

Derek P. Hanak. VULNERABILITY OF FOUR NORTH CAROLINA COASTAL COUNTIES TO A HURRICANE STRIKE. (Under the direction of Dr. Paul Gares) Department of Geography, East Carolina University, July 2002.

The purpose of this study is to develop a method for quantifying vulnerability that incorporates both physical characteristics of hurricanes and the social characteristics of the population being affected. This method is used to assess the spatial characteristics of vulnerability to hurricanes in four North Carolina counties: Brunswick, Carteret, Dare, and New Hanover. North Carolina is an appropriate location for this study because it has a high frequency of hurricane strikes and the population in its coastal counties has grown significantly in the last two decades. The reason behind this study is the frequency at which North Carolina is struck by hurricanes and the growing coastal population.

Physical and social data are collected at the blockgroup level to provide as much detail of spatial variation as possible within the four counties. The physical factors included are wind speed, flooding, frequency, and destructive force of wind. The social factors include a wide range of socio-economic characteristics as well as, hotel and evacuation data. Physical, social, and total vulnerability scores are calculated for the four counties. The blockgroups with the highest total vulnerability scores are located where both physical and social vulnerability intersect. Results also indicate that physical vulnerability seems to be a more important factor than some research has suggested. Dare County is found to be the most vulnerable county in the study because of its high physical and social vulnerability. Identifying these areas can allow emergency managers to improve planning for the most vulnerable populations when a hurricane approaches.

VULNERABILITY OF FOUR NORTH CAROLINA COASTAL COUNTIES TO A
HURRICANE STRIKE

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CHAPTER 1

INTRODUCTION

In 1986, the American Meteorological Society (AMS) stated that the United States is more vulnerable to hurricanes now than it has ever been in its history (AMS, 1986). As evidence of this condition, the AMS reported on evacuation studies for some of the most hurricane-prone areas, including Galveston, Corpus Christi, New Orleans, Charleston, Tampa, and south Florida. The results of these evacuation studies are not good. They indicate that it would take between 15 and 30 hours to evacuate the population from these hurricane prone areas. The AMS also states that millions of people are exposed to hurricanes and storm surge along the Atlantic and Gulf coasts because of rapid population growth. Today, more than 75 million people live in the coastal counties of the Atlantic and Gulf coasts (Jamieson et al. 1997). The AMS reports that forecast lead times are not keeping up with the time requirements for evacuating an increasing coastal population.

Hurricanes pose a huge threat to coastal counties along the Atlantic and Gulf coasts of the United States. The 1990s have witnessed a higher level of destruction as a result of hurricanes than in any other decade of the twentieth century (See Figure 1). Hurricane Hugo ripped through South Carolina leaving over \$7 billion in damages in 1989. In 1992, Hurricane Andrew caused \$25 billion in damages and killed 62 people in Florida and Louisiana. Included in this total were 125,000 houses destroyed or damaged by Andrew (Mayfield et al. 1994). Hurricane Andrew could have had an even worse

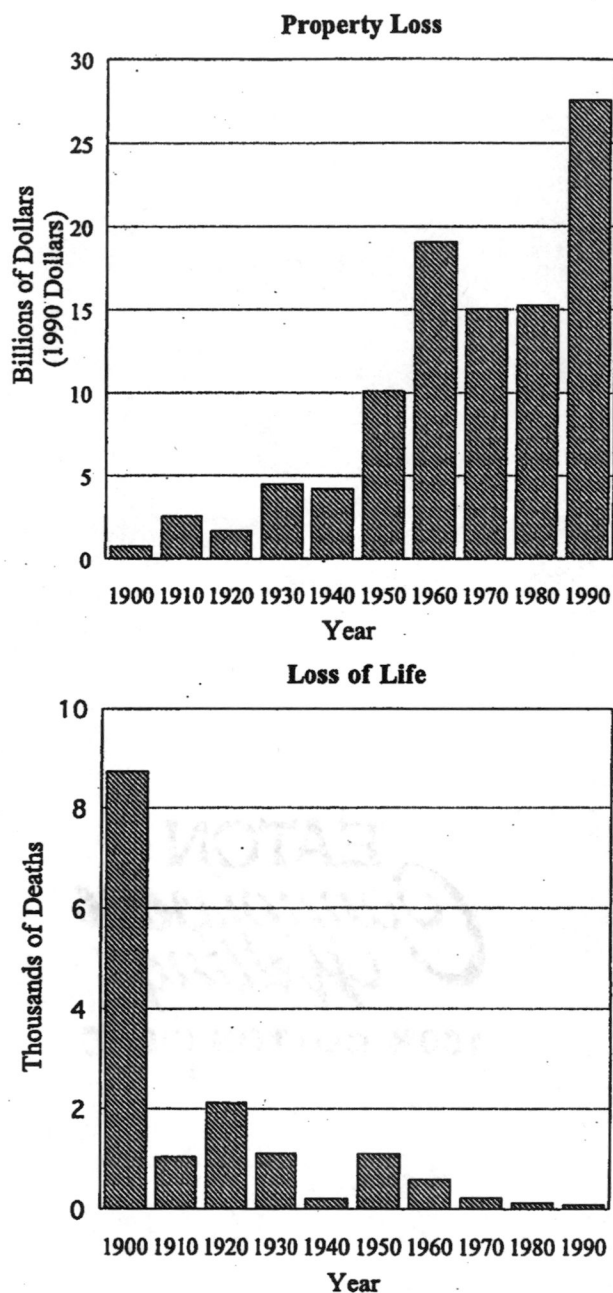


Figure 1. Comparison of Property Losses and Fatalities from U. S. Hurricanes during the 20th Century. From Jamieson and Drury. 1997. "Hurricane Mitigation Efforts at the U.S. Federal Emergency Management Agency." In, *Hurricanes: Climate and Socioeconomic Impacts*. Henry Diaz and Roger Pulwarty.

effect had it made a direct hit on Miami and New Orleans. In 1999, hurricanes Dennis and Floyd helped to create the “Flood of the Century” in North Carolina by “exceeding the predictions for the 100 year event” (Gares, 1999).

Increasing financial losses from weather are due to a variety of societal changes. The reasons behind these losses include population growth along coasts and in large cities, and more expensive holdings subject to damage (Kunkel et al., 1999, 1088). Population growth has led to development in hazardous areas such as floodplains (Reddy, 1992). Coastal counties have experienced rapid growth during the last twenty years. One consequence of this growth has been that, in 1992, approximately 85 percent of the residents of the Atlantic and Gulf coasts residents had no experience with a major hurricane (Pielke and Pielke, 1997a). This means that many people are unaware of the destruction that can result from hurricanes.

Since 1900, hurricane damages in the United States are on the increase while hurricane-related deaths have been on the decrease. During the 1970s and 1980s, there were fewer hurricanes than during the late 1940s through 1960s (Pielke et al. 1997b). Thus, fewer hurricanes are responsible for increased damages. This indicates that it is not the number of storms that is the primary factor responsible for the increase in damages during the 70s and 80s, but it is the rapid population growth (Pielke, 1999). As the coastal population rapidly increases, more hurricane-related deaths can be expected (Pielke, 1999). In addition, the trend in hurricane frequency may have reversed during the 1990s, and it appears that hurricane frequency is on the increase. Twenty-three hurricanes developed during the period 1990-1994. In the years (1995-2000), 43

hurricanes formed in the Atlantic Ocean, Gulf of Mexico, or the Caribbean Sea (Spindler, 2000 or Smith, 1999).

Important Concepts in Hazard Studies

This thesis focuses on the concept of vulnerability that has become a central component of hazards research (Cutter, 1996). Vulnerability is a concept that has developed over the last two decades. The term vulnerability first appears in the literature in the early 1980s (Gabor and Giffith (1980); Timmerman (1981)). Over the years, authors have presented many definitions of vulnerability, but there is no universally accepted definition for vulnerability in the hazards field. For the purpose of this paper, vulnerability will be defined as the “characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard” (Blaikie et al., 1994). This definition involves a combination of factors that determine the degree to which someone’s life and livelihood is put at risk by an identifiable event in nature or society. Furthermore, there is a time element in the definition because it implies how hard it can be for people to reconstruct their lives (Blaikie et al. 1994). Vulnerability can be broken down into physical and social vulnerability. Physical vulnerability is concerned with aspects of the physical environment such as hurricanes, rivers, floodplains, storm surge, and flooding. Social vulnerability is concerned with the aspects of the social environment such as age, housing, ethnicity, gender, new residents, and income.

Hazard Studies

The purpose of this study is to determine the vulnerability of four North Carolina coastal counties to hurricanes. Coastal counties are studied because they face the full force of a hurricane. This research differs from previous studies because census blockgroup level data is used to evaluate spatial variability of vulnerability and because this study will incorporate several variables not used by other researchers, particularly tourists and evacuation. This study will consider only hurricanes because other studies have considered multiple hazards. North Carolina's coastal counties are becoming more vulnerable to a hurricane strike due to rapid population growth. It is important to know that vulnerability is different for each area, city, household, and person. Detailed studies of vulnerability are concerned with spatial variation. There are very few vulnerability studies that examine spatial variation within a county. There are no vulnerability studies that look at the spatial variation of vulnerability within North Carolina's counties. Therefore the major goal of this study is to represent the spatial distribution of vulnerability to hurricane strikes in coastal North Carolina. In order to accomplish this, it will be necessary to develop a vulnerability index that accurately represents real hurricane disasters. The following questions form the basis for this research:

Research Questions

1) Can a method be developed for quantifying vulnerability?

This method needs to incorporate both the physical characteristics of the hazard and the environment and the social characteristics of the population affected.

2) Are there spatial differences in vulnerability both at a county level and within counties?

Once the vulnerabilities are determined for all the blocks in a county, analyses will reveal which blocks are the most vulnerable and what factors are the most important to vulnerability.

3) Is physical vulnerability or social vulnerability more important?

Research (Morrow, 1999) suggests that social vulnerability is more important to determining the overall vulnerability of a population. It will be desirable to determine if the method developed here can identify which factors contribute to vulnerability.

The methodology and analysis of vulnerability will be applied to four counties in North Carolina to test the usefulness of the approach before applying to all 21 of North Carolina's coastal counties. The four counties selected for the study are: Brunswick, Carteret, Dare, and New Hanover. These counties represent a variety of conditions from urbanized to rural, north to south, more developed and less developed.

