Census CD-ROM discs, the original 1990 technique to disseminate census information. Data for the 2000 census was downloaded using the Census application programming interface (API). When available, variables were downloaded as their raw or calculated values, but some variables that were calculated by the Census Bureau in 2000 were not in 1990 and had to be calculated manually. This included calculating the median age for the 1990 census using age frequency distributions.

U.S. Census and ACS data are comprised of different surveys but are comparable as long as ACS margins of error are reasonable, generally requiring a census tract or higher scale of analysis, which is why this neighborhood study is at the census tract scale. ACS 5-year estimates have the largest sample size and are the most reliable dataset from the ACS. The single year ACS is a 20% sample of the population, so a 5-year survey is theoretically a measure of the complete population. ACS data on population, race, median age, and educational attainment were directly downloaded from the census website.

3.2.1 RECONCILING GEOGRAPHIES

The 2010 census tract geography was used for this analysis, which required converting the 1990 and 2000 geographies to the 2010 census tract geography. A crosswalk file was created using 1990 census maps, and 2000 and 2010 census tract shapefiles. This was confirmed using the IPUMS National Historical Geographic Information System census tract files. Since census tracts aim to have a population size between 1,200 and 8,000 people, some census tracts were split while others were combined between 1990, 2000, and 2010 surveys (US Census Bureau, 2021).

In total, 71 census tracts from 1990 and 79 census tracts in 2000 were either split or combined to match the 79 census tracts used in 2010. If a census tract was split into two or three smaller census tracts, the population value was divided equally among the new census tracts and the same percentages and median age were used for each, assuming an equal distribution between the new census tracts. If two or more census tracts were combined, population values were added together, and the raw values for the non-white population, age frequency distribution, and educational attainment variables were used to calculate the correct percentages for the new combined census tract.

3.2.2 VARIABLE COMPUTATION

Non-white population was calculated as the white only population subtracted from the total population for each tract. Since the 2000 census allowed for individuals to select multiple races, the only demographic that was subtracted from the total population was the one race-white only option. This meant that anyone that identified as anything other than only white was counted in the non-white variable. This calculation was repeated for the ACS data.

The median age was a calculated value in the 2000 census data download but had to be calculated from an age frequency distribution for the 1990 census. In addition, the 1990 data download only contained counts of people above the age of 25 who had completed each phase of school (high school, some college, associates, bachelors, graduate degree) so percent of the population that had attained at least a high school education and at least a bachelor's degree were calculated. The population above 25 was also calculated from the age distribution data. The 2000 census and ACS surveys included the percentages of educational attainment for high school and bachelor's degree for the population above 25 years of age.

3.2.3 CREATING A BASELINE

The 1990 and 2000 census data serve as a baseline to which all post-Katrina (2006-2019) data is compared. All ACS 5-year estimates are used to create a moving average (Figure 3.2a) and three specific 5-year surveys (ACS 2006-2010, ACS 2011-2015, and

ACS 2015-2019) were used as interval data to calculate the percentage change of all variables (Figure 3.2b). The moving average data was graphed and used as a descriptive indicator used in creating timelines for each variable at the census tract level. For all of the interval data, the data set is named either the base or baseline (1990-2000) or for the last year in the 5-year average used (2010, 2015, and 2019). Before any statistical analysis could be run on the interval data, the rate of change between each time period was calculated and annualized.

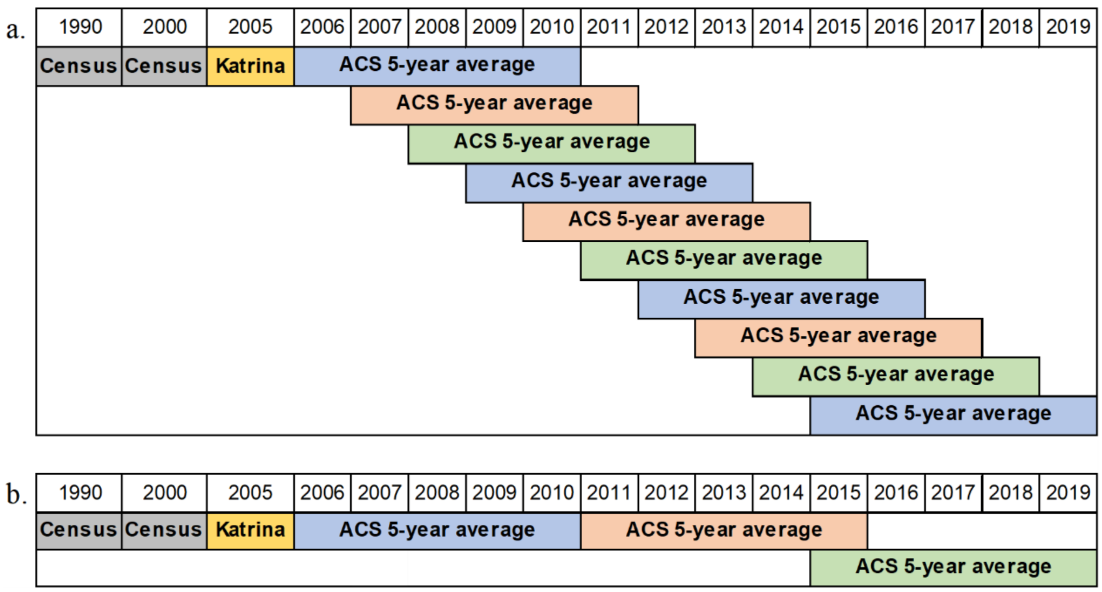

Figure 3.2 Census and ACS data download schema.

The annualized percentage of change or raw change, depending on the variable, is the one compared across different time periods. For instance, the population between 1990 and 2000 for census tract 301 in Hancock County went from 5,792 people to 5,728 people, meaning that the population changed by -1.1%. This is divided by 10 years resulting in an annualized percentage change of -0.11% which is the number used for all statistical analysis. Annualized percentage change was calculated for all variables except for median age, which used annualized raw values, for each census tract and the four time periods used (1990-2000, 10 years; 2010-2015, 5 years; 2015-2019, 4 years; and 2010-2019, 9 years).

3.3 STATISTICAL METHODS

Since this data is both temporal and spatial, a combination of statistical tests is used to understand how rates of change in each variable vary over time. This is done for the study area as a whole and at the census tract level. Descriptive statistics, in this case, include the mean, maximum, minimum, and standard deviation for each variable for each time period. Understanding the distribution of the data as a whole was the first step in understanding where less and more change is happening over time.

All time periods were compared in every combination possible using the paired t-test which compares the rates of change in the entire study area from one time period to another. These combinations are Base (1990-2000) to 2010-2015, Base to 2015-2019, Base to 2010-2019, and 2010-2015 to 2015-2019. The paired t-test measures whether the annualized mean rate of change of the two time periods of the same measurement area are significantly different or not, showing whether the entire study area may have changed over time in each variable when compared to the pre-Katrina baseline or each other.

In addition to paired t-tests and the following concepts of change, the Local Moran’s I test was used to identify patterns of low and high values in each time period for each variable. The Anselin Local Moran’s I test is a cluster and outlier analysis that identifies statistically significant areas of high values, low values, and either high-low or low-high outliers within those clusters (Anselin, 1995). The goal of completing this cluster analysis for each of the individual time periods is to understand where clusters of change develop, grow, fade, and shrink over time.

The Local Moran's I analysis was completed in Arc GIS Pro using a K-nearest neighbors conceptualization of spatial relationships for each variable over each time period. This test used the raw rates of change since the different time periods were not compared to each other. Results were mapped by variable time period to facilitate comparison. Patterns of change are conceptualized by the following: High-High meaning a high value surrounded by other high values, Low-Low meaning a low value surrounded by other low values, High-Low meaning the tract is a high outlier compared to the values surrounding it, and Low-High meaning the tract is a low outlier.

3.4 CONCEPTS OF CHANGE AND OPERATIONALIZATION

To best understand how the rate of change of different variables has altered over time, several concepts of change were adopted, based on existing concepts on how neighborhoods may change after a hazard (Figure 3.3 A-D) (Barnshaw & Trainor, 2010; Lee, 2017). These four concepts of change, depicted in Figure 3.3, highlight the types of change that are further investigated in the case study, connecting the first two research questions (Chapter 1.1) on whether there is significant change occurring, and if so where, to the third research question which accounts for those changes.

The first two concepts of change (Figure 3.3 A and B) consider pre-Katrina trends and follow some of the theories of change outlined in past research (Lee, 2017) with the first (Figure 3.3 A) showing a pre- and post- Katrina with similar rates of change. The second concept that considers pre-Katrina rates of change (Figure 3.3 B) shows largely differing rates of change after the storm when compared to pre-storm levels. These two also assume that the rate of change after Katrina is consistent.

The following two concepts of change (Figure 3.3 C and D) do not consider pre-Katrina trends and were identified as being interesting trends to examine regardless of what was occurring before the storm. The first (Figure 3.3 C) shows a change in any variable that is near zero, meaning the slope of the raw value of the variable over time is nearly flat, and the second (Figure 3.3 D) is a variable with extremely differing rates of change over time. For this study, concepts A and C are considered small change concepts, and concepts B and D are considered large change concepts.

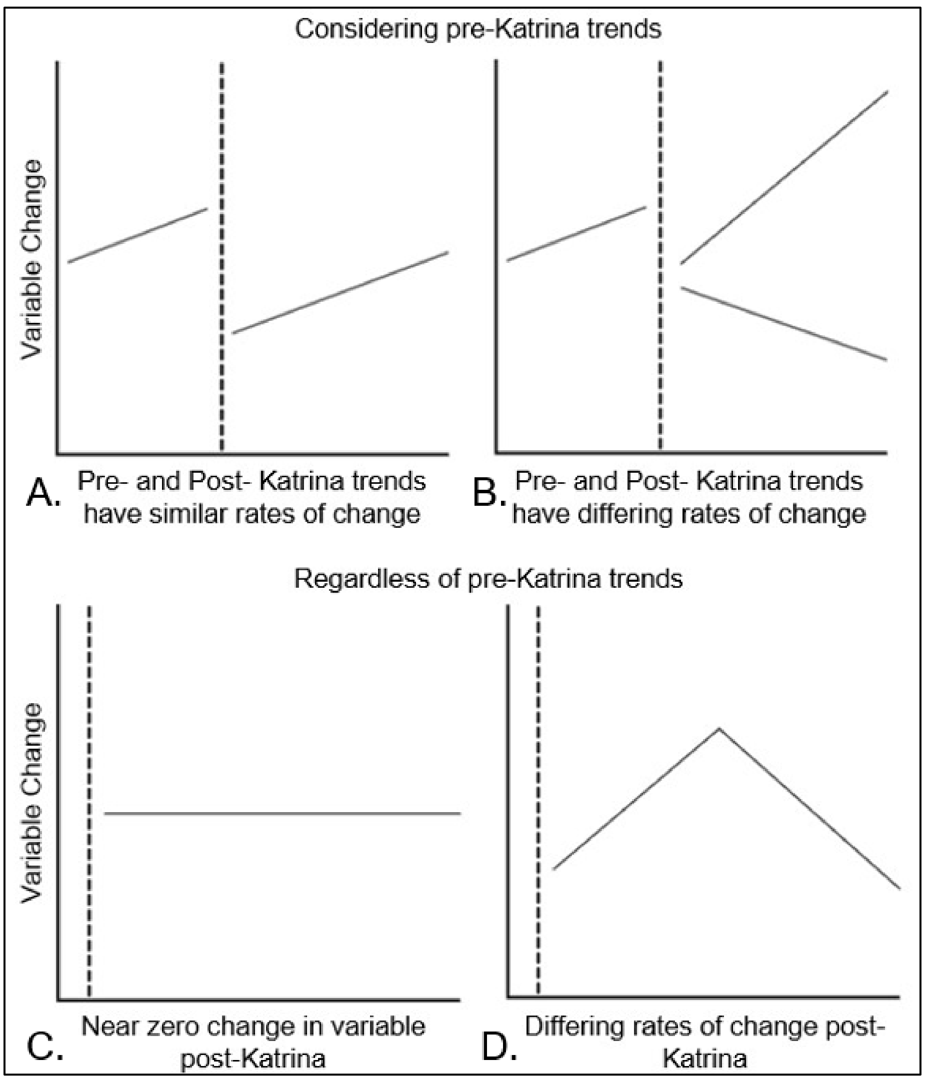

Figure 3.3 Conceptualizations of change in variables with variable change plotted against time (X-axis) and Katrina represented as a dotted line.

Each of these conceptualizations of change was converted into rules for each variable which are summarized in Table 3.2. The rules for concepts A, B, and D use the annualized rate of change and standard deviations from the mean. This allows for the replication of these methods to different study areas and different events in the future. Only the 1990-2000, 2010-2015, and 2015-2019 changes were compared. The entire post-Katrina period (2010-2019) was not used, as it would have removed some of the variability being investigated. Concept C cannot use a standard deviation rule because it relies on whether the rate of change is near zero, not near the mean.

Table 3.2 Rules for operationalizing each concept of change.

Concept	Rule
A – no change	Rate 1990-2000 = Rate 2010-2015 = Rate 2015-2019 All three are within the same z-score category
B – change pre/post-K	Rate 1990-2000 ≠ Rate 2010-2015 = Rate 2015-2019 The pre-Katrina rate is at least two categories different, and the post-Katrina rates are in the same z-score category
C – rate near 0	Rate 2010-2015 = Rate 2015-2019 ≈ 0 Regardless of the pre-Katrina category, the two post-Katrina rates change by less than 1.5%, an arbitrary value
D – change post-K	Rate 2010-2015 ≠ Rate 2015-2019 The two post-Katrina rates are at least separated by one category.

Each time period for each variable's data was converted to z-scores using that time period's mean and standard deviation. Z-scores are a measure of how many standard deviations any point within a data set is away from the mean, generally ranging from -3 to 3. Z-scores are calculated using this formula $Z = (x - \mu)/\sigma$ where x is the observed value for which the z-score is being calculated, μ is the mean for the time period, and σ is the standard deviation for the time period. These z-scores were split into five categories: Less than -1, between -1 and -0.5, between -0.5 and 0.5, between 0.5 and 1, and greater than 1 (Figure 3.4). These z-score categories are mapped as well as used for the concepts of change rules. For a variable to satisfy a rule where the two time periods are equal, they must be in the same category. For a variable to satisfy a rule where the two time periods are different, they must have at least one category between them. This limits but does not completely remove the possibility of a rule being satisfied or not by a z-score changing from just under the category break to just over the category break.