Thesis Design

The second chapter of this thesis introduces the reader to the hazard literature. The components of vulnerability and previous vulnerability studies are among some of the topics discussed. Chapter Three describes the study area and methodology used in this thesis. Chapter Four presents the results and Chapter five presents an analysis of vulnerability for each county and their blockgroups. The final chapter will provide some conclusions about the findings.

CHAPTER 2

LITERATURE REVIEW

Origins of Natural Hazard Studies

The origin of hazard studies began with Harlan Barrows who delivered a presentation of “geography as human ecology” in 1923. Barrows and his students wanted to know how people and society adjust to environmental extremes, such as floods (Cutter et al. 2000). This led the federal government and geographers to wonder why people lived in floodplains? One of the geographers who studied and wrote on the effects of these floods was Gilbert White, who assisted Barrows on his work. Gilbert White’s work proved influential in the evolution of hazard studies and in reshaping national flood management policy. White believed that the increase in damages from floods was due to the fact that more people were living in protected flood-prone areas (Kates and Burton, 1986). He pointed out the inadequacies of government policies that focused on flood controls and ignored other adjustments (Kates and Burton, 1986). White and other geographers began to study floods and other disasters such as hurricanes and earthquakes to see how they affect people. They also developed a research paradigm for studying hazards (White, 1974):

- 1) Estimate the extent of human occupancy in areas subject to natural hazards;
- 2) Determine the range of possible adjustments by social groups to those extreme events and resultant hazard;
- 3) Examine how people perceive the extreme and resultant hazard;
- 4) Examine the process of choosing damage reducing adjustments; and

5) Estimate the effects of varying public policy upon that choice process.

White and his students formed the core of natural hazard research well into the 1970s. White's work placed questions of policy and practice at the heart of hazard studies. He recognized that hazards and disasters have broad social implications and placed humanitarian concerns at the heart of hazard studies (Hewitt, 1997). White (1974) says that extreme natural events illuminate one aspect of the complex process by which people interact with biological and physical systems. White's "range of adjustments" is one of the most influential ideas in hazard studies. This idea "considers the alternative actions that people take in different times and places, but especially the different possible kinds of options in any given place. These may include ways to control or prevent a dangerous process, change human land uses and practices so as to avoid it, insurance against damage, and emergency measures" (Hewitt, 1997, 172). White went on to say that the decisions that people make reflect how they view danger (Hewitt, 1997). Gilbert White situated the issue of hazards within the problems of human choice and public policy (Hewitt, 1997).

White and his students formed the foundation of natural hazard research until his traditional hazard studies were critiqued starting in the 1970s for having a theory that was too broad (Cutter et al. 2000). Several researchers expressed their dissatisfaction with White's approach to hazards. Waddell (1977) thought that White's methodology was too restraining. Another scholar, Watts, found White's approaches to hazards inadequate. According to Watts (1983), White and his students present no social theory capable of addressing social processes, organization, or change. White's views were also seen as

being too focused on extreme natural events because catastrophes are presented as being caused by natural phenomena. Hewitt (1983) points out that White's dominant view of hazard studies views natural hazards as accidents and attributed disasters to nature. Waddell (1977) states that White's work does not consider human action, says that human actions are important because they could intensify the significance of hazards or that political and economic structures associated with a favored capitalist strategy of development might amplify the effects of hazards is nowhere considered.

A number of researchers began to argue that the perception of and adjustments to hazards are constrained by cultural, economic, political, and social forces (Cutter, 1993). Hewitt (1983) thought that hazards researchers needed to understand how social, economic, and political factors contribute to disasters. According to Susman et al. (1983) and Blaikie et al. (1994), hazard theory at that time lacked the notion that natural hazards are socially and culturally constructed. Disasters are the product of the social, political, and economic environment because of the way they structure the lives of different people. The idea that natural hazards are not caused by physical events, but also by socially constructed situations has broadened the definition of hazard and geographer's approaches toward understanding them (Cutter et al. 2000).

Components of Vulnerability

As quoted in Cutter (1996, 531) Gabor and Griffith (1980) defined vulnerability as the "threat to which people are exposed" and Timmerman (1981) says that vulnerability is "the degree to which a system acts adversely to the occurrence of a hazardous event." The majority of authors and researchers can agree that vulnerability is

composed of physical and social vulnerability. The effect on any particular household results from a complex set of interacting conditions including geography, location, housing, and the social and economic characteristics of the people living there (Morrow, 1999). Cutter (1996; 2000) often refers to the study of physical and social vulnerability in a specific area as the vulnerability of place. Physical vulnerability consists of the actual physical event itself such as a hurricane, nor'easter, or flood. It also includes such aspects as elevation above sea level, floodplains, erosion, sea level rise, and storm surge. The physical event (or hazard) reveals those who are the most socially vulnerable to that particular hazard by demonstrating who is unable to resist or recover from the event.

Factors that make-up social vulnerability include demographics, economics, poverty, education, ethnicity, gender, age, and housing. Social vulnerability originates from the activities and circumstances of everyday life or its transformations (Cutter, 2000). Social vulnerability turns a hurricane into a disaster by demonstrating the inadequacies of social systems and people. Any given disaster can be thought of as a failure of the social systems (Heinz III Center for Science, 2000). "It is the patterns of development and social organization in a community that determine the extent to which it is able to withstand a storm" (Heinz III Center for Science, 2000, 114). Finally, it is the interplay of social and physical factors that produce human vulnerability (Clark et al. 1998).

Physical Vulnerability

Physical vulnerability results from the characteristics of the location and the natural hazard. Once a tropical cyclone's wind speed reaches 74 mph, it is classified as a hurricane. Hurricanes then fall into one of five categories based on their wind speed, pressure, storm surge, and expected structural damages (Table 1). A category five hurricane is the deadliest and can cause the most destruction. The major components of a hurricane hazard are storm surge, wind, landlocked flooding, coastal erosion, and tornadoes. Coastal communities will face the full force of a hurricane's winds and storm surge. Storm surge can impact over six million people in the United States that live along the shoreline (Burton et al., 1993). Storm surge accounts for over 90 percent of all deaths due to hurricanes (Pielke and Pielke, 1997a).

Table 1. Saffir-Simpson Scale (Source: Longshore 1998).

Category	Wind Speed (mph)	Storm Surge (ft)	Damage	Example
1	74-95	4-5	Minimal	Diane 1955 Agnes 1972
2	96-110	6-8	Moderate	Emily 1993 Floyd 1999
3	111-130	9-12	Extensive	Opal 1995 Fran 1996
4	131-155	13-18	Extreme	Hugo 1989 Andrew 1992
5	155+	19+	Catastrophic	Camille 1969

High-risk areas are barrier islands or open coastlines with elevations less than 10 feet above mean sea level (Baker 1993). Low-risk areas are usually on the relatively

protected mainland, over 15 feet in elevation. Areas 10 to 15 feet above sea level are considered moderate-risk areas, but can be flooded by intense hurricanes.

Inland areas are also subject to flooding. Recent hurricanes, such as Floyd, have shown the damage that can result from inland flooding. The Federal Emergency Management Agency (FEMA) uses 100 year and 500 year floodplains to classify areas vulnerable to flooding. This means that once every 100 years (or 500 years) areas can be expected to be flooded.

Much information is available on hurricanes and their frequencies (Jarrell et al. 1992; Tait, 1995; Diaz et al. 1997; Ho et al. 1987). These sources show that the Gulf and Southeast Atlantic coasts are frequently visited by hurricanes. These studies conclude that most of the counties in Florida and Texas have experienced at least six hurricanes between 1900 and 1990. As a result, these counties have the greatest risk of being struck by a hurricane. However, these studies contain no societal analysis. The *Living With the Shore* (Canis et al. 1985; Pilkey et al. 1980) series of books deals with the physical aspects (i.e., coastal erosion or elevation above sea level) of vulnerability for coastal counties. These studies show that much of the Outer Banks of North Carolina is unsafe because of the barrier island's low elevation. However, these studies fail to include any aspect of social vulnerability. Aspects of all these studies have been incorporated into the vulnerability studies that have been conducted within the last few years. None of these studies, however, have calculated both physical and social vulnerability.

Social Vulnerability

Social vulnerability can be defined as the susceptibility of social groups to potential losses from hazard events (Cutter et al 2000). Numerous disaster studies have identified factors that make people more vulnerable to disasters have been undertaken (See Peacock et al. 1997; Cutter 1993; 1996; 2000 for a review). These studies show that income, poverty, housing, ethnicity, age, gender, total population, and population densities are some of the factors of vulnerability. Nevertheless, most of these studies do not calculate the vulnerability of people.

Income and poverty are two very important factors in vulnerability. The more wealth a person or family has, the more money can be spent on items that can reduce the damages suffered from a hurricane. People with a higher income tend to be more aware of hurricane watches and warnings (Stein, 1997). In addition, the more money someone has, the easier it is for them to rebuild. People with higher incomes have an easier time finding shelter, getting credit, and continuing with their income-earning activities after a disaster (Blaikie et al. 1994). The poor are at greater risk from natural disasters because they are likely to buy land that is prone to hazards (Mileti, 1999). The poor are more likely to live in more hazardous houses such as mobile homes that are more likely to be damaged or destroyed. Poor households are less likely to have the financial resources to buy supplies in preparation for a storm or be able to rebuild in the aftermath of the storm (H. Heinz III Center for Science, 2000). The poor's lower paying jobs are more likely to be lost when businesses close or are forced to move away after a disaster. The poor will more likely require federal assistance and need temporary housing after a disaster too (H.

Heinz III Center for Science, 2000). Low-income residents are less likely to have access to transportation to evacuate when hurricane warnings are issued. The poor also have a more difficult time in filling out disaster relief forms (Morrow 1997). For all these reasons economics are vital to vulnerability.

Education is another factor important to social vulnerability. Little research has been done on education and how it is related to vulnerability. However, it is expected that higher education levels are associated with better jobs and a greater proficiency in dealing with bureaucracies, resulting in greater access to resources (H. Heinz III Center for Science, 2000). The disadvantages of being illiterate or having a lack of language proficiency will make it more difficult to fill out application forms for aid (Morrow, 1999), which are very complicated requiring a great deal of time to deal with the bureaucracies. King (2000) suggests that many people are inadequately prepared and have flawed knowledge of hazards that they are likely to experience. King (2000) points out that the technical language used in warnings have caused confusion. For example, Stein (1997) found that people with lesser education had worse knowledge of the Saffir/Simpson scale and of hurricane watches and warnings than people with higher education.