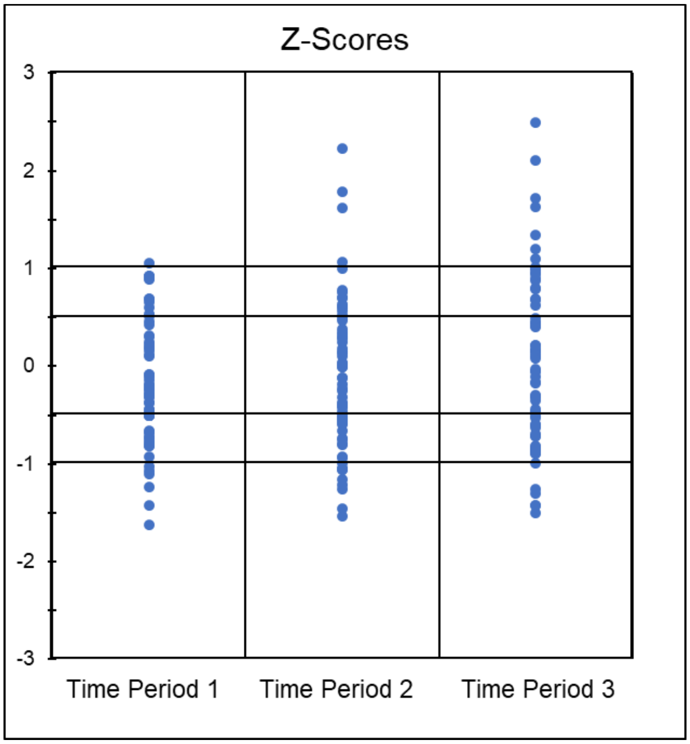

Figure 3.4 Examples of the Z-score categories used over three time periods.

For concept C, a more arbitrary rule had to be created to indicate whether any census tract had a near-zero annualized percentage change in the post-Katrina time periods. An arbitrary value of 1.5% above or below zero was chosen for the entire time period as close enough to zero to satisfy the concept rule. This was converted into an annualized value, 0.3 for the 2010-2015 period and 0.375 for the 2015-2019 period. Since the median age variable uses raw change instead of percentage change, 1.5 years was used as the benchmark, keeping the annualized values for rule satisfaction the same.

Each of these concepts was tested for each variable, resulting in a grid of census tracts that satisfied one or more of the tests per variable (Appendix A, Table A.1). One or more variables might have satisfied more than one test, the most common being a census tract that had close to zero change before and after Katrina would satisfy both the first and third concept of change. These tests in addition to the earlier statistical analysis were considered when finalizing the case study that aimed to answer the third research question accounting for the patterns of changes observed.

The four steps in understanding the data: descriptive statistics, paired t-test, cluster and outlier analyses, and lastly concepts of change analysis, will examine the data through both spatial and temporal lenses. This analysis is a combination of commonly used methods and a novel approach to operationalizing concepts of change present in the literature. These methods examine the data from both scales to make sure that relationships across the census tracts during each time period, as well as across the four time periods, are examined. Chapter 4 presents the results from these methods in the same order that they are presented here.

CHAPTER 4

RESULTS

The results of the descriptive, statistical, and conceptual analysis are described here. Descriptive results are summarized first, including timelines of each of the counties' census tracts compared to the average change for the area. The change analysis in this study consisted of three parts, a paired t-test for the entire study area, the Local Moran's Analysis for each variable and each time period for the entire study area, and a concepts of change test administered at the census tract level.

4.1 DESCRIPTIVE RESULTS

Descriptive statistics for the entire study area are summarized in Table 4.1 for each of the five variables and time periods. For the population, non-white population, and High School attainment variables, the base period (1990-2000) average was higher than any post-Katrina rates of change. Excluding one time period from the population variable, the 1990-2000 period also has the highest maximum growth in those variables. For all variables, the base period also always has the highest minimum value, meaning decreases after Hurricane Katrina were higher.

The standard deviation of the base period is almost always lower than the post-Katrina time periods, indicating more similar rates of change among the region's census tract before Katrina and more dispersed rates of change after Hurricane Katrina. Notably, the average value, max value, and standard deviation of the non-white population are higher in the base period than in any post-Katrina period, likely due to the initial small percentages of the non-white population in the region in the 1990-2000 time period, where small changes can cause large non-white percentage fluctuations.

Table 4.1 Annualized descriptive statistics of census data for the entire study area.

	Year Range	Average	Max	Min	Std. Dev
% Change in Population	1990-2000	2.07	11.41	-4.15	3.43
	2010-2015	1.24	21.57	-5.34	4.20
	2015-2019	0.35	9.12	-7.94	3.30
	2010-2019	0.84	13.65	-5.47	2.79
% Change in Non-White Population	1990-2000	8.06	78.74	-4.98	14.78
	2010-2015	4.99	70.70	-14.60	13.99
	2015-2019	1.68	51.29	-20.77	10.20
	2010-2019	2.82	34.08	-10.32	7.29
Change in Median Age	1990-2000	0.29	0.85	-0.97	0.26
	2010-2015	0.17	4.38	-2.58	1.05
	2015-2019	0.40	3.93	-1.65	1.08
	2010-2019	0.28	3.83	-1.12	0.67
% Change in Population with HS Diploma	1990-2000	1.03	9.46	-0.27	1.29
	2010-2015	0.74	7.45	-2.24	1.88
	2015-2019	0.57	3.37	-8.48	1.52
	2010-2019	0.67	5.76	-4.18	1.23
% Change in Population with Bachelor's Degree	1990-2000	2.84	28.39	-5.61	5.20
	2010-2015	3.20	41.09	-9.54	8.29
	2015-2019	2.32	34.24	-23.36	8.28
	2010-2019	2.48	37.97	-8.89	5.91

In addition to descriptive statistics, all rates of change are graphed by variable and time period (Figure 4.1). The population, non-white population, and bachelor’s degree variables use the first legend in the figure and the median age and high school variables use the second legend. This separation is used to best depict where changes occurred for each variable. These percentages are then graphed as raw values on a timeline, with 2010-2019 values graphed by county and then compared to the average raw values for each county from 1990-2000. This is done for each of the five variables considered in the study with the 2010-2019 raw values depicted in grey, the average for each year from 2010-2019 by year in blue, and the 1990-2000 county average values depicted in black.

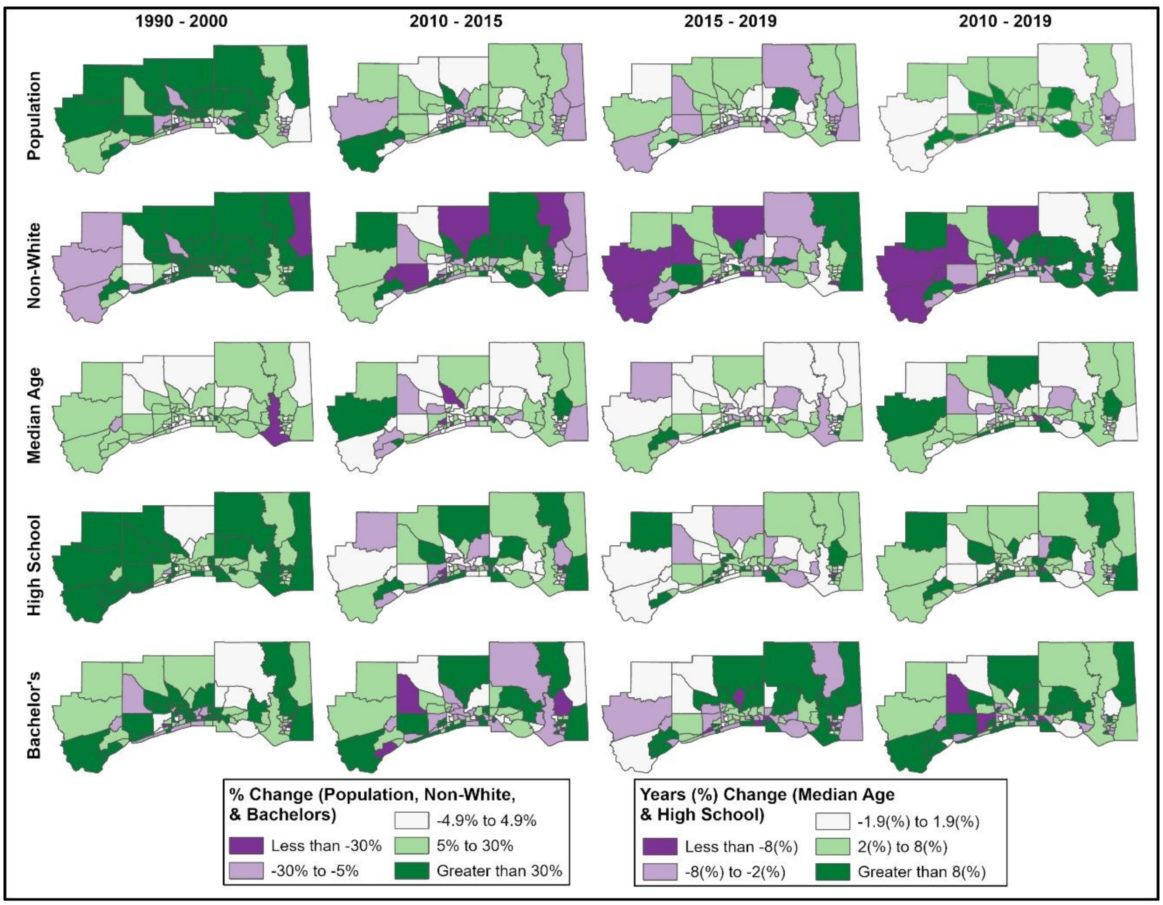

Figure 4.1 Raw percentage or year change arranged by variable (row) and time period (column).

In Hancock County (Figure 4.1), the majority of census tracts had populations above the average 2000 population, but over the 2010-2019 period, the growth and decline rates of the population varied widely. The average proportion of the population that was non-white between 1990 and 2000 hovered around 10% but the post-Katrina time period shows large a flux in these proportions over time including one census tract that reached 40% non-white population in the 2013 ACS (containing data from 2009-2013).

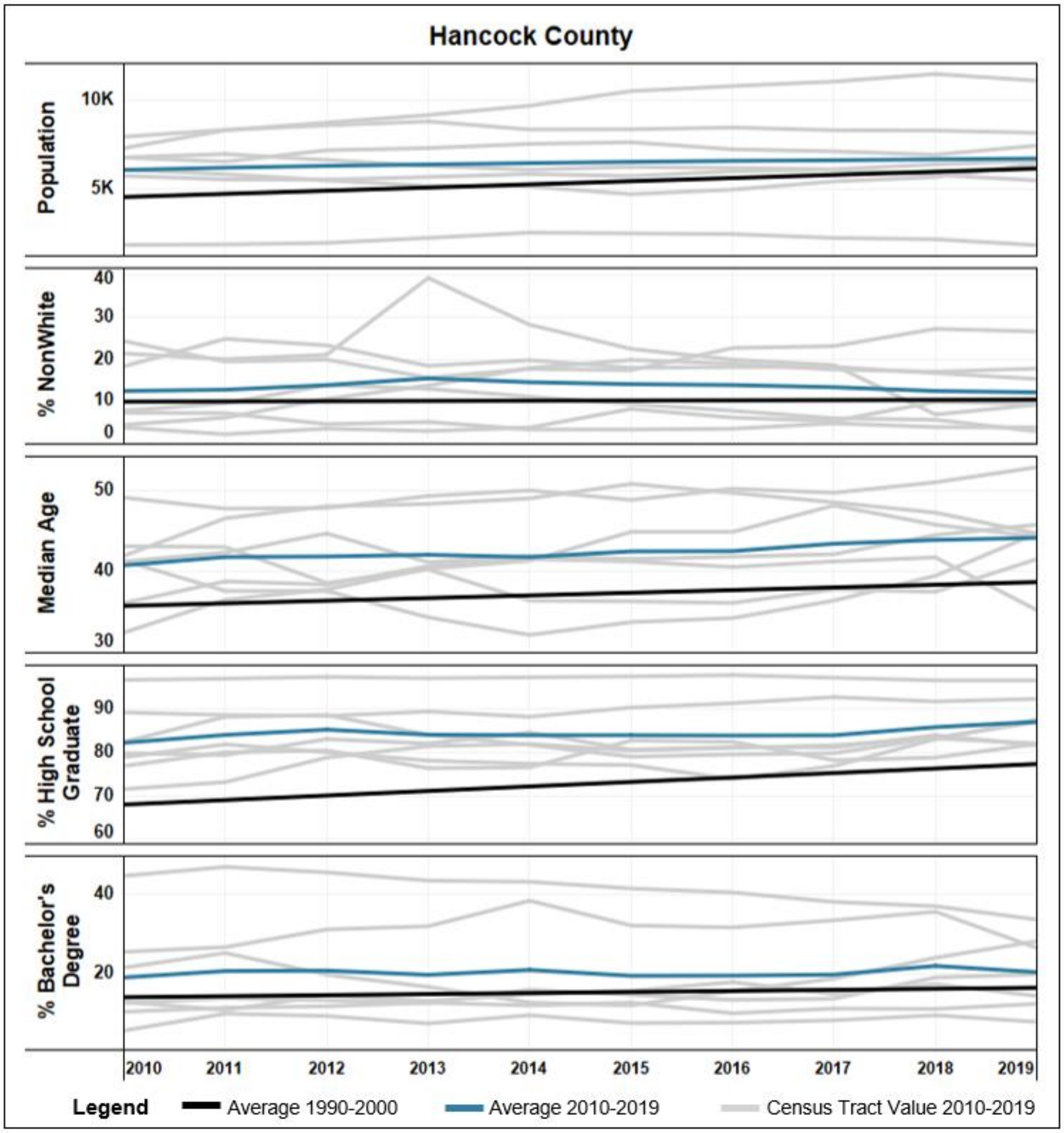

Figure 4.2 Hancock County variable change from 2010-2019.