Experience represents informal education. It too has been found to affect vulnerability. King (2000) suggests that near misses and weak hurricanes may have given some people a complacent attitude toward storms. The recent experience of Hurricane Andrew in Dade County, believed to be among the best-prepared counties, suggests that many coastal areas may not be as prepared for a hurricane as thought (Pielke and Pielke,

1997a). Clearly, if people do not understand the meanings of hurricane watches and warnings, then there is a serious problem.

In many cases, race and ethnicity are key factors in social vulnerability. There are many ways in which being a member of a racial or ethnic minority can result in social and economic marginality and influence disaster impact, resiliency, and outcome. Mortality rates tend to be higher among minorities in disasters (H. Heinz III Center for Science, 2000). Minorities are more vulnerable to disasters because they lack the resources to recover from disasters (Peacock et al. 1997). Peacock and Girard (1997) conducted a damage assessment from Andrew and found that blacks suffered the most damage from the storm. Segregation may also play a role in vulnerability. Minorities, particularly black households, are disproportionately located in poor quality housing segregated into low-valued neighborhoods (Peacock and Girard, 1997). Being poor is likely to be the most definitive marginality, but is compounded by membership in a minority or disenfranchised group (Morrow, 1999). Marginalized minority groups are often excluded from community disaster planning and preparation (Morrow, 1999). Minorities are more likely to live in inadequate and poorer quality housing that may well be subject to greater damage (Peacock and Girard, 1997). Blacks were found to have suffered the most damage from Hurricane Andrew (Peacock and Girard, 1997). Florida City, a predominantly black community, suffered some of the most damage from Hurricane Andrew (Peacock and Girard, 1997). Minorities may also encounter discrimination when seeking disaster aid, which may change the ability to prepare for the next storm (Peacock and Girard, 1997). Minorities are often unable to get a mortgage because they are unable

to obtain property insurance (Peacock and Girard, 1997). Minority homes sustained more damage from Hurricane Andrew and received less-adequate insurance settlements (Morrow, 1999). Black households were found to be three times as likely not to have homeowners' insurance than white households (Peacock and Girard, 1997). Policyholders in these groups often lack supplemental flood or earthquake coverage or options that include temporary housing expenses (Peacock and Girard, 1997). Recovery is especially difficult in black neighborhoods where poorer quality building construction may have made the neighborhood more vulnerable (Peacock and Girard, 1997).

Children, the elderly, and the disabled are also socially vulnerable (Hewitt, 1997). Young children require the extra burden of childcare, which can be disrupted during storm events. In addition, parents may have to take time off from work to take care of their children should their daycare close (Clark et al. 1998). Many senior citizens lack the physical and economic resources necessary for effective disaster response, are more likely to suffer health-related consequences, and will recover more slowly. Senior citizens are also more likely to need disaster related assistance because they tend to be reluctant to leave their homes (Morrow, 1999). Some citizens also have physical and mental limitations that can influence their response to disasters (H. Heinz III Center for Science). Living arrangements can also have an effect on vulnerability. The resources available to a household depend on the ratio of healthy adults to dependents. The more dependents a healthy adult must take care of the more likely they are to face difficult economic situations (H. Heinz III Center for Science, 2000).

Gender can also play an important role in vulnerability. Fothergill (1996) says “women’s heightened exposure results from gender inequality, social roles, especially as caregiver, and a lack of mobility.” Women are disproportionately living in poverty (Fothergill, 1996). Women tend to work in low-status jobs, which are likely to close or move after a disaster. Women have fewer resources and less freedom within households and are less able to respond to an impending disaster (Morrow, 1999). Often women and minorities are less educated (Fothergill, 1996). Women often have fewer resources to complete disaster preparations. Women are absent in decision-making positions, leadership roles, and higher levels of organization (Fothergill, 1996). Single women tend to be more vulnerable to disasters because they lack the finances and resources to recover. Single-parent families, particularly those headed by women, are likely to live on the economic margins (Morrow, 1999). Enarson and Morrow (1997) found from Hurricane Andrew that low-income, single mothers were among those having the most difficult time recovering. The disadvantages of being a poor woman are compounded when they are additionally marginalized by race, ethnicity, or old age (Morrow, 1999). Households headed by poor, minority women tend to be the last to recover (Fothergill, 1996). Women often have a difficult time in the recovery phase. They have less insurance, less savings, and are less likely to recover (Fothergill, 1996). Even two years after Hurricane Andrew, more than 500 households remained in FEMA trailers and many were headed by women (Morrow, 1997).

Types of housing are also very important to the study of social vulnerability. Vulnerability can depend on the “quality of setting buildings and land uses; public

infrastructure and services; and ways of life” (Hewitt, 1997). Mobile homes are very vulnerable places to be in during a hurricane or tornado since mobile homes are unable to withstand the high winds produced by these storms. According to a study after Hurricane Andrew, a mobile home was 21 times more likely to be destroyed than a conventional home (Morrow, 1999). Mobile homes are vulnerable to overturning or having windblown objects penetrate their exterior (Baker, 1991). Hurricane Andrew destroyed over 99 percent of all the mobile homes in Homestead, Florida (Mayfield et al., 1994). And, about 97 percent of all the mobile homes in Dade County, Florida were destroyed by Andrew (Mafi, 1994). Many of the mobile homes in open areas suffered severe damage as Andrew moved through Louisiana (Levitan et al 1994). Mobile homes can contribute greatly to the vulnerability of a place.

Demographics play an important role in social vulnerability. Population shifts from rural to urban areas can contribute greatly to the vulnerability of a county (Cutter et al. 2000). Coastal areas have grown at a rapid rate so that nearly one-third of the world’s urban population lives within 40 miles of the coastline. In the United States, nearly 70 million people live within 100 miles of any coast (Mileti, 1999). In cities, densely populated neighborhoods and heavily occupied structures could create a bigger disaster. Destruction in one district or the collapse of one building can spell disaster (Hewitt, 1997). Loss of life due to hurricanes over the past few decades has decreased, but the downward direction of this trend may not last. The growing urbanization of coastal areas means that evacuation routes might become insufficient to take care of the population in

emergencies (Burton et al., 1993). In addition, tourists visiting an area will make evacuation more difficult in times of an emergency.

Hurricane Vulnerability Studies

The studies that do calculate the vulnerability of populations using both physical and social vulnerability are becoming popular. Dixon (2000) considered the vulnerability of Texas coastal counties and found the area around Galveston, TX to be the most vulnerable county. Dixon's study took into consideration the total population and the frequency that each county was struck by a hurricane, but failed to consider the magnitude of the hurricane and did not include other demographic or social statistics. Clark et al. (1998) and Cutter et al. (2000) are the only other studies that point out the different kinds of vulnerabilities. Clark et al. (1998) states that there are two components to vulnerability: social and physical. Cutter et al. (2000) expands on this notion and adds technological hazards as a third component to vulnerability. These studies measure the vulnerability of places. Each study takes a different approach to measuring vulnerability.

Clark et al. (1998) did a vulnerability study of Revere, Massachusetts to extreme storms. This study uses only the 100 and 500-year floodplains from FEMA's Insurance Rate Maps of flood zones as its physical factor. This study does not consider the magnitude of storms. Clark et al. (1998) collected a wide range of census data. They used census blockgroups as their observational units as they are the smallest in which socioeconomic data are available. Clark et al. used factor analysis to reduce all their variables down to 5 components (or factor scores).

A technique called Data Envelopment Analysis (DEA) was used to assign weights to the factors. (See Clark et al., 1998; Haynes et al., 1993; and Charnes, Cooper, and Rhodes, 1979 for more about DEA). They then combined the factor scores to produce an overall social vulnerability score by using DEA. Then, the social vulnerability was mapped on top of physical vulnerability to show the most vulnerable blockgroups in the county. The results indicated that physical and social vulnerability varies spatially. They found areas along the coast to be the most physically and socially vulnerable. They also found that blockgroups where medium or high levels of social and physical vulnerability coincide are the most vulnerable. The areas of highest vulnerability are also those along the coast.

Cutter et al. (2000) differs from Clark et al. (1998) study in several ways. As in the Clark et al study, Cutter et al. (2000) uses the same flood zones used in the Clark et al. 1998 study. In their study they identified areas that are socially, physically, and technologically vulnerable within Georgetown County, South Carolina. Technological hazards included chemical releases or highway accidents. Instead of using just hurricanes, they considered hurricanes, tornadoes, earthquakes, and floods as all part of their physical vulnerability component. They considered magnitude and frequency of physical events. Cutter et al. (2000), however, used county and block level census data as their observational units. They collected numerous census variables and then standardized each variable, determining the ratio of that variable in each census block to the total number of that variable in the county. This value was then divided by the maximum value to create an index between 0 and 1. A ratio of the population that would

be affected by various physical and technological events was determined and then standardized as the social variables were. Again, values were adjusted to range between 0 and 1. No weights were used in this study.

The areas next to the ocean and rivers are the most physically vulnerable. Roads, where chemical releases have occurred, are the most technologically vulnerable. The areas with the highest social vulnerabilities are scattered throughout the county. The layer of physical/technological (or biophysical) vulnerability and a layer of social vulnerability were then mapped. The two layers were then combined into a single composite of intersecting polygons. The results from this study found a high degree of spatial variability in overall hazard vulnerability. They found also that the most vulnerable biophysical places do not always coincide with the most vulnerable populations. They found that the most vulnerable places are the result of a combination of medium levels of biophysical vulnerability with medium to high levels of social vulnerability. The areas where physical, social, and technological vulnerabilities score medium or high are the most vulnerable areas in the county.

As has been seen, there are many aspects that make people vulnerable to hazards. This has included many physical and social aspects. There are some unclear questions about which factors are the most important to vulnerability. Finally, there is also a need to fill in some of the gaps that exist in current hazards methodology.

CHAPTER 3

STUDY AREA AND METHODOLOGY

Introduction

This chapter begins with a look at the study area. The study design is covered next, followed by an explanation of how the data were collected. The next section consists of the construction of the vulnerability index. The final section in this chapter deals with calculating physical, social, and total vulnerability.