Any outliers in the Harrison County (Figure 4.2) variables are easier to discern because of the larger number of census tracts in Harrison County, showing a more solid

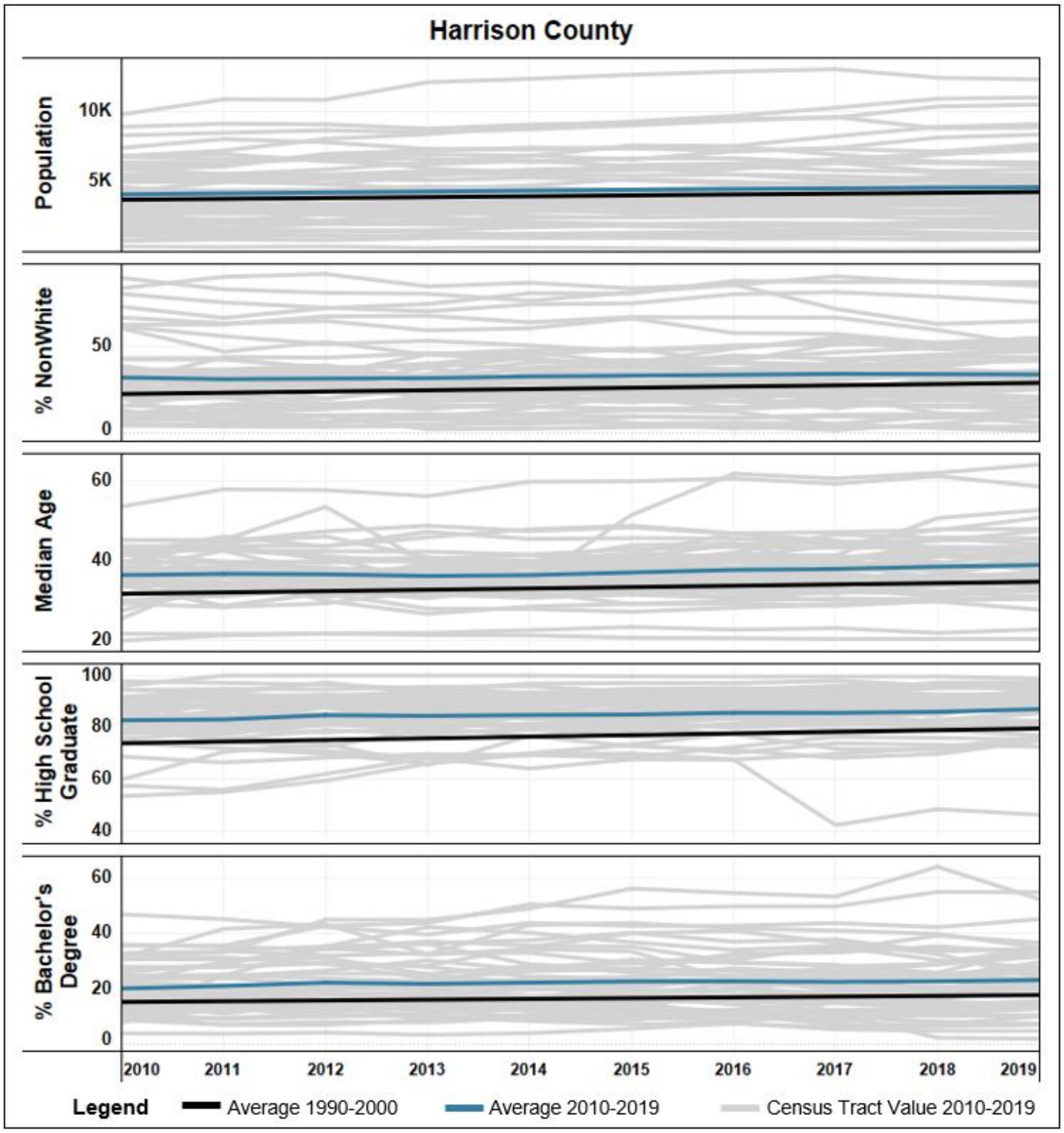

Figure 4.3 Harrison County variable change from 2010-2019.

gray where the tracts follow the same trend and lines above and below where there are census tracts with outlying raw numbers. While some census tracts regularly have the highest population or non-white population, there are census tracts that change drastically in the median age, high school attainment, and bachelor's degree attainment. Similar to Harrison County, some census tracts in the Jackson County (Figure 4.3) non-white population variable show steady high values, separate from the majority of the census tracts in the county. Median age and bachelor's degree attainment have a wider variability in raw values while high school attainment seems most similar in Jackson County among all census tracts.

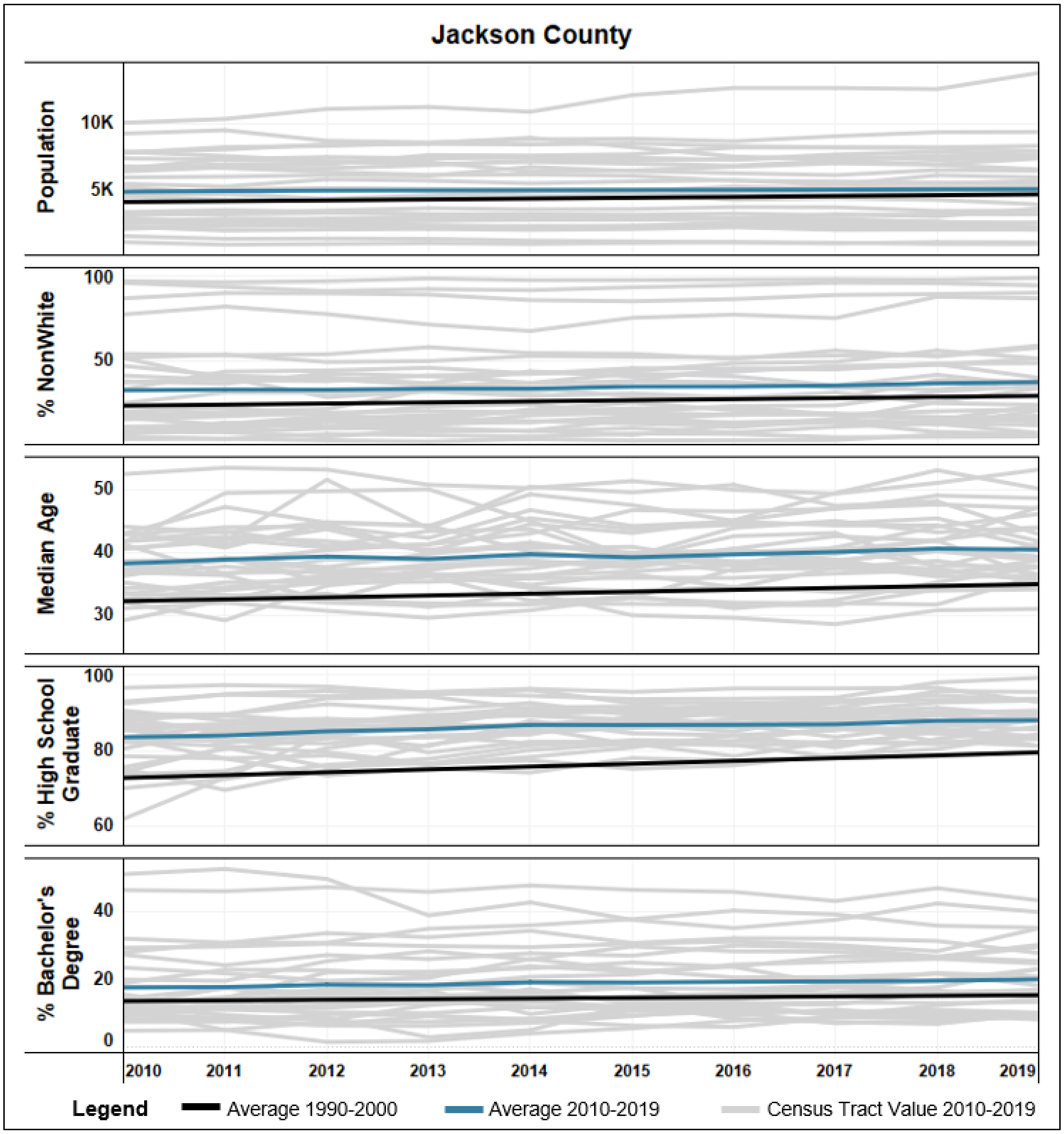

Figure 4.4 Jackson County variable change from 2010-2019.

For all three counties, change rates reflect what is shown in Table 4.1, the 2010-2019 trendline has a slightly flatter slope than the 1990-2000 trend line in most cases. The most variation by census tract seems to be in the median age and bachelor's degree attainment variables which have a large spread as well as some possibly notable outliers.

For each of the counties, the yearly average for 2010-2019 is above that of 1990-2000 showing that the value for each variable was above 1990 levels in 2010 and above 2000 levels in 2020. In some cases, this is a very small difference, especially for the population in Harrison and Jackson Counties and the non-white population in Hancock and Harrison Counties. The wider the gap between the two trend lines, the larger the difference in raw values of each variable. If the gap lessens over time, as it does for the population variable in Hancock County, the rate of change from 2010-2019 is less than that of 1990-2000. If the gap widens, as it does visibly from 2010-2013 in the non-white variable for Hancock County, the 2010-2019 rate of change is higher than that of 1990-2000.

4.2 PAIRED T-TEST RESULTS

The paired t-test results (Table 4.2) show very few significant changes in annualized rates of change for the entire study area between the base period (1990-2000) and the post-Katrina periods. The two post-Katrina periods (2010-2015 and 2015-2019) show no significant changes between the two for any of the variables, indicating that the rates of change over the 2010-2019 time period did not change significantly over the entire study area. From the base period to the 2010-2015 period, the annualized rates of change for the study area were also not significantly different.

The two variables that do show significant differences between means of annualized rates of change are population and non-white population. Returning to Table 4.1, the average annualized rate of change of population and non-white population decreased from the Base period to the post-Katrina periods. These two variables are only significantly different from the Base period in the 2015-2019 period and the 2010-2019 period.

Table 4.2 Paired t-test values for study variables for the entire study area (two-tailed *p < .05, **p < .001).

	Base v 10-15	Base v 15-19	Base v 10-19	10-15 v 15-19
Population	1.371	4.026**	2.822*	1.445
% Non-White	1.281	3.511**	2.751*	1.510
Median Age	0.889	-0.943	0.159	-1.222
% Attain High School	1.277	1.685	1.750	0.597
% Attain Bachelors	-0.365	0.443	0.395	0.583

4.3 LOCAL MORAN'S I RESULTS

The Local Moran's I test was completed for each variable and each time period and mapped alongside the rate of change for that time period (Figure 4.4). The test did not use annualized data as it only compared data within each time period, not across time periods. Clustering was most apparent in the Base time period, especially for population, non-white population, and high school graduation rates of change.

This clustering shifted depending on the variable. Population and non-white population clusters were in the northern third of the study area in Hancock and Harrison Counties and near the coast and Moss Point in Jackson County. Non-white population growth had a large low-low cluster in Harrison County and there were few significant clusters or outliers for median age in the base period. High School attainment changes were clustered as a low spot in coastal Harrison County, crossing over to low outliers in Jackson County. Bachelor's degree attainment changes were clustered in a low spot in Moss Point and Pascagoula with a small high cluster on the Harrison-Jackson County border.

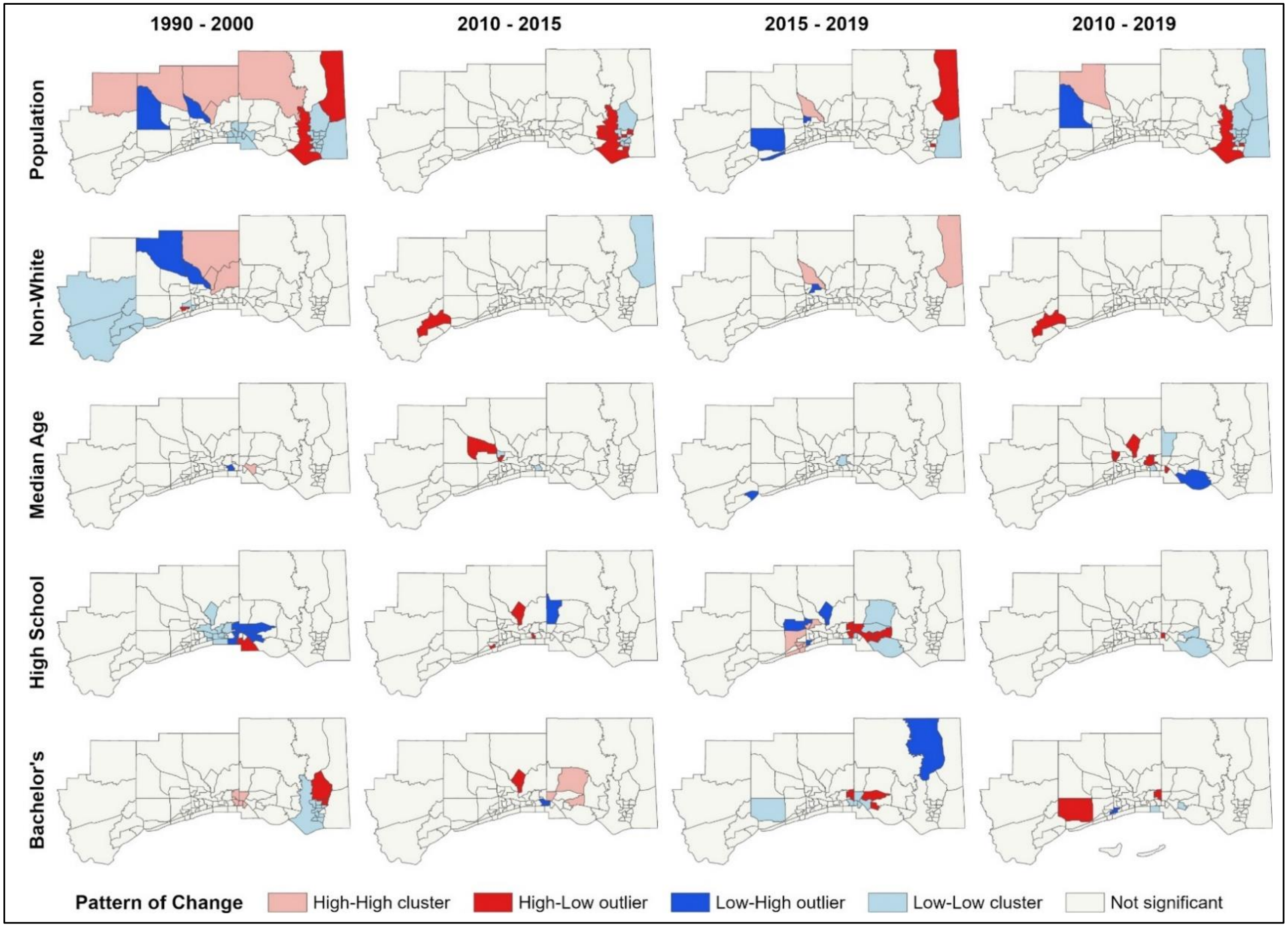

Figure 4.5 Local Moran's I cluster and outlier results arranged by variable (row) and time period (column).

Population growth clusters remained low in Jackson County across all time periods, with low outliers in parts of Harrison County in later time periods. Only one census tract in Harrison County, north of Gulfport, was part of a statistically significant high-high area in 2015-2019, meaning the population was part of a cluster growing faster than the area around it. This census tract was also a high-high cluster in the non-white variable for the same time period.

Non-white change in population had very few clusters beyond the base period. The only cluster that appears in both the Base and post-Katrina periods is in Hancock County and is the Bay St. Louis census tract which was a low spot in the Base period but was growing in non-white population faster than its neighbors in the post-Katrina period. This is again possibly due to a small proportion of the non-white population, so any growth in that population is disproportionately large.

Median age also contains very few consistent patterns of clustering across time periods. One census tract in Harrison County is a consistent low outlier or low cluster whereas census tracts in the upper third of the county tend to be higher clusters, meaning their aging faster than the census tracts around them.

High school education had mostly low clustering in the base period, which switched to some high outliers in the 2015-2019 period. High school attainment and bachelor's degree clustering were more focused on the Harrison-Jackson County border but were inconsistent over time, especially in the full 2010-2019 period. There are few trends across the different variables. Clustering is rare in Hancock County and is often focused away from the coast in Harrison County and is scattered in Jackson County. Education variables show the most clustering in later time periods, especially from 2015-2019.

4.4 CONCEPTS OF CHANGE RESULTS

While the means of some variables for the entire study area did not change significantly over time, as shown in the paired t-test, some census tracts experienced large change or small change as defined by this study. These differences were identified through the concepts of change rules explained in Section 3.4. The z-scores used to define three of the four concepts of change are mapped (Figure 4.5) and show how the category of z-score for each census tract may change over time.

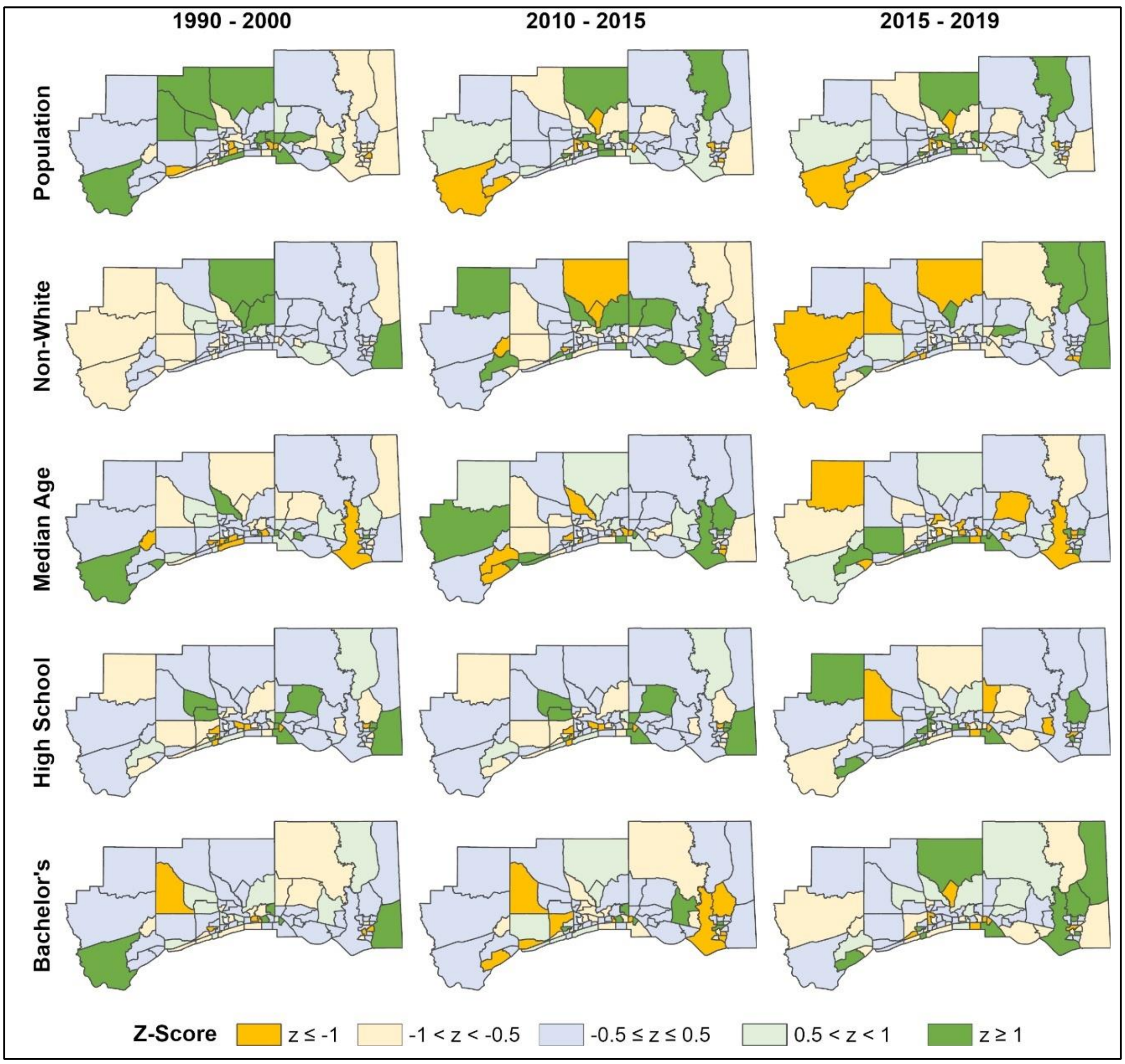

Figure 4.6 Z-scores in five categories by variable (row) and time period (column).

These z-scores and the additional rules for the near zero-change concept (Concept C) were applied to each variable and each census tract, resulting in a table summarizing what variable satisfied what rule for each census tract (Appendix A, Table A.1). Any census tract with three or more variables that satisfied one or both small change concepts and any census tract that had three or more variables that satisfied one or both large change concepts were mapped (Figure 4.6).

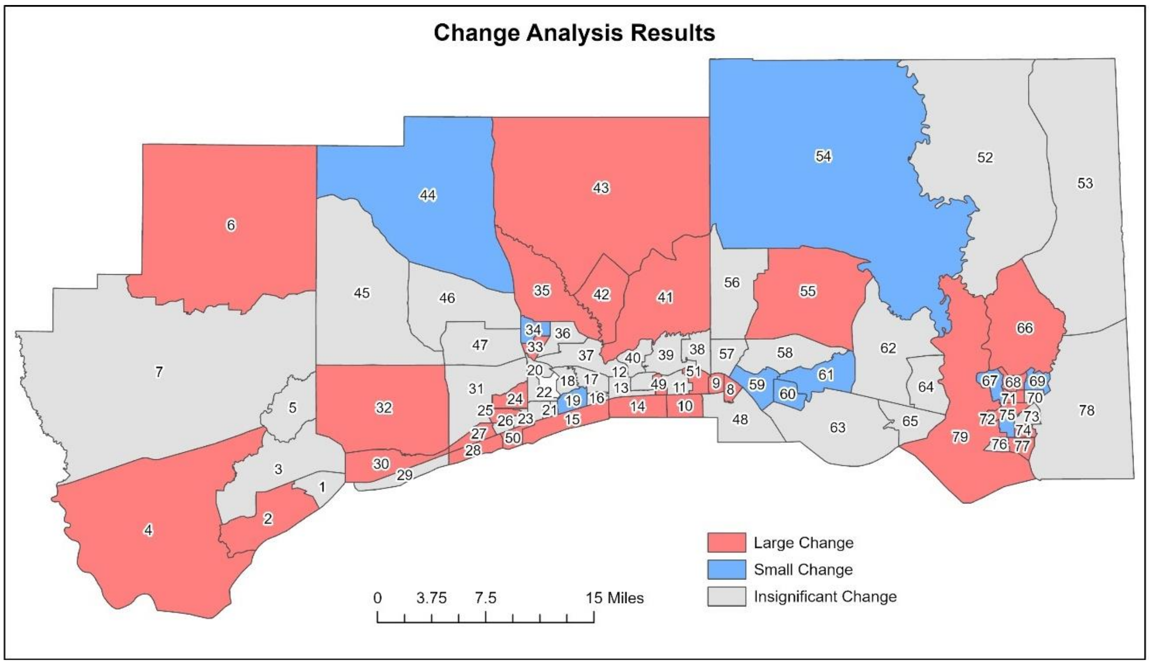

Figure 4.7 Results from the concepts of change analysis.

All census tracts in Table A.1 and Figure 4.6 are labeled with a number to simplify reference to certain areas and tracts and are referred to by that number in the text. To find the actual census tract name, refer to Table A.1 in Appendix 1 which has both the label number and the census tract number. A larger map of labeled census tracts can be found in Appendix 1, Figure A.1.

Out of the forty census tracts highlighted in this analysis, thirty are highlighted as large change census tracts and ten are highlighted as small change census tracts. The breakdown of what variables were judged as large, small, or insignificant change according to the concepts of change rules is included in Table 4.3. In the table, ↑ indicates that a variable experienced a large change, ↓ indicates the variable experienced a small change, and = indicates that the variable experienced an insignificant change.

Most of the large change is due to satisfying concept D, which tracked whether the rate of change fluctuated when comparing the two post-Katrina time periods. Seventy of the seventy-nine census tracts had at least one variable that satisfied concept D. Large change census tracts were generally highlighted for a combination of age and education variables, though since a census tract needed a large change concept in three variables to be highlighted, the combinations vary.

The majority of the small change census tracts are highlighted due to concept A, where the rate of change before and after Katrina was in the same z-score category. Any near-zero census tracts generally also had concept A highlighted, meaning that they had rates of change near zero and in the same z-score category before and after Hurricane Katrina. Variables that weighted the census tract to small change varied, with high school education, bachelor's attainment, and non-white population almost equally present. All but two of the small change census tracts (59 & 60) had a combination of large and small change concepts represented with the most common being population change.

There are several clusters of large change and small change in each county except for Hancock County which only has large change census tracts. Hancock County (1-7) high change census tracts are concentrated in rural areas (4 & 6) and Waveland (2), with Bay St. Louis (1 & 3) and Diamondhead (5) not having any distinct large or small change patterns. Hancock County (8-51) large change census tracts are concentrated along the

Table 4.3 Highlighted results from the concepts of change analysis. Colors correspond to Figure 4.6 large (red) and small (blue) change.

	Map Num.	Tract Num.	Population	Non-White Population	Median Age	High School Attainment	Bachelor's Degree Attainment
Hancock County	2	302	↑	=	↑	↑	↑
	4	304	↑	↑	=	=	↑
	6	306.01	↓	↑	↑	↑	↓
Harrison County	8	1	↑	=	↑	↑	↑
	9	3	=	=	↑	↑	↑
	10	6	↓	↑	↑	=	↑
	14	13	↑	=	↑	↓	↑
	15	14	↑	=	↑	↑	↑
	19	17	↑	↓	↑	↓	↓
	24	24	↑	=	↑	↑	=
	25	25	↑	↑	=	=	↑
	27	27	↑	↑	↓	↑	=
	28	28	=	=	↑	↑	↑
	30	30	↑	=	↑	↓	↑
	32	31.02	↑	↑	↑	=	=
	33	32.04	=	↑	↑	↑	=
	34	32.05	↑	↓	↓	↓	=
	35	32.06	=	↑	↑	=	↑
	41	34.02	↑	↑	↓	↑	=
	42	34.03	↑	↑	=	=	↑
	43	34.04	↑	↑	↑	=	=
	44	35.01	↑	↓	↓	↓	↓
	49	37	=	↓	↑	↑	↑
	50	38	↑	↑	=	↑	↑
	51	39	↑	=	↑	↑	=
Jackson County	54	402.01	↓	=	↓	↓	↑
	55	402.03	=	↑	↑	↑	=
	59	405	↓	=	=	↓	↓
	60	406	↓	=	=	↓	↓
	61	407	=	↓	↑	↓	↓
	66	413	↓	↓	↑	↑	↑
	67	414	↑	↓	↑	↓	↓
	68	415	↓	↓	↑	↑	↑
	69	416	↓	↓	↑	↑	↓
	71	418	↑	=	↑	↓	↑
	72	419	=	↑	=	↑	↑
	74	421	↑	↓	↑	=	↑
	75	422	↑	↓	↓	↑	=
	77	426	=	↑	↑	↑	↑
	79	429	↑	↑	↑	=	↑

coast including the Biloxi Bay. Moving inland, the tracts have less of a significant change pattern and then moving even further inland to the upper Northeast quadrant of the county, tracts have large change again. Small change census tracts are more scattered and large change tracts vastly outnumber small change tracts. In Jackson County (52-79), there is a more even ratio of small change to high change census tracts. Small change tracts are mixed with large change tracts in Moss Point and Pascagoula (67-77, 79) with some scattered small change tracts in the Ocean Springs area (59-61).

4.5 SUMMARY OF ANALYSIS RESULTS

The results from this analysis emphasize the place-based nature of change and recovery and show that scale of analysis is important when assessing hazard impacts. At the study area scale, average rates of change did vary from the base period to post-Katrina periods, but the paired t-test showed that these differences were only found to be significant in later time periods and only in the population and non-white population variables. The graphs of different census tracts compared to county averages show the fluctuations on a temporal scale, while the cluster analysis highlights census tracts where outliers and major trends in change occurred over the time periods studied.

The Local Moran's I cluster and outlier analysis did not show consistent patterns across variables, but there were some census tracts and areas that were consistent across time within one variable. Specifically, Jackson County has consistent low clusters in population and high school educational attainment and some variable clustering in bachelor's attainment. This means that these variables were changing at low rates, not that the raw percentage of those variables was very low. Jackson County having consistently low rates of change may be connected to how far it was away from Katrina's track, which will be explored further in Chapter 4. Hancock County showed almost no clustering beyond the population and non-white population variables in the pre-Katrina period. Harrison County had inconsistent clustering between time periods and variables, leading to few interpretations of the results.

The variable cluster and outlier analysis in combination with the descriptive statistics show a very inconsistent pattern of changes across the study area when comparing the baseline to post-Katrina time periods or when comparing the two post-Katrina periods to each other. This led to the concept of change analysis which attempted to understand the change within each census tract across the base and post-Katrina time periods. The z-scores of each census tract showed how rates of change in the study area varied over both space and time, and the operationalized concepts of change identified forty census tracts that experienced either large or small changes compared to the rest of the tracts.