Study Area

This study of hurricane vulnerability focuses on North Carolina because of the high frequency of hurricane strikes along its 300 miles of coastline. North Carolina is threatened on average by a tropical system once every two years and directly impacted by a hurricane once every five years (Longshore, 1998). North Carolina ranks third among the states, behind Florida and Texas, in the frequency of hits by hurricanes (Table 2). Twenty-eight hurricanes have made landfall in North Carolina during the 1900s. North Carolina is also affected by hurricanes that hit farther south and then cut a path across North Carolina as in the case of Hurricane Hugo in 1989.

In order to examine spatial vulnerability to hurricanes across North Carolina, four coastal counties were selected for this study: Brunswick, New Hanover, Carteret, and Dare (See Figure 2). These four counties are very different from each other. They cover the southern, central, and northern part of the state. Some counties, such as New Hanover, are more urban than others. There are also counties, such as Dare, that are

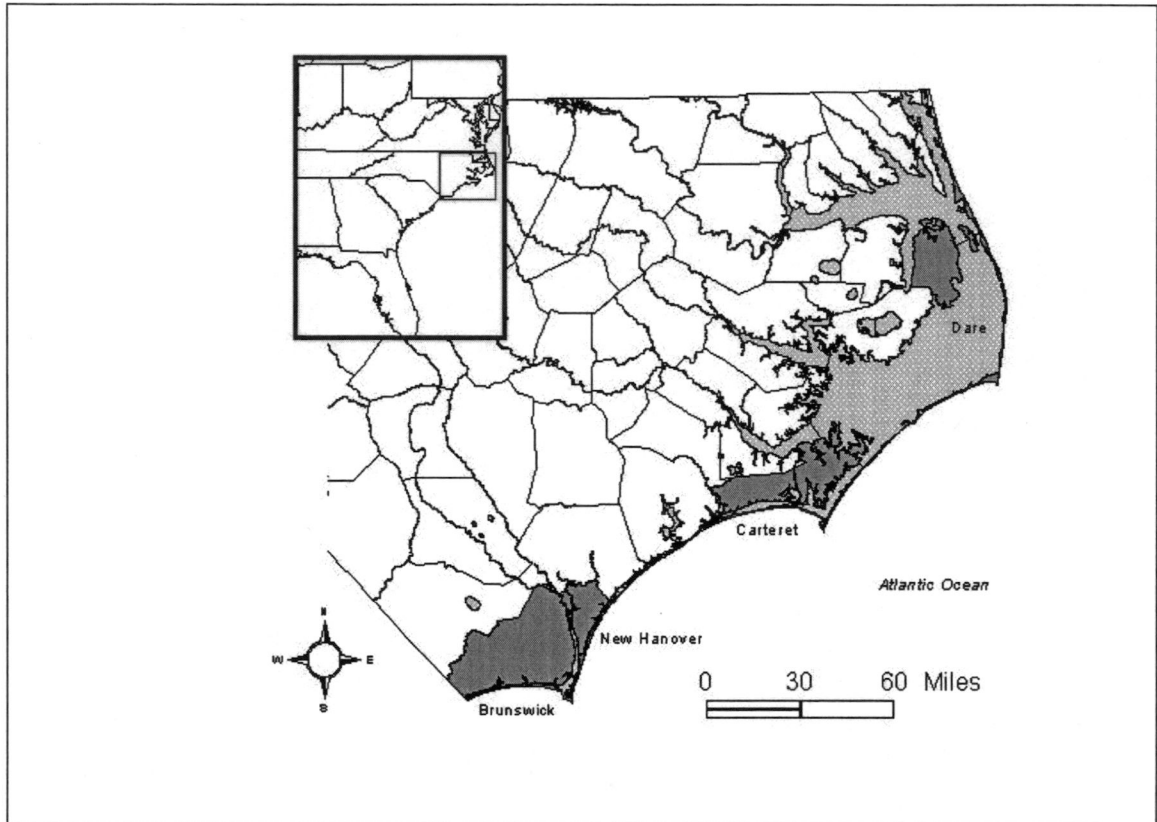
Table 2. U. S. Mainland Hurricane Strikes by State, 1900-2000 (Source: Longshore, (1998) and Diaz et al (1997).

State	Total Hurricane Strikes	Last Landfall
Florida	61	2000
Texas	37	1999
North Carolina	28	1999
Louisiana	25	1992
South Carolina	14	1989
Alabama	11	1997
Mississippi	9	1998
New York	9	1985
Connecticut	8	1985
Massachusetts	6	1954
Georgia	5	1979
Maine	5	1969
Rhode Island	5	1991
Virginia	4	1944
New Hampshire	2	??
Maryland	1	1933
New Jersey	1	1903
Delaware	0	None

struck much more frequently than others by hurricanes. Some counties have an east-west orientation and others have a north-south orientation. There are also major population differences in these counties (Table 3).

Population has increased in the last ten years and these counties are notorious for being struck by hurricanes, making this area a perfect place for a vulnerability study. Brunswick and New Hanover are the two southern most counties in coastal North Carolina. Hurricanes, such as Fran (1996) and Floyd (1999), have recently passed over these two counties.

Figure 2. Study Area (Source, NCCGIA, 1998)



North Carolina's major port city of Wilmington is located mostly in New Hanover County. New Hanover is also the only urban county in the study area as the other three counties are mostly rural. New Hanover County's other major communities include Wrightsville Beach, Carolina Beach, and Kure Beach. This county has about 40 miles of coastline and has mostly a north-south orientation. The Cape Fear River is the boundary line between New Hanover and Brunswick. Brunswick County's 40 miles of ocean shoreline beach is distributed among six islands of various sizes and at different stages of

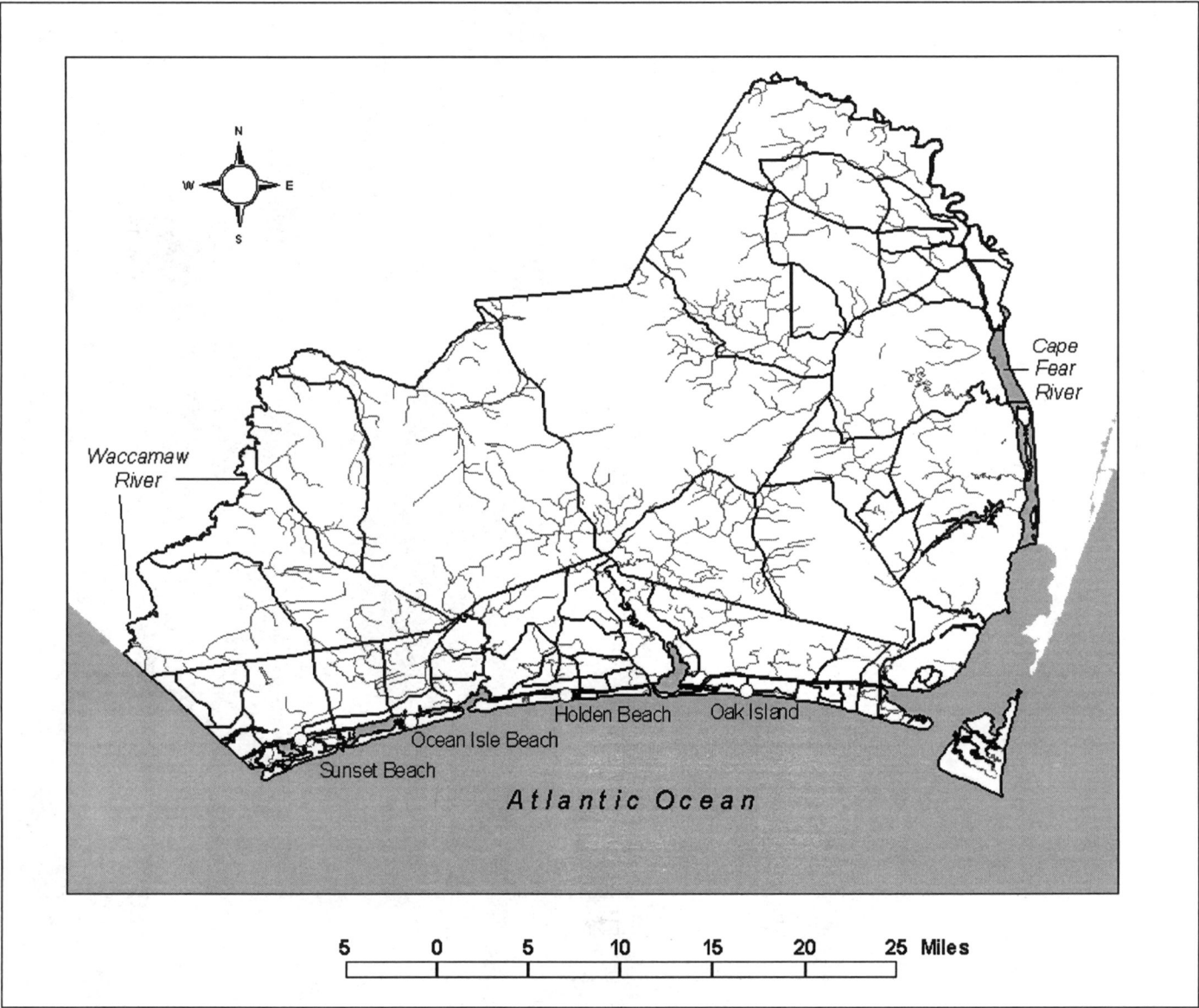


Figure 3. Brunswick County.



Figure 4. New Hanover County.