These large changes were focused along the Mississippi coast, where damage was higher due to the storm surge, and far inland, where development moved to minimize future risk. Patterns of small change were focused in urban areas or in rural areas that had not been developed as much. There are very few census tracts that experienced declines or gains in all variables studied at the same time, meaning that the relationship between these variables is nonlinear and not fully understood. Most census tracts satisfied enough concept of change rules to be considered in the case study, leading to a regional and county-based approach. The goal of the subsequent case study is to further investigate the patterns of these large and small changes and examine why there are fluctuations in the raw numbers and rates of change at each time period.

CHAPTER 5

ACCOUNTING FOR CHANGE

The case study applied for this thesis seeks to account for the patterns of cluster analysis and of high and low changes across space and time observed in Chapter 4. A combination of quantitative and spatial data and archived recovery and mitigation plans are used to gain a deeper understanding of the local, county, and state dynamics after Katrina and throughout the late 2000s and the 2010s that impacted neighborhood change in this area. This analysis is completed for the study area at the city, region, and county level, but includes information for the entire state to contextualize observations. The chapter is organized by first explaining the data used for the case study, including any methods to convert data to applicable information, followed by a discussion of the damage inflicted by Katrina, and lastly reviews recovery and other change factors at the city and county scale.

5.1 DATA AND METHODOLOGY

In a search to understand the decisions and priorities of cities, counties, and people in the years after Katrina, many different data sources were assessed. FEMA makes public data on each federally declared disaster and the federal funds used for each declaration which is accessed through OpenFEMA. National Flood Insurance Program (NFIP) claims, project descriptions for Hazard Mitigation Grant funding, and information on Individual Assistance (IA) applications and disbursed funds were all downloaded and aggregated to the census tract scale for descriptive spatial analysis and in-depth information on where funding was allocated.

Landcover data from the National Land Cover Database was used to investigate where urban development has focused over the 2006-2019 period. This database processes Landsat imagery to classify it as one of twenty land cover classes, including specific classes on development (Dewitz & U.S. Geological Survey, 2021). The database also includes maps on impervious surfaces, which are used as a proxy for increased development in this case study. The impervious raster layers were downloaded for the years 2006 and 2019. Using ArcGIS, the mean imperviousness for each census tract was calculated and the 2006 value was subtracted from the 2019 value to reach a change in mean imperviousness for each census tract. Other spatial information considered includes Katrina storm surge damage polygons produced by the National Geospatial-Intelligence Agency (NGA) for FEMA and archived by HVRI during the lab's previous work researching Hurricane Katrina, and census data by county and for the entire state of Mississippi downloaded from the U.S. Census website.

This more map-based approach was followed up by a close reading of several reports, including Katrina recovery reports by the Office of Governor Haley Barbour, independent reports completed by the Gulf Coast Policy Institute and the Mississippi Center for Justice, and comprehensive city and county plans for the study area. These reports were chosen to obtain at least a county-level understanding of regional plans for the study area. Comprehensive plans for Hancock County and plans completed before Hurricane Katrina could not be found online and as such were not included in this study. To understand the impacts of the 2008 housing lending crisis, the BP oil spill, and other events separate from Katrina, future development and specific recovery plans were collected as well. In total, twelve plans spanning 2008-2020 were considered for this case study.

This case study considers the city-level as well as census tract and county-level scales since many decisions for development and recovery are made within city jurisdictions, especially over the long term. Census tracts do not always align with city boundaries, so city boundaries, local maps, and the census tract maps used for analysis were carefully compared. Figure 5.1 shows the cities discussed in the case study as well as Hurricane Katrina's track and Interstate-10, which is a common reference on the Mississippi coast. In addition, Google Earth Pro was used to collect satellite images of specific areas before and after Hurricane Katrina to illustrate some of the patterns explained in the case study.

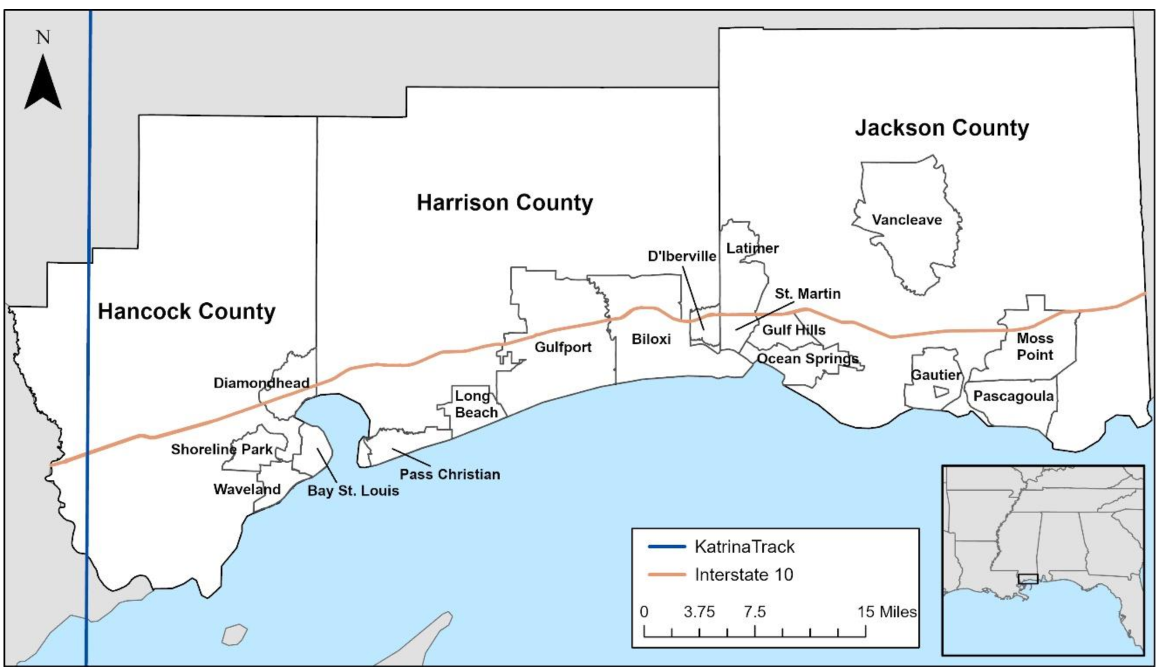

Figure 5.1 The study area with city boundaries displayed.

5.2 DAMAGES AND LAND USE CHANGE

Damage from Hurricane Katrina is shown in Figure 5.2 from the NGA polygons created for FEMA. Storm surge damage is focused along the coast and concentrated in Hancock and Harrison Counties. Inland damage is also focused in the same two counties, with Bay St. Louis and Waveland receiving the brunt of the damage in Hancock County and almost all of the Harrison County coast receiving catastrophic damage ratings. Moss Point in Jackson County received some of the highest damage in its region though very few individual assistance dollars were disbursed in the area and very few NFIP claims were completed there as well.

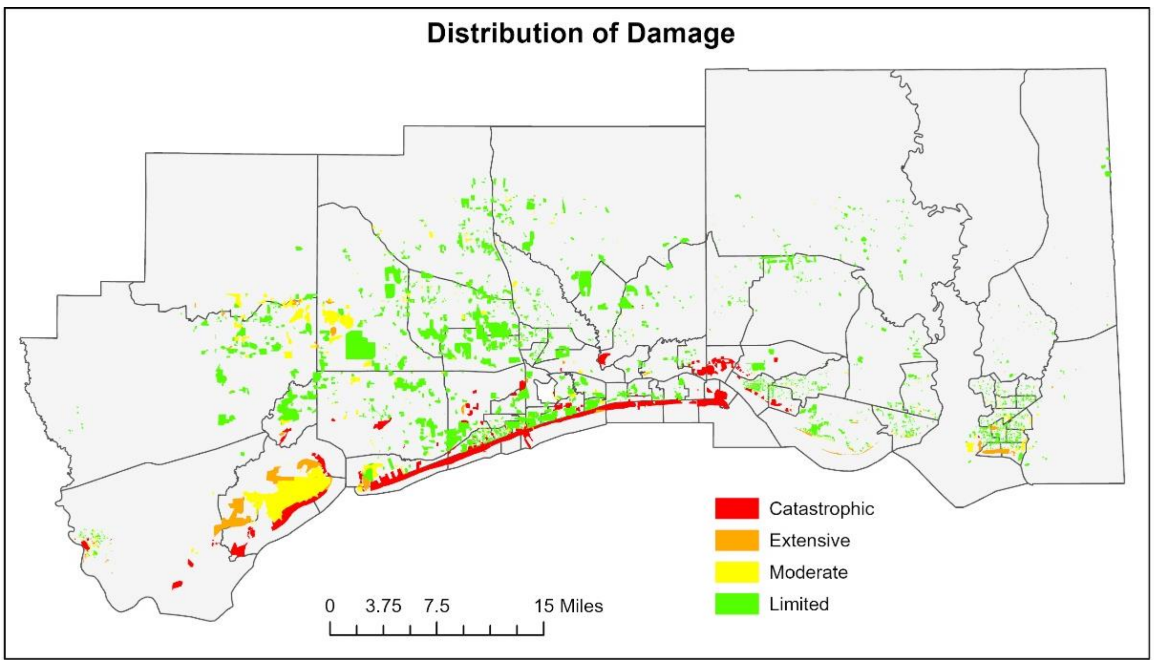

Figure 5.2 The distribution of damage in the study area (ITS Mapping and Analysis Center, 2005).

Wind damage continued inland, and while not shown in this figure, damaged buildings throughout Mississippi, which is one of the reasons the FEMA disaster declaration covered most of the state. The damage polygons follow the contours of the coast more closely than census tract polygons, meaning the red catastrophic damage is located directly on the coast. These red and yellow polygons align closely with some of the large change census tracts identified in Chapter 4.

Individual assistance dollars disbursed downloaded from OpenFEMA are summarized in Figure 5.3 and show a concentration of assistance in Hancock County and coastal areas, following storm surge and flooding damage patterns. NFIP claims, also retrieved from OpenFEMA, are even more concentrated on the coast showing the impacts of storm surge rather than riverine or flash flooding in the impacted area (Figure 5.4). Jackson County has the least IA dollars and NFIP claims in the study area, understandably considering the area received less storm surge and wind damage due to Hurricane Katrina.

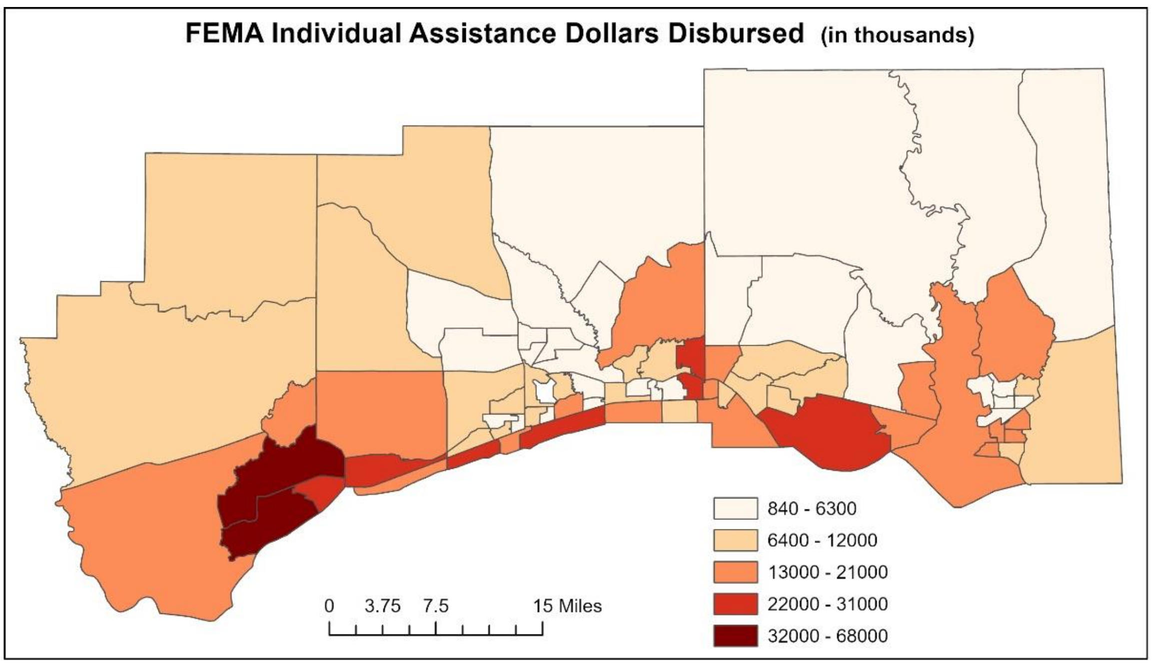

Figure 5.3 Individual Assistance awarded by FEMA (OpenFEMA 2022a).

In addition to disbursing IA funding and fulfilling NFIP claims, Hancock and Jackson Counties, through the Hazard Mitigation Grant program, acquired private property. Jackson County reported 123 properties acquired by the state, mostly in Moss Point but also including a few in Ocean Springs. Hancock County acquired 80 properties, mostly in Pearlington, near where Katrina made landfall, but also acquired property in Waveland.

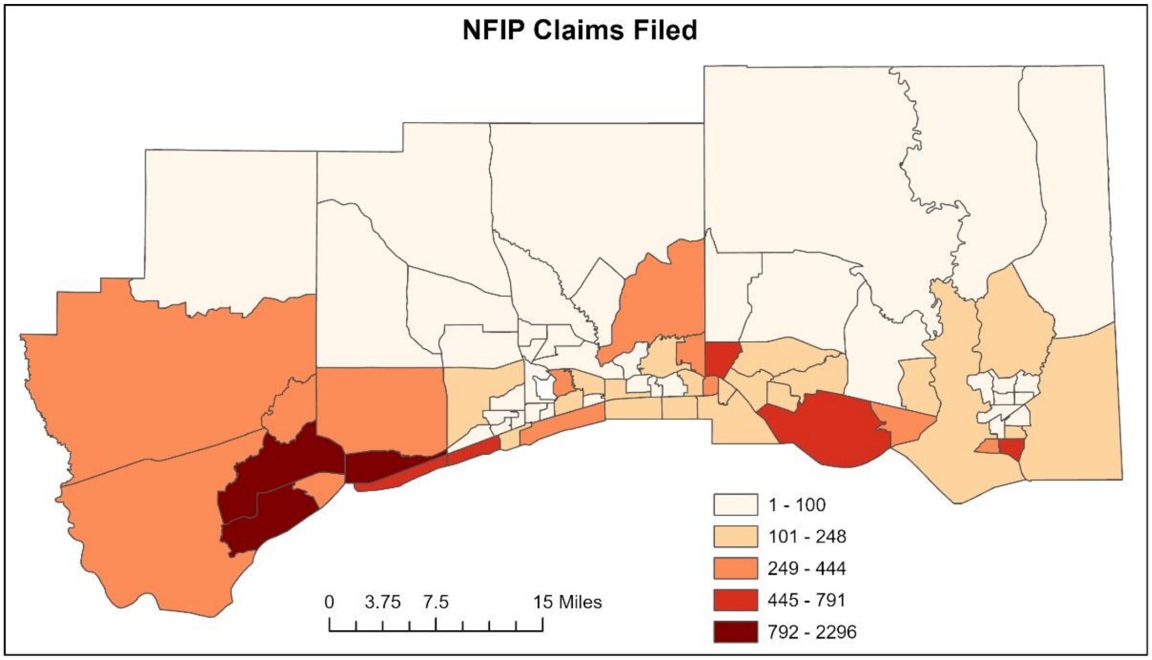

Figure 5.4 NFIP claims filed after Hurricane Katrina (OpenFEMA, 2022b).

Development followed different patterns than damage and recovery funding. As seen in Figure 5.5, the increase in the average percent of the census tract that was covered in an impervious surface was concentrated in cities, meaning that urban areas were adding even more impervious, or hard surfaces, between 2006 and 2019 more than rural areas which are generally the top third of the study area.

The coastal Biloxi area is an important outlier, showing very little growth in impervious areas even while other highly impacted coastal areas do. Inland areas of Harrison County, and to a lesser degree Jackson County, show patterns of growing hard surface away from the coast and urban centers, though Hancock County does not see this trend in its more rural census tracts.

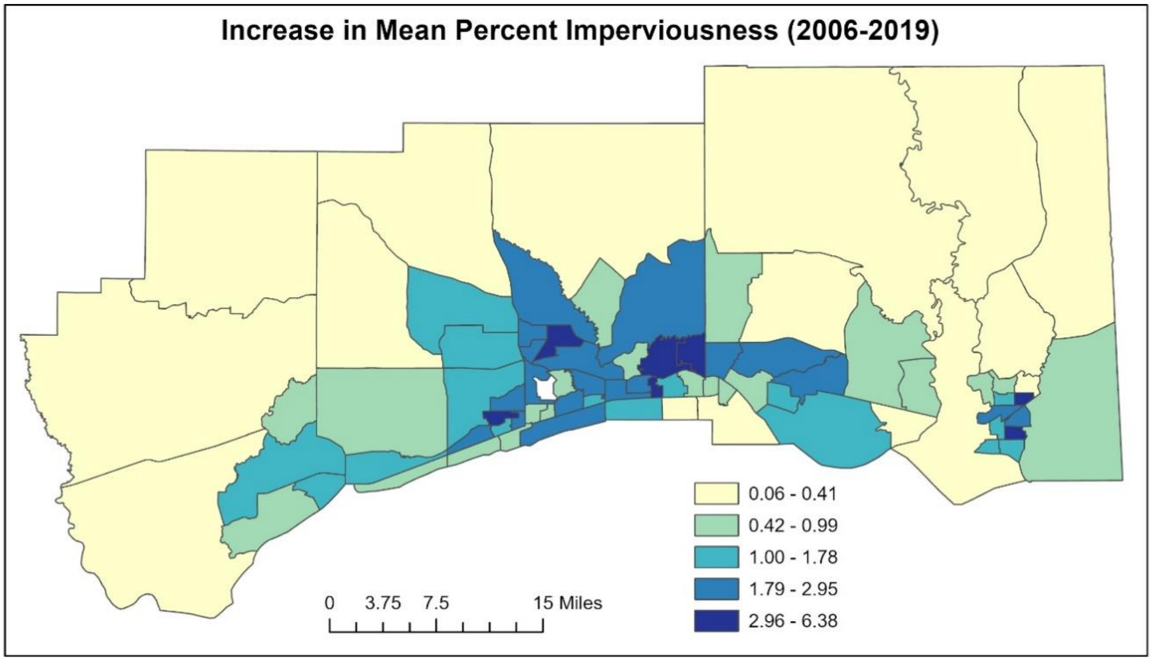

Figure 5.5 Mean percent increase in impervious surfaces, 2006-2019 (Dewitz & U.S. Geological Survey, 2021).

5.3 STATE AND COUNTY CHANGE

When discussed as a region, the changes observed in the study area follow some similar patterns. Areas directly on the coast and on the edges of urban areas away from the coast tended to have the largest changes with urban areas having mixed changes in Jackson County. Some specific cases can be explained by local phenomena, but in general, changes are understood and explained on a regional scale. In recent history, Mississippi has a low population growth rate that has slowed compared to the 1990s and 2000s, with the state losing about 6000 people between the 2010 and 2020 censuses. All three coastal counties are in the top ten growing counties between 2010 and 2020, with other growth focused on counties outside the city of Jackson, the state capital, and in the Northern half of the state.

Coastal areas were slow to redevelop after Hurricane Katrina due to a combination of factors. Some homeowners wanted to leave the more coastal census tracts that were heavily impacted by storm surge for more security and safety inland, while other homeowners who did want to rebuild were delayed for various reasons. Slow decision making on new elevation requirements, increased insurance premiums and construction costs, and the 2008 lending crisis all lead to large delays in rebuilding projects, with many homeowners relocating elsewhere instead. In addition, Community Development Block Grant Disaster Recovery (CDBG-DR) funding, which is granted to communities for long-term recovery purposes by the Department of Housing and Urban Development (HUD), can take years to be disbursed to communities. These CDBG funds are generally required to have at least 50% of funding go towards low and moderate income (LMI) families, but Mississippi received a waiver to ignore income in applications for $4 billion of the $5.5 billion granted, resulting in only 23% of that funding going to LMI households (MS Center for Justice, 2010).

By 2010, there were still thousands of open cases and households with unmet needs on the Mississippi Coast, impacting a disproportional amount of wind-damaged African American neighborhoods, including Moss Point, (MS Center for Justice, 2010). Though Governor's Reports on Katrina recovery included sections on affordable housing and its successes, the actual portion of allocated funding toward income-targeted housing programs lagged behind other housing programs (MS Center for Justice, 2010; Office of the Governor, 2010). In addition, a draft of the Gulfport 2030 plan, a comprehensive plan for the future of Gulfport written in 2010, highlights that even "newly constructed housing in the $150,000 to $200,000 range is plentiful but should not be considered "affordable" for this area…" (City of Gulfport, 2010 p18).

This has led to a patchwork of rebuilt communities, especially ones impacted by storm surge, like Waveland, Long Beach, and the Biloxi peninsula (Figure 5.6), which were highlighted as large change areas in the change concept analysis. This figure highlights an area of Waveland directly on the coast; the beach is in the bottom left corner of each image. Instead of rebuilding on the coast, many people and developers looked north of the I-10 corridor to build new homes which have led to population growth on the northern edges of Gulfport, Biloxi, and the more rural areas of Jackson County (Partnership for Sustainable Communities, 2013). The Jackson County 2022 Comprehensive Plan Update specifically highlighted the Vancleave area, corresponding to the middle third of the county, as a high development area, which was also highlighted as a large change area in this study (Jackson County Planning Commission, 2022).

The economic downturn starting in 2008 heavily impacted the tourism industry on the coast, where a large portion of the coast's income and employment are focused. Highway 90, which runs directly along the coast in Harrison County was heavily damaged by storm surge, limiting access to the beaches and casinos of the county, with the highway fully reopened in January 2006 (Office of the Governor, 2010). Unemployment in the tri-county area spiked after Hurricane Katrina and then again after the 2010 BP oil spill and while high school graduation rates have risen throughout the area, there is a lack of skilled worker training and affordable housing to support economic growth in some of the main industries in the area (Partnership for Sustainable Communities, 2013).

Coastal Mississippi, while not the largest residential housing development area, is still a focus of economic and tourism activities, including beaches, fishing, and the twelve casinos located on the coast, mostly situated in Biloxi (Community Development Department, 2011). These casinos were originally heavily structured barges that were technically off the coast of Mississippi, though most were semi-permanent structures. After sustaining severe damage in the Katrina storm surge and inflicting damage to nearby buildings, Mississippi legalized onshore gambling activities on the coast, though they were still required to be within 800 feet of the waterfront. Currently, the casinos in Mississippi employ almost 9000 people, though this is still less than they employed before Katrina or even in 2006 (Community Development Department, 2011).

Figure 5.6 Waveland neighborhood in July 2005 (upper left), September 2007 (upper right), October 2012 (bottom left), and March 2019 (bottom right). Source: Google Earth Pro 7.3.

Beach activities and recreational fishing were further impacted by the 2010 BP Oil Spill which had devastating impacts on the local wetlands and wildlife, and subsequently the tourism industry on the coast. Even with other employers such as the Ingalls Shipyard, Chevron Refinery, Ports in Gulfport and Pascagoula, and the Keesler Air Force Base, most Gulf Coast residents work in the tourism and retail industries, exposing their livelihoods to the physical vulnerabilities of the coast (Partnership for Sustainable Communities, 2013). In the year of the oil spill, a lack of tourism was controlled for through short-term workers staying on the coast to assist in clean-up efforts, but by 2012 tourism has not rebounded to pre-2010 levels, which had already not completely recovered from Katrina (GoCoast, 2012).

5.3.1 HANCOCK COUNTY

Hancock County received the most direct impact from Hurricane Katrina, the storm making landfall near the border of Louisiana and Mississippi and causing devastating wind and storm surge damage. Most of Hancock County's population is on the coast in Bay St. Louis, Waveland, Shoreline Park, and Diamondhead, but a major employer of the area is Stennis Space Center which is further inland. There was little recorded development further inland after Katrina, and though the population has stayed low, and is still much less than Harrison and Jackson Counties, Hancock County has almost reached its pre-Katrina population in 2020, fifteen years after the storm.

The high change census tracts in Hancock County show a few different patterns depending on whether the tract was rural or urban. The two coastal large change tracts (Figure 4.6, Numbers 2, 4) had below-average populations, but the two rural tracts highlighted (Figure 4.6, Numbers 4, 6) were below average in educational attainment in both high school and bachelor's degrees. There is little development in these areas, with growth in impervious surfaces more concentrated in the Waveland and Bay St. Louis areas.

Waveland, the only urban census tract highlighted in the concept of change study, and a more diverse area of the Mississippi Coast, has repeatedly been heavily impacted by storms, sustaining damage from Hurricanes Camille, Katrina, and, in 2012, Isaac. A parcel-level study by Cutter et al. (2014) shows an uneven recovery even across different neighborhoods of the city and cites a “lack of personnel…lack of a tax base…lack of political clout…and a general lack of public awareness of their plight.” (p 136) for their difficulties in recovering from Katrina. These are issues that larger cities like Gulfport and Biloxi did not have to face as severely, though a lack of public awareness could be cited by all Mississippi communities when compared to the public awareness of damage in New Orleans.

5.3.2 HARRISON COUNTY

Harrison County has three focus areas of high change, and three specific neighborhoods identified by this study with large or small change. The first high-change area north of Biloxi is best explained by growing development in the area (Figure 5.7), with above-average population and educational attainment but below average non-white population. Some of this development may have been in the planning stages before Hurricane Katrina, but the storm made an impact on who moved to these areas, and the speed with which people moved away from the coast. The second high-change area is the Biloxi coast and bay (Figure 4.6, Numbers 8-10, 14) which is a center of casino activity on the coast and where commercial development has outpaced residential building (Department of Community Development, 2009).

Figure 5.7 Northern Harrison County development in 2004 (right) and 2019 (left). Source: Google Earth Pro 7.3.

The population on the Biloxi peninsula is largely black or of Asian descent. The third high-change area (Figure 4.6, Numbers 28, 50, 15), along the waterfront, is closer to downtown Gulfport and the port itself and has higher fluctuations in non-white population growth, steady population growth, and increased education attainment, possibly a result of the attempts to increase skilled labor in the area.

One area surrounded by large change census tracts but labeled as insignificant change in the concept analysis corresponds with Keesler Air Force Base (Figure 4.6, Number 11). This base is used for the education and training of Air Force members, so its population has near 100% high school attainment, and a below-average median age between 20 and 22, though it changed too much to qualify for a small change variable for high school attainment. The population of the base fluctuated largely as housing was rebuilt and the base reopened fully. Bachelor's degree attainment fluctuated after Katrina as well, possibly due to the large investments made in the base in the 2010s (City of Gulfport, 2010). This can also be seen in the cluster analysis which shows the median age of Keesler Air Force Base as a low-low cluster in multiple time periods.

The Naval Construction Battalion Center and Naval Construction Training Center overlap with a large-change census tract (Figure 4.6, Number 25). This tract is closer to downtown Gulfport and shows the same above-average high school attainment and low median age, though it fluctuated too much to satisfy the low-change rules. The non-white population of this area was a hotspot of growth before Katrina but has decreased since the storm and is instead has a high Hispanic population and the bachelor's degree attainment has consistently grown.

One of the only three low change areas in the county is one near the Gulfport-Biloxi International Airport. The area experienced extensive damage from the storm, likely due to a combination of wind damage and storm surge depending on the location, but its population dropped about 1200 people from pre-Katrina levels and then remained steady. Educational attainment has remained steady both before and after Katrina, with high school attainment growing between 2% and 6% each time period including the base period, and bachelor's degree attainment growing between 7.5% and 11% in each time period. This census tract has some of the highest non-white population in the study area and was highlighted as an area with unmet needs in 2010 (MS Center for Justice, 2010).

5.3.3 JACKSON COUNTY

Jackson County was the fastest to regain its population after Hurricane Katrina and even showed increases in school enrollment and residence that suggested that people from other impacted areas moved there (Department of Community Development, 2009). The county relies less on tourism than its neighbor, Harrison County, and suffered less housing and infrastructural damage than either Hancock or Harrison County. However, Jackson County suffered similar impacts from the economic downtown as the other two counties, issuing fewer building permits in 2007 and 2008 than in previous years, and permit numbers not recovering to pre-Katrina levels until 2017 (Jackson County Planning Commission, 2022)

As previously mentioned, the Vancleave region, the middle third of Jackson County, is one highlighted for development and growth (Jackson County Planning Commission, 2022). In addition, all together, the unincorporated areas of Jackson County have a higher population than the urban areas, showing again that rural areas are experiencing growth after Hurricane Katrina (Jackson County Planning Commission, 2022). Both the cluster and outlier analysis and the change analysis highlighted some rural Jackson County census tracts as large change areas.

There are three focuses of small change in Jackson County, a mixture within Moss Point and Pascagoula, one large rural tract that is not as much of a development focus, and three tracts in the Ocean Springs area. Ocean Springs is very white, with above-average educational attainment, and stability in population and education is why it is categorized as a low change area. The Pascagoula-Moss Point low change tracts have a much higher non-white population and comparable high school graduation but lower bachelor's degree attainment. The Moss Point area is also a cold spot for population growth and change in high school attainment before and after Katrina, though the percentage of bachelor's degree attainment has grown.