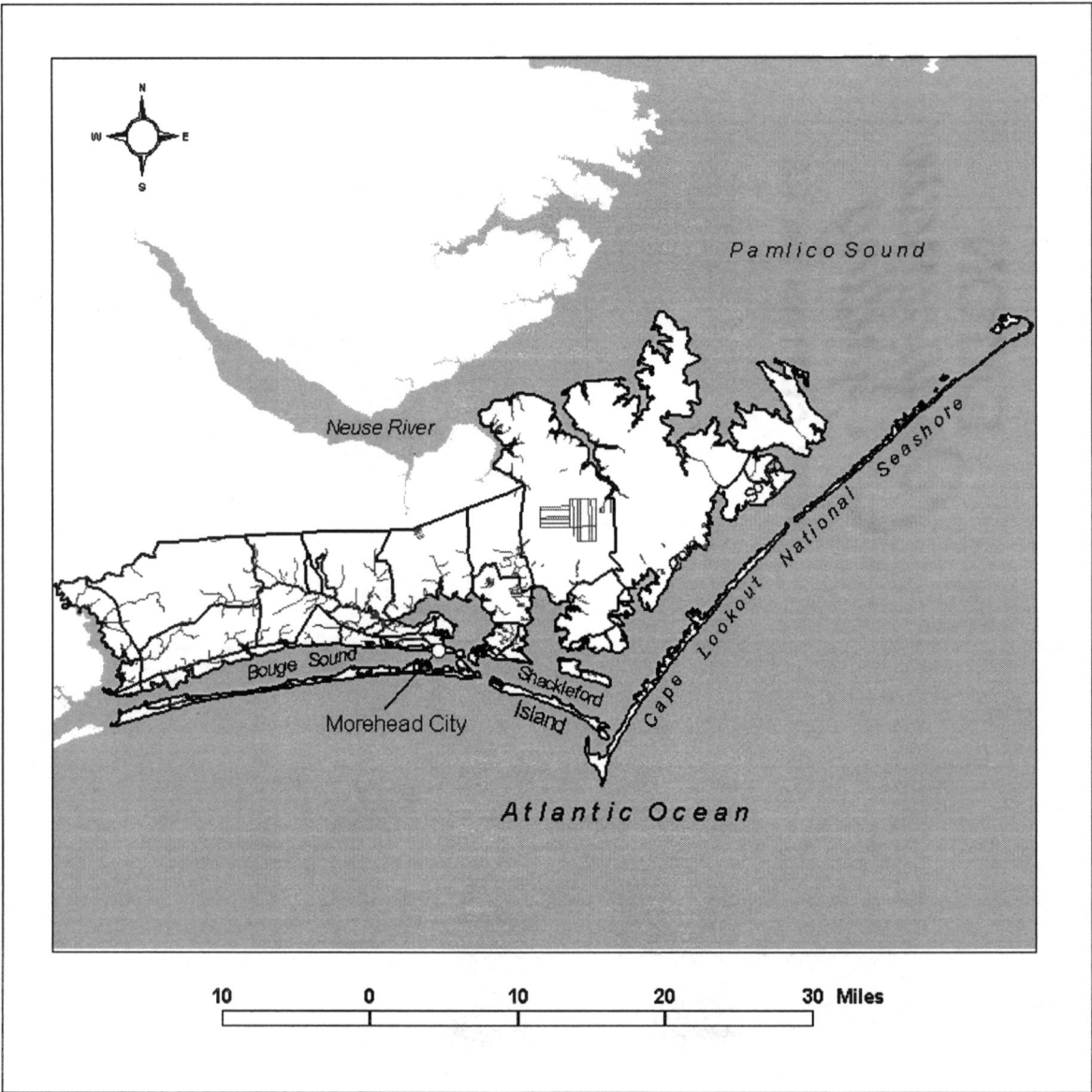


Figure 5. Carteret County.

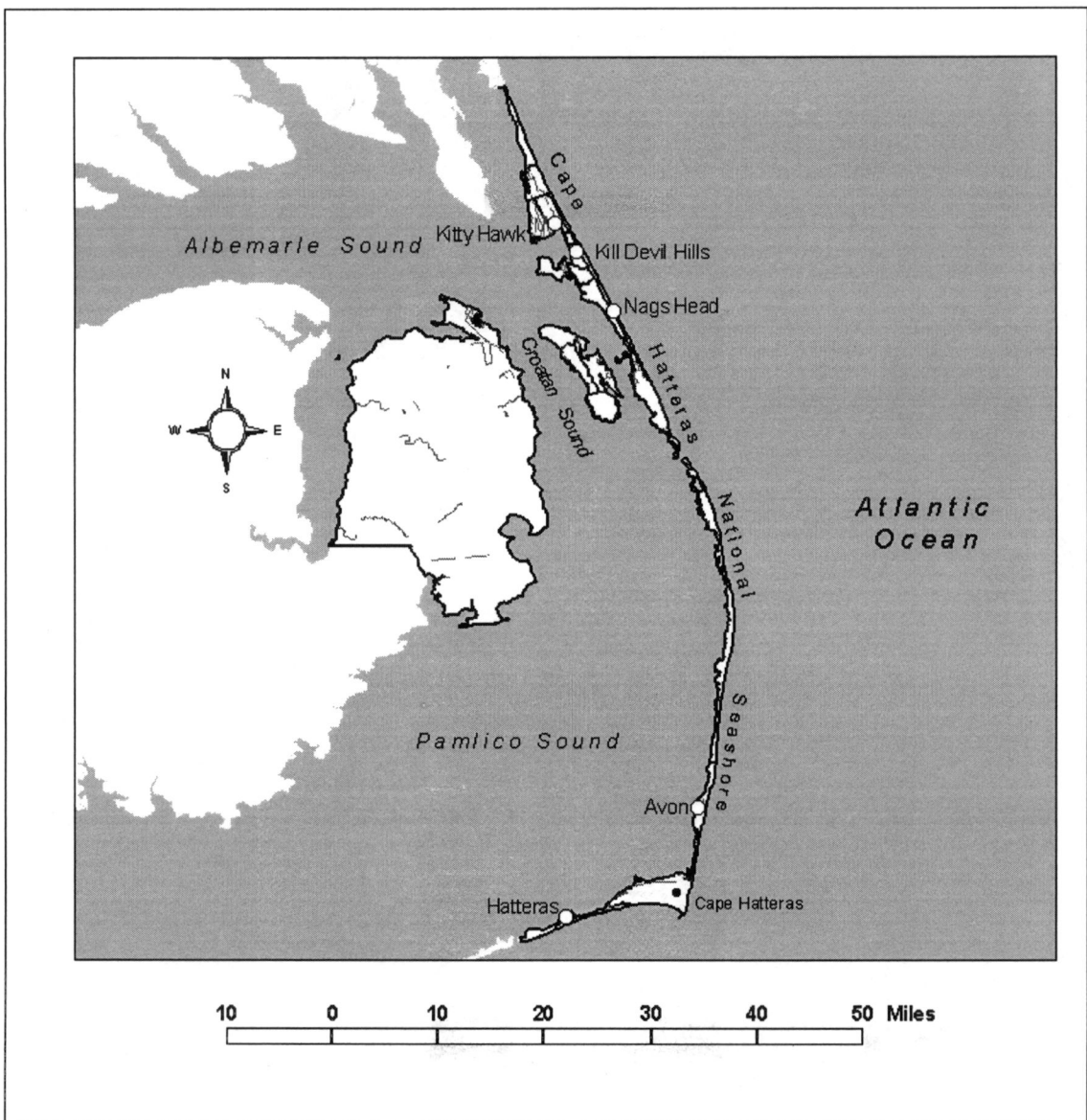


Figure 6. Dare County.

Table 3. County Population and Hurricane Data.

County Name	Area (Sq Mi)	Population		Number of Blockgroups	Length of Coastline Miles	Direct Hurricane Strikes (1900-2000)	Category			
		1990	1999				1	2	3	4
Brunswick	836.2276	50985	71020	71	42	11	3	4	3	1
Carteret	488.0529	52556	60801	61	81	10	5	3	2	0
Dare	364.4591	22746	30043	29	87	18	6	6	6	0
New Hanover	166.2939	120284	153053	111	36	10	3	4	2	1

- Population totals are from the Census Bureau.
- Length of coastlines were calculated in *ArcView GIS*.
- Strikes and categories for counties can found in Jarrell et al. (1992) and at the National Hurricane Center's website at www.nhc.noaa.gov.

development (Pilkey, 1980). This coast has mostly an east-west orientation that places it in the direct path of hurricanes that come up from the south (Pilkey, 1980). Carteret County is approximately 65 miles northeast of Wilmington and sits in the middle of the North Carolina coastline. The islands of Portsmouth, Core Banks, and Schackelford make up the Cape Lookout National Seashore (Pilkey, 1980). Morehead City is the major city in the county. Carteret County has over 80 miles of barrier island that is exposed to hurricanes. It has been visited by over 150 hurricanes and nor'easters that have caused severe flooding and erosion (Pilkey, 1980). Recently hurricane Bonnie (1998) cut a path across here. This county also has an east-west orientation making it more exposed to hurricanes approaching from the south. Dare County is the northern most county in the study area and is the home of the Cape Hatteras National Seashore. Dare County protrudes the most out into the Atlantic Ocean of any North Carolina county it has been hit or brushed with 25 hurricanes between 1900 and 1990 (Jarrell et al. 1992). Other hurricanes, such as Bonnie (1998) have cut a path across Dare County since 1990. Approximately, four-fifths of the northern Outer Banks lie in Dare County. This 70-mile stretch of barrier island contains isolated pockets of private property (Pilkey, 1980). The most densely populated areas can be found in the northern part of the county. This area contains the towns of Manteo, Kitty Hawk, Kill Devil Hills, Avon, Hatteras, and Nags Head. These four counties provide an interesting contrast in population, orientation, development, and frequency of hurricane strikes.

Study Design

The goal of this study is to measure the vulnerability of blockgroups in the four coastal counties to a hurricane strike. The ultimate goal is to develop a vulnerability index for each blockgroup and then to map those vulnerability scores in order to examine the spatial distribution of vulnerability. Methodologies used by Clark et al. (1998) and Cutter et al. (2000) will be used as a basis for composing the vulnerability index. Both studies calculated vulnerability by using a combination of physical and social vulnerability.

Data Collection

Physical Vulnerability.

The essential components in physical vulnerability are the identification of hazards, their frequency, and their locational impacts (Cutter et al, 2000). An issue not recognized by Cutter et al. 2000 is hazard speed and this will be accommodated in this study. Here, the focus is solely on hurricanes. The magnitude of these events is accommodated by examining hurricanes in each of the 5 Saffir-Simpson scale classes. Other aspects of hurricanes that need to be considered for physical vulnerability include a hurricane's wind speed, storm surge, forward speed, and frequency. In addition, the 100-year floodplain can be used to predict the amount of flooding that may result from rainfall. The frequency is the number of hurricanes of each class that hit a county within 101 years (1900-2000) of hurricane data. Locational impacts include damage due to high water within floodplains or to storm surge along the coast. Both have relatively well defined spatial impact areas within a county.