The mix of large and small changes in the Pascagoula-Moss Point area shows a local scale to change. As the section of the study area least impacted by Hurricane Katrina, this area had to recover the least from damage, though Moss Point was also highlighted as having a large number of unmet needs from Katrina in 2010 (MS Center for Justice, 2010).

The factors of neighborhood change in this area are not as easily attributable to Katrina or other events examined here and are possibly the best example of how recovery, and the neighborhood change associated with hazards, are not fully understood.

5.4 KEY TAKEAWAYS

This case study has highlighted some larger trends occurring in the coastal Mississippi region as well as some specific scenarios identified in Chapter 4 and explained further here. Delays in funding, competing priorities, and regulations caused a delay in home rebuilding that may have prevented homeowners who wanted to rebuild on the coast from doing so, leading to a patchwork of rebuilt homes and empty lots on much of the coast. Areas north of Interstate-10 are being developed for new housing instead of reconstruction on the coast, which is seen through growth in population and education categories, but often does not include proportional growth in non-white demographics.

Some specific census tracts, like the Naval Construction Battalion Center in Harrison County and the Moss Point area in Jackson County were highlighted in Chapter 4 as anomalies, and this case study explained what was occurring on a neighborhood scale. There are other areas, such as the Keesler Air Force Base, that were not highlighted in the concepts of change, but do show stability separate from the surrounding area. It is difficult to conclude all the factors at play in the long-term recovery of the Mississippi Coast, especially since the coast had also experienced the 2008 recession, the 2010 BP oil spill, and more currently, the COVID-19 pandemic that also impacted housing and economic recovery on the coast. This analysis supports the idea that recovery and neighborhood changes vary across hazard-impacted areas, following some patterns of damage and development.

CHAPTER 6

DISCUSSION AND CONCLUSIONS

The goal of this thesis was to understand whether the Mississippi coast underwent demographic changes after Hurricane Katrina with and without comparing these changes to pre-storm rates. The spatial nature of these changes was understood using cluster and outlier analysis as well as operationalized concepts of change based on the literature. The results from this cluster and change analysis were then compared to reports from Katrina recovery, as well as city and county planning documents to try to account for the changes observed.

6.1 DISCUSSION

This thesis proposed three research questions to examine demographic change on the Mississippi coast:

- Has there been a significant change in population, race, age, and education demographics in the study area over the years 2006-2019?
- Are these changes or lack of changes geographically clustered, isolated, or random?
- What accounts for these patterns of change?

Descriptive statistics and a paired t-test were used to answer the first research question by comparing annualized rates of change from pre- to post- Katrina in three different time periods. The paired t-test found that the study area only experienced significant changes in the annualized rates of change in population and non-white population when comparing the pre-Katrina rates to 2015-2019 and 2010-2019. Age and education variables did not show a significant change when comparing three annualized post-Katrina time periods to a baseline from 1990-2000.

Since population and non-white population changed, but the makeup of that population other than race did not the next part of the analysis looked at each variable and where the change occurred. This helped account for a change in the distribution of each variable even though the total amount of that variable did not significantly change over time as well as answering the second research question focusing on where changes occurred and did not occur.

When examining change at the census tract level, the rates of change per variable were not consistent across the study area or within counties. Hancock County has only seven census tracts, which made it easy to understand what areas were consistent outliers or areas of low change. This was done by graphing each variable over time. Harrison and Jackson County were less easy to understand by a visual inspection, and required more spatial analysis, in this case using Local Moran's I cluster and outlier analysis.

Across all four time periods (Base, 2010-2015, 2015-2019, and 2010-2019) the spatial clustering of change was inconsistent for almost every variable. The base time period showed the highest number of statistically significant clusters and outliers of change from the Local Moran's I analysis. Jackson County contained the most consistent low-low clusters, meaning it had consistently lower rates of change in some variables than the surrounding area. This is consistent with the patterns for the coast, where Jackson County received the least damage from Hurricane Katrina, and thus had less change in population and demographics as a result.

Using the rules for concepts of change defined in this thesis, based on more established concepts in the literature (Barnshaw & Trainor 2010; Lee 2017) this thesis identified forty of the seventy-nine census tracts as areas of large or small change. The large change census tracts fell into two main categories, either urban and directly coastal tracts or northern exurban tracts. There were many fewer small change census tracts, and most were scattered in urban areas. The most common variables that caused a census tract to be defined as large change were rates of change in the non-white population and educational attainment. Part of the reason why these two variables were the ones that stood out so often is that they generally have smaller raw values, resulting in larger annualized rates of change even as small changes occur.

The spatial patterns identified through the cluster analysis and concepts of change analysis show some common clusters of large change and small change, generally corresponding with impact and damage or a lack thereof. This corresponds with other hazard recovery studies that find a correlation between recovery time and damage severity but was further explained by socioeconomic factors (Finch et al., 2010).

To answer the third research question, attempting to account for these patterns of demographic change, a case study of the study area was completed. An analysis of local recovery, development, and comprehensive plans resulted in conclusions on the trends of new development and rebuilding in coastal Mississippi. Instead of housing that was damaged or destroyed by Katrina being rebuilt in the same location, delays and limitations for homeowners, as well as considerations about future safety, led to a growth in development on the northern edge of larger cities, especially in Harrison County. Coastal development continued, especially regarding economic and tourism development, but many of the areas are rebuilt in a patchwork network. Hancock County did not see as large of a trend of development of urban areas, though there was more growth in the St. Louis Bay census tracts than the direct on the coast census tract that overlapped with Waveland.

High damage and corresponding fluctuations in population and other demographics were captured by the change concepts analysis, by highlighting the large changes on the coast of Harrison County, Waveland in Hancock County, and the Moss Point area in Jackson County. The study's concepts of change also highlighted areas of high development in Harrison County north of Biloxi that are also discussed in other literature (Trivedi, 2020). This shows that while the concepts and operationalization of these concepts can be improved, they do successfully highlight areas of change that can be accounted for through case study research.

6.2 CONCLUSIONS

This thesis found evidence of variable change in coastal and northern exurban parts of the study area echoing reports of either unmet needs or development in these areas. These patterns of change can be attributed to Hurricane Katrina through the storm's pattern of damage and reference within city and county development plans. These changes that have persisted over the fifteen years since Hurricane Katrina and their inconsistency over the study area show the spatial nature of recovery. The two approaches of analysis, temporal and spatial, needed to be combined to understand how these changes and lack of changes were distributed over the study area and throughout the years since Katrina.

The concepts of change proposed in this research were tested through a case study that was able to support and account for many of the areas highlighted. These concepts of change and their associated rules can be applied to other hazards, areas, and variables, to examine whether the patterns of change observed in coastal Mississippi are reflected elsewhere or if other place-based contexts will alter what patterns are observed.

Long-term recovery planning and mitigation planning can learn from these patterns of changes to identify what may cause people to abandon rebuilding their home after a hazard, and where they move instead. While it is very difficult to match whether the people that did not rebuild on the coast are the same people that occupied newly built homes north of I-10, the general pattern of development still tells a story of priorities for homeowners after a disaster. Alternatively, they can identify communities that stay relatively stable such as the Ocean Springs community, and compare them to areas in flux, like Harrison County's coast, and examine what may be driving those disparities, leading to a more equitable recovery.

6.3 LIMITATIONS AND FURTHER RESEARCH

As discussed in Chapter 2, recovery is conceptualized as either the process to bounce back to the pre-disaster conditions or of attaining a counterfactual state (Cheng, 2015). Since long-term recovery, specifically, has no accepted measurement model, concepts of change were proposed in this thesis which only sought to understand where large and small changes occurred and connect them to larger recovery and planning literature. Due to the issues in defining recovery, these concepts of change could not determine whether any of these neighborhoods recovered in relation to population characteristics, just how they grew and declined over time. The next steps in identifying the true impacts of Hurricane Katrina and change due to subsequent impacts require looking even farther back in time for this study area and creating a counterfactual state to compare post-Katrina demographics to. This could result in an additional concept of change that compares the last time period (2015-2019) to pre-Katrina rates of change and determine whether the rates bounce back or reach a counterfactual.

This study was also unable to look at any smaller scale than census tract or city level data due to margins of error in ACS data below the census tract level. Data from the early 2000s and information about Katrina was also difficult to find, as much had to be accessed through web archives that may not have all relevant documents saved. Local government comprehensive reporting on Katrina-specific recovery generally ended after five years, also limiting how much qualitative information could be found.

Lastly, due to the nature of long-term recovery, there is no way to isolate the lasting impacts of Hurricane Katrina from previous or subsequent events. The extended timelines of long-term recovery mean that the recovery from one hazard studied is occurring at the same time as other events. In this case, Hurricane Katrina recovery occurred in the context of the recession of 2008 and the BP oil spill in 2010, which slowed down recovery even more (Trivedi 2020).

The causes behind the spatially variable neighborhood change observed in this thesis may be attributed to several causes outside of solely damage caused by Hurricane Katrina. Economic growth on the Mississippi coast is unequal, focused on tourism, and highly susceptible to economic downturns. Local development may also generate variations in vulnerability depending on what areas invest in growth rather than prioritizing mitigation and preparedness (Pais & Elliott, 2008). The interaction of these subsequent events is important to understand and contextualize as recovery does not occur in a vacuum. Decisions made in one recovery situation may impact recovery from other events as well. Future research should continue to investigate how communities have changed in longer time periods after a disaster and whether planning by local governments has influenced those changes.

Again, these next steps will be limited by data availability, just as this thesis was. As data availability improves at smaller scales, the methods included in this thesis and the next steps should only be improved. Recovery will continue to be difficult to define as it can be measured through a variety of variables including population demographics, housing, economic health, and more; and it depends on pre-existing trends and conditions and subsequent events almost as much as it depends on the nature of the hazard impact itself. This is why studying ongoing processes such as neighborhood change will continue to be an important way to understand how to assess how a disaster and subsequent recovery can change a population, and what we can do to limit those changes.

REFERENCES

Anselin, L. (1995). Local Indicators of Spatial Association-LISA. Geographical Analysis. 2 (27) 93-115.

Barnshaw, J. & Trainor, J. (2010). Race, class, and capital amidst the Hurricane Katrina diaspora. In *Sociology of Katrina* (Issue January 2007, pp. 91–105). Rowman & Littlefield.

Black, R., Arnell, N. W., Adger, W. N., Thomas, D., & Geddes, A. (2013). Migration, immobility and displacement outcomes following extreme events. *Environmental Science and Policy*, *27*, S32–S43. doi:10.1016/j.envsci.2012.09.001

Burton, C. (2015). A Validation of Metrics for Community Resilience to Natural Hazards and Disasters Using the Recovery from Hurricane Katrina as a Case Study. *Annals of the Association of American Geographers.* 105(1): 67-86.

Burton, C., Mitchell, J. T., & Cutter, S. L. (2011). Evaluating post-Katrina recovery in Mississippi using repeat photography. *Disasters*, *35*(3), 488–509. doi:10.1111/j.1467-7717.2010.01227.x

Chang, S. E. (2010). Urban disaster recovery: A measurement framework and its application to the 1995 Kobe earthquake. *Disasters*, *34*(2), 303–327. doi:10.1111/j.1467-7717.2009.01130.x

Cheng, S., Ganapati, E., & Ganapati, S. (2015). Measuring disaster recovery: Bouncing back or reaching the counterfactual state? *Disasters*, *39*(3), 427–446. doi:10.1111/disa.12112

City of Gulfport. (2010). *Gulfport 2030, the City of Gulfport Comprehensive Plan*. http://media.sunherald.com/static/images/graphics/0331%20Gulfport%20Comprehensive%20Plan.pdf

Comerio, M. C. (1998) *Disaster hits home: new policy for urban housing recovery.* Berkeley: Univ. of California Press.

Community Development Department. (2011). *Biloxi General Market Analysis* 2011-2012. City of Biloxi. https://biloxi.ms.us/wp-content/static/resources/market-analysis/GMAfull.pdf

Cross, J. A. (2014). Disaster devastation of US communities: long-term demographic consequences. *Environmental Hazards*, *13*(1), 73–91.

Cutter, S. L., Boruff, B. J., & W. L Shirley. (2003). Social Vulnerability to Environmental Hazards. *Social science quarterly, 84*(2): 242-261. doi:10.1111/1540-6237.8402002

Cutter, S. L., Emrich, C. T., Mitchell, J. T., Boruff, B. J., Gall, M., Schmidtlein, M. C., Burton, C. G., & Melton, G. (2006). The Long Road Home: Race, Class, and Recovery from Hurricane Katrina, *Environment: Science and Policy for Sustainable Development*, *48*(2): 8-20.

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. *Global Environmental Change*, *18*(4), 598–606. doi:10.1016/j.gloenvcha.2008.07.013

Cutter, S. L., Piegorsch, W. W., Weber, L., Mitchell, J. T., Emrich. C. T., & Smith, M. M. (2014). *Hurricane Katrina and the Forgotten Coast of Mississippi.* United Kingdom: Cambridge University Press.

Department of Community Development. (2009). *City of Biloxi Comprehensive Plan.* City of Biloxi. https://biloxi.ms.us/departments/community-development/comprehensive-plan/

Dewitz, J., and U.S. Geological Survey, 2021, National Land Cover Database (NLCD) 2019 Products (ver. 2.0, June 2021) [Data set]. U.S. Geological Survey. doi:10.5066/P9KZCM54

Elliott, J. R. & Pais, J. (2006). Race, class, and Hurricane Katrina: Social differences in human responses to disaster. *Social Science Research*, *35*(2), 295–321. doi:10.1016/j.ssresearch.2006.02.003

Elliott, J. R., Hite, A. B., & Devine, J. A. (2009). Unequal return: The uneven resettlements of New Orleans' uptown neighborhoods. *Organization and Environment*, *22*(4), 410–421. doi:10.1177/1086026609347184

Finch, C., Emrich, C. T., & Cutter, S. L. (2010). Disaster disparities and differential recovery in New Orleans. *Population and Environment*, *31*(4), 179–202. doi:10.1007/s11111-009-0099-8

Frey, W. H. & Singer, A. (2006). *Katrina and Rita Impacts on Gulf Coast Populations: First Census Findings*. *June*. https://www.brookings.edu/wp-content/uploads/2016/06/20060607_hurricanes.pdf

Fussell, E. (2015). The Long Term Recovey of New Orleans' Population after Hurricane Katrina. *Am Behav Sci.*, *59*(10), 1231–1245. doi:10.1177/0002764215591181

Fussell, E., Curtis, K. J., & DeWaard, J. (2014). Recovery migration to the City of New Orleans after Hurricane Katrina: A migration systems approach. *Population and Environment*, *35*(3), 305–322. doi:10.1007/s11111-014-0204-5

Go Coast 2020. (2013). *Go Coast 2020 Final Report*. Mississippi Department of Environmental Quality. http://www.gocoast2020.com/wp-content/uploads/finalreport.pdf. Archived at web.archive.org.

Haas, J. E., Kates, R. W., & Bowden, M. J. (1977). *Reconstruction Following Disaster*. The MIT Press.

Hunter, L. M. (2005). Migration and environmental hazards. *Population and Environment*, *26*(4), 273–302. doi:10.1007/s11111-005-3343-x

ITS Mapping and Analysis Center (2005). *FEMA-1604-DR, Mississippi – Imagery Derived Assessment Mississippi Affected Population from Flooding as of 09/08/2005 18:00 EDT*. FEMA. http://www.gismaps.fema.gov/2005graphics/dr1604/rs_MS_Floodpop_090805_1800.pdf Archived at web.archive.org.

Jackson County Planning Commission. (2022). *Jackson County Comprehensive Plan Update*. https://www.co.jackson.ms.us/DocumentCenter/View/1048/Comprehensive-Plan-2022-PDF

Kates, R. W., Colten, C. E., Laska, S., & Leatherman, S. P. (2006). Reconstruction of New Orleans after Hurricane Katrina: A research perspective. *PNAS*, *103*(40), 14653–14660.

Kendra, J., Clay, L., Gill, K., Trivedi, J., Marlowe, V., Aguirre, B., Nigg, J., Trainor, J., Carbone, E., & Links, J. (2021). Community Resilience: Toward a Framework for an Integrated, Interdisciplinary Model of Disaster. *Natural Hazards Review 22*, 04021049 doi:10.1061/(ASCE)NH.1527-6996.0000495

Knabb, R. D., Rhome, J. R., & Brown, D. P. (2005). Tropical Cyclone Report: Hurricane Katrina 23-30 August 2005. *National Hurricane Center.*

Koslov, L., Merdjanoff, A., Sulakshana, E., & Klinenberg, E. (2021). When rebuilding no longer means recovery: the stress of staying put after Hurricane Sandy. *Climatic change*, *165*(3), 1-21. doi:10.1007/s10584-021-03069-1

Lee, D. (2017). Neighborhood Change Induced by Natural Hazards. *Journal of Planning Literature*, *32*(3), 240–252. doi:10.1177/0885412217696945

National Research Council, Committee on Disaster Research in the Social Sciences: Future Challenges and Opportunities. (2006). Facing hazards and disasters: Understanding human dimensions, *Washington, DC: National Academies Press.*

National Weather Service (NWS). (2016). Hurricane Katrina- August 2005. https://www.weather.gov/mob/katrina

NWS. (2019). Hurricane Camille – August 17, 1969. https://www.weather.gov/mob/camille

National Hurricane Center (NHC). (2021). Historical Hurricane Tracks. https://coast.noaa.gov/hurricanes/#map=4/32/-80.

Office of the Governor. (2010). *Five Years After Katrina: Progress Report on Recovery, Rebuilding, and Renewal*. Office of Governor Haley Barbour. http://www.governorbarbour.com/news/2010/aug/Katrina5years.pdf

Office of the Governor. (2015). *Katrina: Ten Years After*. Office of the Governor Phil Bryant. https://mississippi.org/manage/wp-content/uploads/10yr-Katrina-Report-Final-webversion1.pdf. Archived at web.archive.org.

Olshanksky, R.B. (2005). How do Communities Recover from Disaster? A Review of Current Knowledge and an Agenda for Future Research. In *46th Annual Conference of the Association of Collegiate Schools of Planning*, 27, 1-19.

OpenFEMA. (2022a). *Individuals and Households Program – Valid Registrations* (1) [Data set]. FEMA. https://www.fema.gov/openfema-data-page/individuals-and-households-program-valid-registrations-v1

OpenFEMA. (2022b). *FIMA NFIP Redacted Claims* (1) [Data set]. FEMA. https://www.fema.gov/openfema-data-page/fima-nfip-redacted-claims-v1

Pais, J. F. & Elliott, J. R. (2008). Places as recovery machines: Vulnerability and neighborhood change after major hurricanes. *Social Forces*, *86*(4), 1415–1453. doi:10.1353/sof.0.0047

Peacock, W. G., Van Zandt S., Zhang, Y., & Highfield W. E. (2014). Inequities in Long-Term Housing Recovery After Disasters, *Journal of the American Planning Association*, 80:4, 356-371.

Partnership for Sustainable Communities. (2013). *Plan for Opportunity*. http://www.gulfcoastplan.org/wp-content/uploads/2014/04/Plan-for-Opportunity-Small.pdf. Archived on web.archive.org.

Raker, E. J. (2020). Natural hazards, disasters, and demographic change: The case of severe tornadoes in the United States, 1980-2010. *Demography, 57*(2), 653-674. doi:10.1007/s13524-020-00862-y

Schultz, J. & Elliott, J. R. (2013). Natural disasters and local demographic change in the United States. *Population and Environment*, *34*(3), 293–312. doi:10.1007/s11111-012-0171-7

Siebeneck, L., Schumann, R., Kuenanz, B. J., Lee, S., Benedict, B. C., Jarvis, C. M., & S. V. Ukkusuri. (2020). Returning home after Superstorm Sandy: phases in the return-entry process. *Natural Hazard*, *101*(1), 195-215. doi:10.1007/s11069-020-03869-1

Smith, N. (1979). Toward a theory of gentrification: A back to the city movement by capital, not people. *Journal of the American Planning Association*, *45*(4), 538–548. doi:10.1080/01944367908977002

Smith, G. P. & Wenger, D. (2007). "Sustainable disaster recovery: Operationalizing an existing agenda." In *Handbook of Disaster Research*, 234–257. New York: Springer.

Stevenson, J. R., Emrich, C. T., Mitchell, J. T., & Cutter, S. L. (2010). Using building permits to monitor disaster recovery: A spatio-temporal case study of coastal Mississippi following Hurricane Katrina. *Cartography and Geographic Information Science*, *37*(1), 57–68. doi:10.1559/152304010790588052

Trivedi, J. (2020). *Mississippi After Katrina: Disaster recovery and reconstruction on the Gulf Coast.* Lanham: Lexington Books.

U.S. Census Bureau. (2020). *U.S. Census Quick Facts.* https://www.census.gov/quickfacts/fact/table/MS,jacksoncountymississippi,harrisoncountymississippi,hancockcountymississippi/PST045219.

U.S. Census Bureau. (2021). *TIGER/Line Shapefiles.* https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html

van Holm, E. J. & Wyczalkowski, C. K. (2019). Gentrification in the wake of a hurricane: New Orleans after Katrina. *Urban Studies*, *56*(13), 2763–2778. doi:10.1177/0042098018800445

Wang, F., Tang, Q., & Wang, L. (2014). Post-katrina population loss and uneven recovery in New Orleans, 2000-2010. *Geographical Review*, *104*(3), 310–327. doi:10.1111/j.1931-0846.2014.12028.x

Wyczalkowski, C. K., van Holm, E. J., Esnard, A. M., & Lai, B. S. (2019). Uneven Neighborhood Recovery: Hurricane Damage and Neighborhood Change in the Houston–Galveston Region Since 1970. *City and Community*, *18*(2), 689–709. doi:10.1111/cico.12390

Yabe, T., Rao, P. S. C., & Ukkusuri, S. V. (2021). Resilience of Interdependent Urban Socio-Physical Systems using Large-Scale Mobility Data: Modeling Recovery Dynamics. *Sustainable Cities and Society 75*, 103237. doi:10.1016/j.scs.2021.103237

APPENDIX A

CONCEPTS OF CHANGE ANALYSIS RESULTS

Table A.1 Results from the concepts of change analysis. An X indicates that the census tract satisfied the concept rule for the indicated variables. Concepts are labeled according to Figure 3.3 and colors correspond to small (blue) or large (red) change.

	Map Num.	Tract Num.	Population				Non-White Population				Median Age				High School Attainment				Bachelor's Degree Attainment			
			A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Hancock County	1	301								x				x								
	2	302		x										x				x				x
	3	303	x							x				x								
	4	304				x				x										x		
	5	305		x						x							x		x			
	6	306.01	x							x				x				x	x			
	7	306.02								x				x			x					
Harrison County	8	1				x						x				x						x
	9	3												x				x		x		
	10	6	x							x				x								x
	11	9										x	x									x
	12	12.01	x				x							x								
	13	12.02				x												x	x			
	14	13				x								x	x							x
	15	14		x										x				x				x
	16	15.01												x								
	17	15.02																x				
	18	16	x				x							x								
	19	17		x			x					x			x				x			
	20	18																x				
	21	19								x				x								
	22	20					x							x					x			
	23	23																x				
	24	24				x								x				x				
	25	25				x				x										x		
	26	26									x							x	x			
	27	27				x				x	x							x				
	28	28												x		x						x

	29	29												x								
	30	30				x								x	x							x
	31	31.01	x				x															
	32	31.02				x				x				x								
	33	32.04								x				x				x				
	34	32.05				x	x				x				x							
	35	32.06								x				x								x
	36	32.07												x				x				
	37	32.08		x											x							
	38	33.01	x								x											x
	39	33.03																				
	40	33.04	x											x			x					
	41	34.02				x				x	x		x					x				
	42	34.03				x				x												x
	43	34.04				x		x				x										
	44	35.01				x	x				x		x		x				x			
	45	35.02																x				x
	46	35.04																x				
	47	35.05				x												x				
	48	36														x						x
	49	37					x							x				x				x
	50	38				x				x								x				x
	51	39				x						x						x				
Jackson County	52	401.01				x				x												
	53	401.02								x					x							x
	54	402.01	x								x		x		x							x
	55	402.03								x				x				x				
	56	402.04								x			x					x				
	57	403				x												x	x			
	58	404		x						x	x											
	59	405	x												x				x			
	60	406	x												x				x			
	61	407					x							x	x				x			
	62	408															x					x
	63	409	x							x	x											
	64	410																				
	65	411													x		x					
	66	413	x				x							x				x				x
	67	414				x	x							x	x				x			
	68	415	x				x							x				x				x
	69	416			x		x							x				x	x			
	70	417																x				x
	71	418				x								x	x							x
	72	419								x								x				x

	73	420					x															
	74	421				x	x							x								x
	75	422				x	x				x		x					x				
	76	425				x				x					x		x					
	77	426								x				x				x				x
	78	427								x								x				
	79	429				x				x				x								x

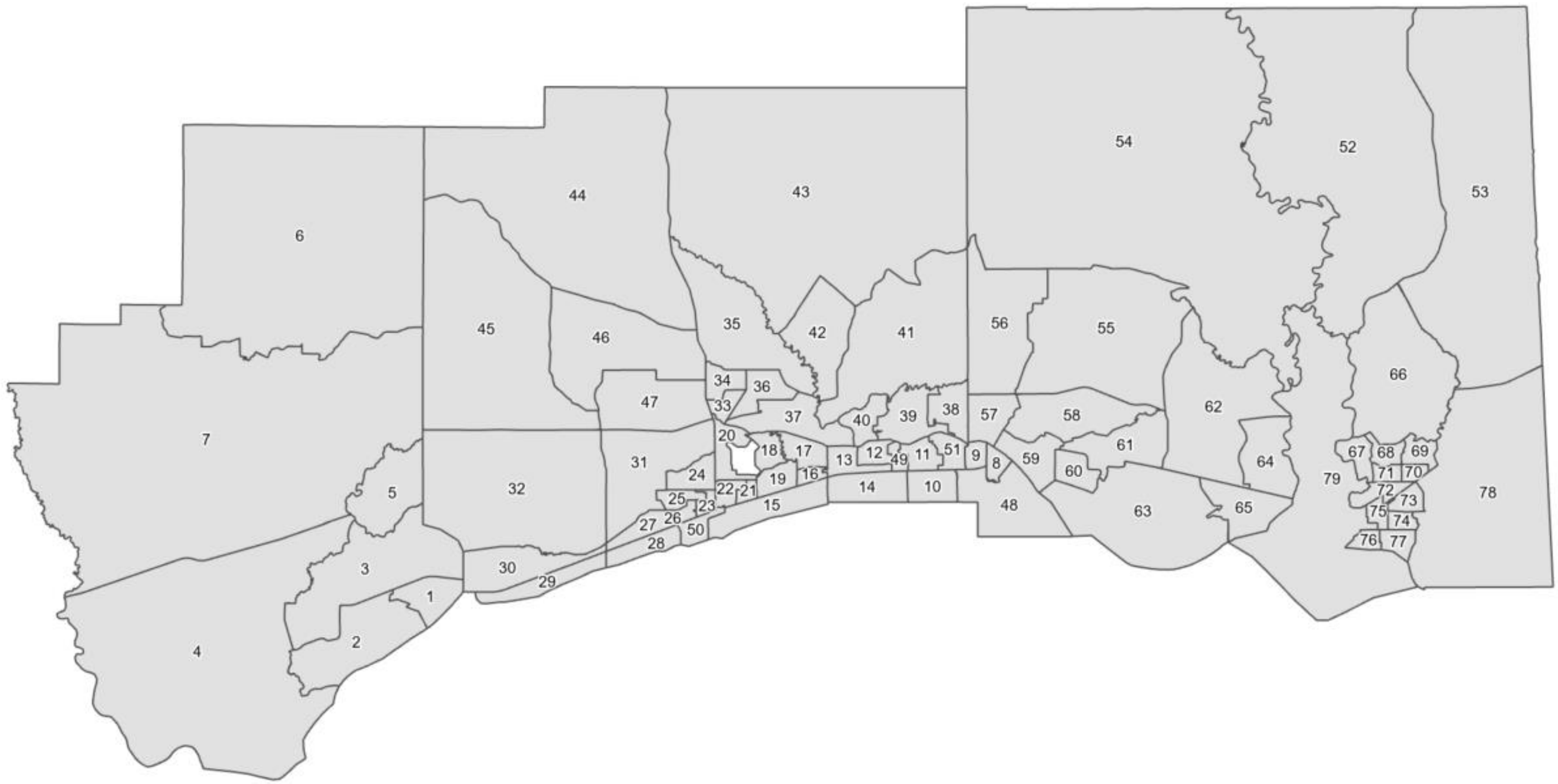

Figure A.1 Map of all census tracts with labeling used in Section 4.4.