I. Flooding. Storm surge is evaluated using data generated by the United States Army Corps of Engineers. Surge height estimates were made using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model. The SLOSH model was used to develop data for various combinations of hurricane strength, wind speed, and direction of movement. The modeling for each hurricane category was done using the mid-range wind speed in that category. Seven storm track headings (W, WNW, NW, NNW, N, NNE, and NE) were selected as being representative of storm behavior in North Carolina based on observations by forecasters at the National Hurricane Center (Cheryl Pearce, NCCGIA). To determine surge values, the SLOSH model uses a telescoping polar grid as its units of analysis. The polar grid configuration has the distinct advantage of allowing individual calculations to be made for each grid square. This also provides increased resolution of storm surge at coastlines, harbors, bays, and rivers. Once surge heights have been determined for the appropriate grids, the maximum surge heights are plotted by storm track and hurricane category. These plots of maximum surge heights for a given hurricane category and storm track are referred to as Maximum Envelopes of Water (MEOW)'s. The surge inundation limits, displayed on the maps in this atlas reflect further compositing of the (MEOW)'s to the Maximum of Maximums (MOM)'s. The (MOM)'s represent the maximum surge expected to occur at any given location, regardless of the storm track or direction of the hurricane. The only variables are the intensity of the hurricane represented by category strength and the forward speed of the hurricane. The MOM surge heights are the data used in this study. The storm surge data is broken down into three categories. The first category is surge from a category 1 or 2

hurricane. The second category is storm surge for a category 3 hurricane. The last category is for surge from category 4 or 5 hurricanes.

A factor that affects the magnitude of the storm is its forward speed, which modifies the potential impacts of hurricanes of all magnitudes. A consequence of forward speed is that it determines the duration of time over which a storm affects a given area. A slow moving hurricane will dump more rain on an area than a fast moving hurricane. It also exposes a county to the hurricane's winds for a longer period of time. Slow hurricanes move at speeds up to 15 mph. A fast moving hurricane is any hurricane moving faster than 15 mph (Pearce, NCCGIA).

Storm surge data were obtained in digital form from the North Carolina Center for Geographic Information and Analysis (NCCGIA). The maps provided by NCCGIA summarize the hurricane storm surge inundation information developed in *A Storm Surge Atlas for the Pamlico Sound Area*, completed by the Storm Surge Group of the National Hurricane Center in 1996. This atlas is a result of the Coastal North Carolina Hurricane Evacuation Restudy, covering coastal counties of North Carolina. The Wilmington District of the Army Corp of Engineers performed the role of project manager responsible for technical direction, coordination, scheduling, and overall quality control. NCCGIA was contracted by the Wilmington District of the Army Corp of Engineers and the North Carolina Division of Emergency Management to provide digitized surge maps (Cheryl Pearce, NCCGIA).

Another physical variable is represented in part by coastal and river flooding. In order to determine what areas are prone to flooding, the Federal Emergency Management

Agency flood data will be used. These maps are digital generalizations of the Federal Insurance Rate Maps (or FIRMS) done at the county scale. These maps show floodways for both coastal and riverine environments and represent them as the 100-year and 500-year flood inundation zones (Cutter et al., 2000). The areas classified as being within the 100-year floodplain will be used in this study. The flooding from hurricanes and the 100-year flood plain data were joined together using *ArcView GIS 3.2* to create a single flooding extent variable.

X_1 = Flood Extent

Percentage of each blockgroup that is predicted to be flooded from storm surge or riverine flooding for each category 2-4 hurricane an speed of hurricane

II. Wind Speed. Hurricanes are classified into five different categories according to their wind speed. The five hurricane categories have different destructive powers. Pielke and Pielke (1997a) provide a measure of the destructive force of hurricane winds relative to the destructive force of a tropical storm with 45 mph winds. Using Pielke and Pielke's (1997a) graph, a 135 mph category 4 hurricane is determined to have nine times the destructive power of a 45 mph tropical storm (Figure 7). Wind speed effects will be determined using Pielke and Pielke's graph. However, because this study focuses only on hurricanes, the relative destructive power of hurricanes of different categories has been recomputed using a category 1 hurricane with 84.5 mph winds. This is the basis for all the wind speed calculations. The median wind speed of each category is used to determine the destructive force of winds because the SLOSH data uses the

median speeds (Table 4). In this study, Category 2 through 4 hurricanes will be considered.

Because there is no storm surge data for Category 1 hurricanes, these storms will not be considered here. Category 5 hurricanes will not be considered because only two Category 5 hurricanes (Camille in 1969 and the 1935 Florida Keys Hurricane) have struck the United States and neither of these made landfall near the Carolinas. The relative destructive wind power of each category is presented in Table 4.

This became the second physical vulnerability variable where:

$$X_2 = \text{Relative Destructive Power of Wind}$$

Table 4. Destructive Power of Wind.

Category	Destructive Power
1	1.00
2	1.43
3	1.86
4	2.71

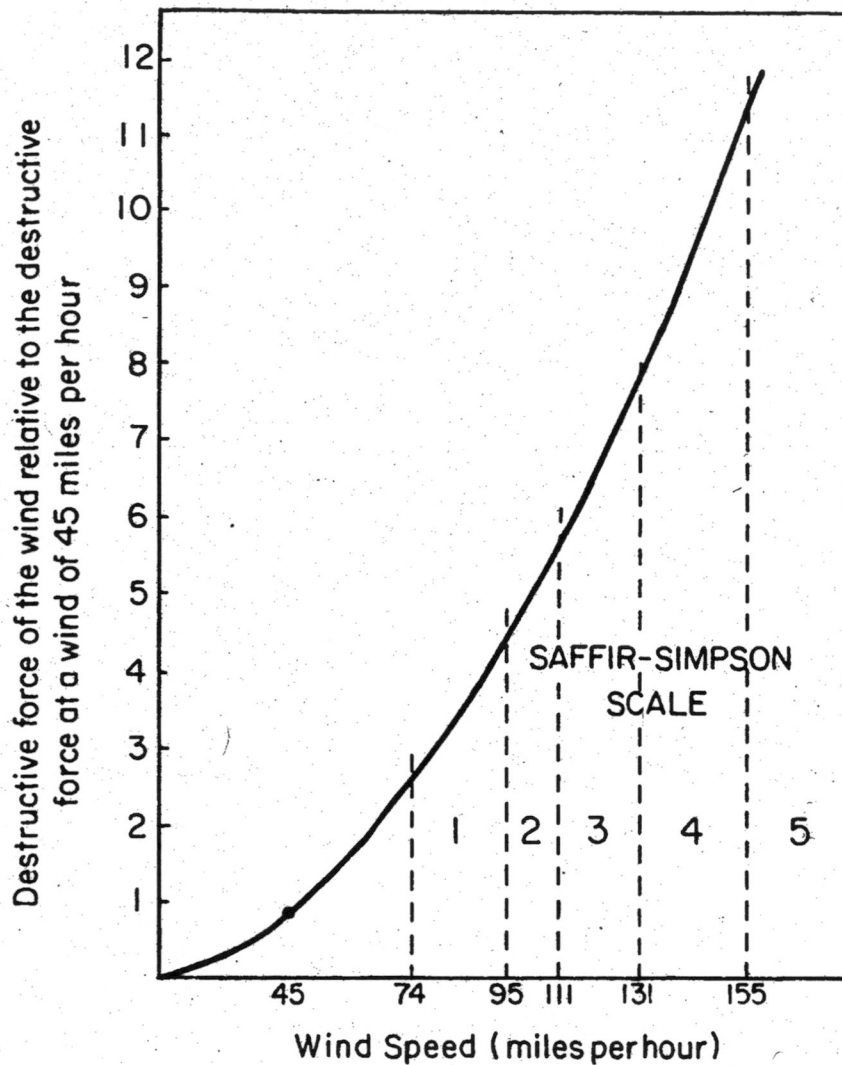


Figure 7. Destructive Force of Wind.

Relationship between wind speed and destructive force relative to a 45 mph tropical storm (Pielke and Pielke, 1997a, 124).

III. Probability. Frequency is the probability that a place will be struck by a hurricane. The frequency of occurrence is a calculation from historical data and the length of the record. In this case, it will be the number of hurricanes that made a direct hit on a county within 101 years (1900-2000) of hurricane data (Table 3). Category 1 and 2 hurricanes develop and strike more frequently than major hurricanes (Categories 3-5).

A direct hit is defined as occurring when the eye moves over a county. A county is credited with a direct strike when all or parts of a county fall within a distance $2R$ (where R is defined as the radius of maximum winds in a hurricane) to the right or within $1R$ to the left (Jarrell et al. 1992). On average, this direct hit zone is about 50 miles wide along the coastline (Jarrell et al. 1992). Some hurricanes were smaller or larger than this and cases were judged individually (Jarrell et al. 1992). Much of the work on where hurricanes have made landfall between 1900-1990 can be found in Jarrell et al. 1992. Hurricane landfalls for 1991 to the present can be found at the National Hurricane Center's website (<http://www.nhc.noaa.gov/paststate.html>). The frequency was converted to a probability by dividing the number of hurricanes of each category to strike a county by the total length of the record (101 years).

X_3 = Hurricane Probability for Each County.

This will be the total number of direct hits that a county has received divided by the 101 year record (1900-2000) for each category 1-4 hurricane.

Social Vulnerability.

Social vulnerability is made up of demographic and housing characteristics that are important to amplifying and reducing overall vulnerability (Cutter et al. 2000). There is a wide range of socioeconomic features that play key roles in preparedness, responsiveness, and recovery. All of the social variables were collected from the 1990 census (except hotel rooms and evacuation times). Census blockgroups provide the best observational unit to assess differing levels of vulnerability for people within a county. County level data is inadequate for this study because it does not provide any spatial variation within a

county. For example, two blockgroups could have drastically different vulnerabilities within Dare County. One blockgroup could be much less vulnerable than another blockgroup because of the characteristics of the population living in each blockgroup. Blockgroups are the smallest level for which socioeconomic data is available. The social variables (Table 5) were chosen because the literature points to these factors as being the most important to vulnerability. Mileti (1999) and Cutter et al. (2000) point out the importance of housing, income and race. Fothergill (1996) and Marrow (1999) show the importance of gender to vulnerability. The Heinz III Center for Science (2000) and Fothergill (1996) indicate the significance of education. The importance of age to vulnerability is shown in Hewitt (1997) and Clark et al. (1998). Burton et al. (1993) and Blaikie et al. (1994) demonstrate the significance of population to vulnerability. All of these data was collected at the blockgroup level. The assumption is that these characteristics correlate strongly with commercial development in the coastal margin.

When a hurricane approaches land, the first people told to evacuate the area are tourists. Because it is impossible to determine the number of tourists in each blockgroup, the number of hotel rooms will be used to estimate the potential number of people that need to evacuate an area. The *American Business Disk* (2000), *AAA Tour Book* (2001), and an internet search were used to collect the location of hotels. The *AAA Tour Book*, an internet search, emails, and phone surveys were used to find out the number of rooms in each hotel. Nearly 300 hotels, motels, inns, condos, resorts, etc., were located in the study area. The website, Eagle Geocoding (<http://www.geocode.com/>) was used to find the blockgroup numbers in which hotels are located.

Tourists and people who live on the coast are usually ordered to evacuate an area when a hurricane approaches. Many of these people will evacuate to places much farther inland to escape the storm so a time is needed to get to safety. Evacuation times were calculated using the network analysis in *ArcView GIS 3.2*. The amount of time was calculated by placing a point at the center of each blockgroup and at various points along Interstate 95. Times were then calculated using the network analysis. Interstate 95 was used because Hurricane Floyd demonstrated how much flooding could occur east of 95. Times were calculated along the major evacuation routes in North Carolina.

Table 5. Social Vulnerability Data.

Y ₁	= median household income (median income in household in each blockgroup)
Y ₂	= population density (people per square mile)
Y ₃	= total population (total population in each blockgroup)
Y ₄	= Percentage without education (percentage of people without high school a diploma)
Y ₅	= Percentage of ethnicity (percentage of Blacks, Hispanics, Asians, etc. in blockgroup)
Y ₆	= Percentage of female headed households
Y ₇	= Percentage of female headed households with children
Y ₈	= Percentage of population age 65 and up
Y ₉	= Percentage of population age under 5
Y ₁₀	= Percent year of entry (percentage of foreigners who enter a blockgroup between 1985-89)
Y ₁₁	= Percentage of householders who moved into a unit between 1985-89
Y ₁₂	= Percentage of manufactured homes
Y ₁₃	= Percentage of housing units with 50 or more units
Y ₁₄	= median house value
Y ₁₅	= median year structure built
Y ₁₆	= number of households
Y ₁₇	= Percentage of housing units with units of 50 and more
Y ₁₈	= Number of hotels
Y ₁₉	= Evacuation time (The time it takes to get from the center of the blockgroup to interstate 95.)

Some of the variables are grouped together to provide for an easier discussion.

Table 6 introduces some terms and definitions used in future chapters.

Table 6. Terms and Definitions.

Term	Definition
New residents	Percentage of the population that is made up of new people moving into the blockgroup since the last census. Also, the percentage of the population made up of foreigners that have moved into the blockgroup since the last census.
Susceptible age	Percentage of the population under age 5 and age 65 and over.
Multiple housing units	Housing units with 50 or more units in them.

Vulnerability Index

The meager literature on this subject that does exist suggests two dimensions of hurricane vulnerability: (1) hurricane or physical environment attributes, (2) and the socio-economic environment made up of population and housing attributes. The relationship between vulnerability and these two dimensions can be stated as:

$$(Eq. 1) \quad VUL_i = f(\text{physical environment and social environment})$$

The variables described earlier are used to define each of these dimensions. The physical environment is represented by hurricane attributes. The social environment is represented by social, economic, and housing factors.

Either of two approaches can have a substantial impact on the final result by contributing vulnerability to factors that are not necessarily the most important. One algebraic approach would incorporate “compensatory” effects, i.e., a low vulnerability score on the physical dimension could be compensated for with a high score on the social environment (Mitchelson, 2000). This approach is accomplished with an additive algebraic structure such as the equation below.

$$(Eq. 2) \quad VUL_i = (\sum a_j x'_{ij}) + (\sum b_j y'_{ij})$$

X represents the physical variable and a is the weight of the variable. Y represents the social variable and b is the weight of that variable. Then, all of the physical variables are added together and all the social variables are added together. The two components are then added together to compute an overall vulnerability.

In contrast, we might suppose that extreme vulnerability can only be achieved when conditions in the physical and social environments are poor, i.e., when a blockgroup receives a high score on both the physical and social dimensions of vulnerability. Multiplying the two scores together emphasize the extreme vulnerability scores (Mitchelson, 2000). Thus, unlike the additive approach, a small vulnerability score on any one of the dimensions causes the overall (aggregate) measure to be small (regardless of values on other the dimension). Then, a “noncompensatory” effect is in evidence. If both dimensions have a moderate or high score, then multiplication will produce an overall moderate or high score. Equation 3 demonstrates this approach:

$$(Eq. 3) \text{ VUL}_i = (\sum a_j x'_{ij}) * (\sum b_j y'_{ij})$$

The multiplicative model is used in this thesis because this requires both physical and social vulnerability scores to be high in order to get a high total vulnerability score. This approach will identify the places of extreme vulnerability that this study seeks to identify. Furthermore, emergency managers would be interested in areas of extreme vulnerability in order to focus emergency management's efforts.

Calculating Vulnerability Scores

For this study, one social vulnerability score was calculated for each blockgroup. Six physical vulnerability (one for each combination of speed and category 2-4) scores were calculated for each blockgroup. Each blockgroup also received one average physical vulnerability score calculated from the six physical vulnerability scores. Six total vulnerability scores were calculated for each blockgroup by multiplying the social vulnerability by each combination of speed and category of hurricane. Finally, the six total vulnerability scores were averaged to produce one final total vulnerability score for each blockgroup.

Calculating physical vulnerability involves three physical attributes: probability, destructive power of wind, and flooding. The probability was calculated in the following way: for category 1–4 hurricanes, divide the strikes by the record of 101 years. Then take the z score of the categories. Next, add the lowest value plus 1 so that the lowest positive z score is equal to 1. For wind speed, a category 1 hurricane received a 1. A calculation was made from Pielke and Pielke (1997a, 124) graph to determine the wind's destructive power for category 2-4 (Figure 7). To calculate flooding, ArcView 3.2 was used to join storm surge and flood data to calculate the area potentially flooded for each category and speed. This was then divided by the area of the blockgroup. A Z score was calculated for each blockgroup. Next, the lowest value was added plus 1 so that the lowest positive Z score is equal to 1. Add all three variables together. This was then divided by the maximum aggregate value and multiply by 10 to produce scores between 0

and 10 for each blockgroup. The same calculation was used for each category storm and for slow and fast hurricanes.

Calculating social vulnerability involves converting the social variables to percentages by dividing them by either total population, total housing units, or households. (Evacuation times, hotel rooms, median year structures were built, median house value, and median household income were not converted.) A principal components analysis (PCA) was then performed on the social variables to reduce the data set. When many of the original variables are highly correlated, it is necessary to reduce the original data from a large number of variables to a small number of underlying factors (Rogerson, 2001, 192). Using PCA in *SPSS 10.1*, the 16 variables were reduced down to 6 components. The groupings for each component are determined by looking at the Rotated Component Matrix in SPSS and seeing which variables fell into which component. The Groupings were first determined for the study area. Then, the groupings were determined for the each individual county to determine the most important components to each county. The rotated PCA matrix for the study area is presented in table 7. The results for the component groupings are presented for the study area in Table 8.

Table 7. Rotated PCA Component Matrix.

	Component 1	2	3	4	5	6
POP90_SQMI	.744	1.440E-02	-6.962E-02	-.101	.146	-4.101E-02
PER_ETHNCITY	.819	.136	.226	-7.391E-02	-.121	.149
PER_UNDER5	9.543E-02	.953	3.193E-02	2.379E-03	-1.631E-02	2.255E-02
PER65&UP	7.656E-02	.949	1.988E-02	2.390E-02	-2.931E-02	2.238E-02
PER_YR_ENTRY	.106	.114	-6.098E-02	6.229E-02	-.119	.768
PRYRMSTB	.344	.296	-.269	9.968E-02	-.122	-.550
PER_HH_1F	.678	.414	8.066E-02	-9.070E-02	-6.330E-02	-.110
PR_FHH_CH	.692	-8.656E-03	.115	-2.733E-03	-.163	-7.587E-02
MED_HH_INC	-.317	-.123	-.427	.648	-.125	2.587E-02
PR_WO_ED	.195	-8.905E-03	.855	-2.246E-02	-1.934E-02	8.377E-02
PERUT50	3.945E-02	-.287	.323	.129	.580	-.146
PER_MH	-.519	.176	.538	5.957E-02	-.382	-.194
EVAC_TIME	-.423	4.863E-02	-2.703E-02	1.034E-02	.377	.387
HOTEL_ROOMS	-.107	7.508E-02	-.180	-6.542E-04	.737	2.006E-03
MEDYRSTRBUILT	7.246E-02	.139	.213	.792	6.634E-02	-1.835E-02
MED_HOUS_VAL	-.401	-.182	-.380	.556	.204	9.513E-02

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

Table 8. Groupings of Factors (Study Area or Total Sample)

<u>Literature Theme (Factor Loading)</u>	<u>Census Variables</u>	<u>Component</u>
Factor grouping 1 (23.8%)	1990 pop/sq mile Percentage of ethnicity Percentage of female headed households Percentage of female headed households with child Evacuation time	Population
Factor Grouping 2 (12.5%)	Percentage Age 65 and up Percentage Under age 5	Age
Factor Grouping 3 (10.4%)	Percentage of people without high school diplomas Percentage of mobile homes	Education
Factor Grouping 4 (7.9%)	Median household income Median year structures built (MEDYRSTRBUILT) Median house value	Income
Factor Grouping 5 (7.2%)	Number of hotel rooms Percentage of housing units 50 and up	Hotels
Factor Grouping 6 (6.6%)	Percentage of foreign entry (1980-89) Percentage of people moving into buildings (1980-89) (PRYRMSTB)	Newcomers

Each component score then had the lowest value added to all of them plus 1 to produce a value of at least 1.

A set of weights needs to be calculated for the vulnerability index because some variables are more important to vulnerability than others. A major difficulty is to how to assign the weight. Very little literature can be found on how weights are determined. Only two studies, Lowry et al. (1995) and Clark et al. (1998) seem to exist on how to calculate weights for a vulnerability index. However, Clark et al. (1998) use a Data Envelopment Analysis technique that seems inappropriate for calculating vulnerability. Whether a compensatory (Eq. 2) or a noncompensatory index is adopted (Eq. 3), the internal weighting scheme in each dimension (a_j , b_j) must also be determined

(Mitchelson, 2000). In most previous research, weights were not used because of the difficulty in determining weights. In this study, all of the physical variables were given weights equal to 1.0. The social variable weights were determined by calculating how to get each maximum component score to equal 10. Therefore, 10 was divided by the maximum component score for each of the five components. More detail about how the weights were calculated can be found below in Table 9 and in Lowry et al. (1995) in their study on hazardous contaminants.

Table 9. Calculation of Weights.

Population Component $10 = \text{weight} * 7.67$ (highest component score in that blockgroup) weight = 1.30	
Age Component $10 = \text{weight} * 6.63$ weight = 1.50	
Education Component $10 = \text{weight} * 9.16$ weight = 1.09	Hotel Component $10 = \text{weight} * 9.14$ weight = 1.09
Income Component $10 = \text{weight} * 16.7$ weight = 0.6	Newcomers Component $10 = \text{weight} * 11.74$ weight = 0.85

To calculate the total vulnerability of a blockgroup, take each of the 6 types of physical vulnerability scores and multiply them by the social vulnerability score. Each of the 6 scores were then divided by the maximum in the blockgroup and multiplied by 10 to produce an overall score between 0 and 10 to produce a grand total of 6 vulnerability scores for each blockgroup. The 6 vulnerability scores were then averaged to compute

one score for the blockgroup. An example of how vulnerability scores are calculated is presented in Table 10.

Once all the blockgroups have received their vulnerability index score, the data were entered into ArcView 3.2, a geographical information system (GIS). The GIS was used to classify the index values into different quantiles. Then, theme layers for physical, social, and total vulnerability are created using *ArcView GIS*. The results were then mapped to show the most vulnerable census blockgroups in the four counties.

The same method above was also used to calculate vulnerabilities score for the entire study area was then applied to calculate vulnerability scores for each blockgroup within each county. This resulted in new factor and components scores for each county.

Classifying Data

The classification is based on basic descriptive statistics of the data sets. First, each county is evaluated separately to identify within county variation in vulnerability. Next, all the blockgroups are evaluated together to analyze between county variation in vulnerability. In each case, the mean vulnerability for each blockgroup is categorized according to its standard deviation from the grand mean. The focus of discussion is on those blockgroups that are at the ends of the distribution because these areas have very high or low relative vulnerability. The numbers listed in the text and on maps are the numbers that identify the blockgroup numbers.

Table 10. Calculating Vulnerability Scores.

Example: BKG 370190201981 Slow Category 2

$$\begin{aligned} VUL_i &= f(\text{physical environment and social environment}) \\ VUL_i &= \text{physical vulnerability} * \text{social vulnerability} \\ VUL_i &= (\sum a_j x'_{ij}) * (\sum b_j y'_{ij}) \end{aligned}$$

Physical Vulnerability

$$\begin{aligned} PV &= (\text{weight}) \text{probability} + (\text{weight}) \text{wind speed} + (\text{weight}) \text{flooding} \\ PV &= (1.0)(3.12) + (1.0)(1.43) + (1.0)(1.49) \\ PV &= 6.04 \end{aligned}$$

Divide by the highest score for that category and speed and then multiply by 10 to produces scores between 0 and 10. The highest blockgroup score for that category and speed of hurricane equals 10 and the other scores are between 0 and 10.

$$PV = 6.04 / 8.88 * 10 = 6.80$$

Social Vulnerability

$$\begin{aligned} SV &= (\text{weight}) \text{population component} + (\text{weight}) \text{age component} + (\text{weight}) \\ &\quad \text{education component} + \text{income component (weight)} + \text{hotel component (weight)} + \\ &\quad \text{new comers (weight)} \\ SV &= (1.3) 3.07 + (1.5) 4.05 + (1.09) 5.48 + (0.6) 13.73 + (1.09) 1.89 + (0.85) 2.89 \\ SV &= 28.80 \end{aligned}$$

Divide the maximum social vulnerability and multiply by 10 so that the highest blockgroup score for that category and speed of hurricane comes out equal to 10 and so that the rest are between 0 and 10.

$$SV = 28.80 / 41.32 * 10 = 6.97$$

Total Vulnerability for Slow Category 2

$$\begin{aligned} OV &= PV * SV \\ OV &= 6.80 * 6.97 \\ OV &= 47.41 \end{aligned}$$

Adjust score once again so that the highest blockgroup scores an overall vulnerability score of 10.

$$\begin{aligned} OV &= 47.41 / 75.23 * 10 \\ &= 6.30 \end{aligned}$$

Average Total Vulnerability Score

Take the six overall vulnerability scores for a particular blockgroup and find the mean.

Blockgroup 370190201981

Six Overall Scores

Slow Category 2 = 6.30	Fast Category 2 = 5.44
Slow Category 3 = 4.20	Fast Category 3 = 4.24
Slow Category 4 = 7.04	Fast Category 4 = 6.90

$$(6.30 + 4.20 + 7.04 + 5.44 + 4.24 + 6.90) / 6 = 5.69$$

Divide and multiply once again to adjust all scores so that the highest score is equal to 10.

$$5.69 / 8.51 * 10 = 6.68$$

CHAPTER 4

RESULTS

Introduction

The presentation of information in this chapter focuses on vulnerability within each county and vulnerability between counties. Each of these topics is examined in terms of physical, social, and total vulnerability. The relative importance of physical and social vulnerability is evaluated in each case. More detailed assessments of the importance of magnitude and hurricane speed are made. The individual social variables are also examined. In all instances, results are presented in the form of maps of the study area showing physical, social, and total vulnerability.

Vulnerability Within Each County

Physical Vulnerability Index (PVI).

Physical vulnerability scores were determined for each of six combinations of three hurricane magnitude categories and two forward wind speed situations. These six scores were then averaged to determine an overall physical vulnerability index (PVI) score for each blockgroup. A county mean and standard deviation is then obtained. Each blockgroup is then categorized as being within +/- 1, 2, or 3 standard deviations from the mean.

Brunswick County. The mean PVI for Brunswick County is 7.4. The blockgroups with extreme PVI scores are generally located along the coast (Figure 8). The blockgroups with the highest PVI scores are: East Oak Island (BKG 3026), Holden

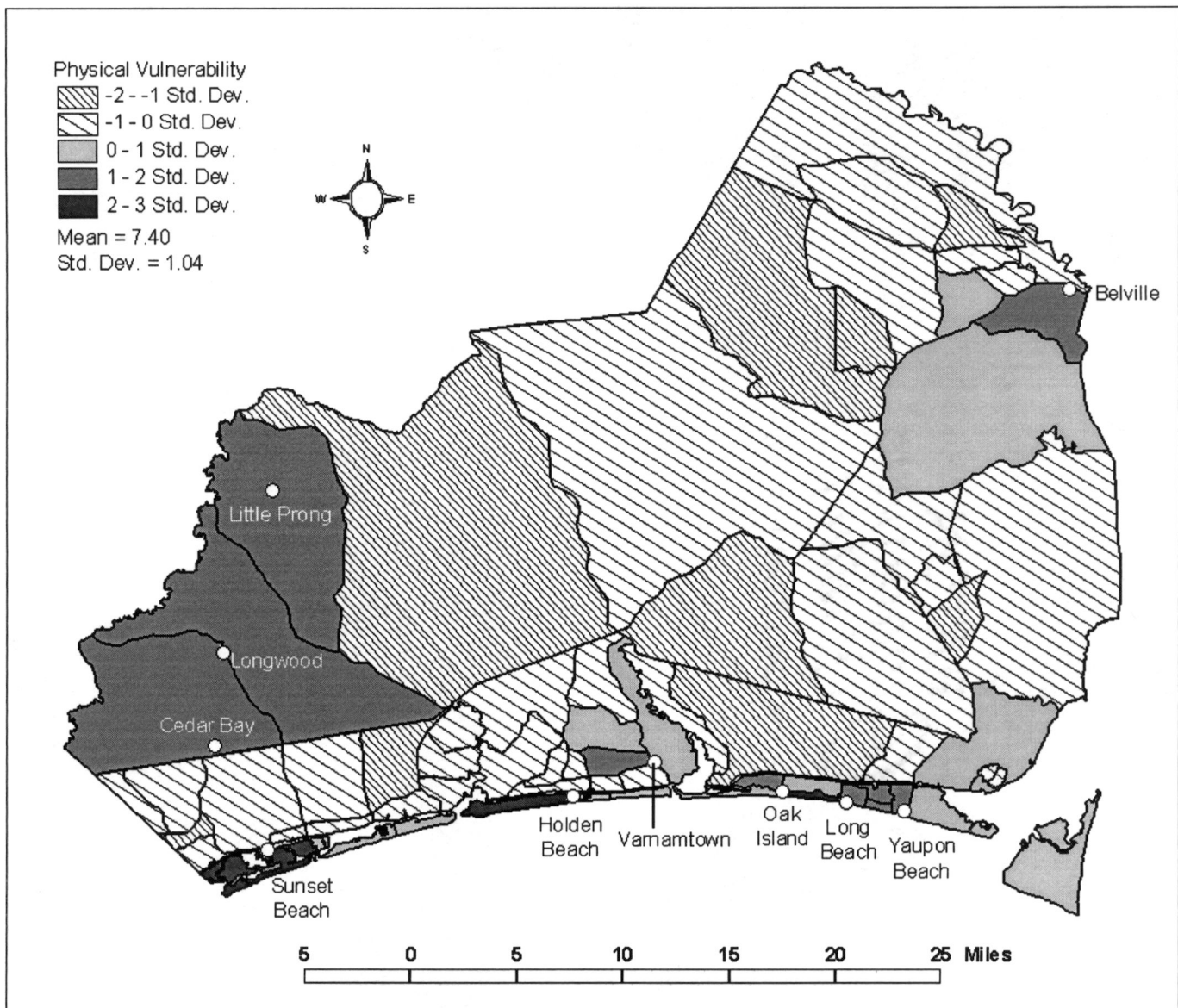


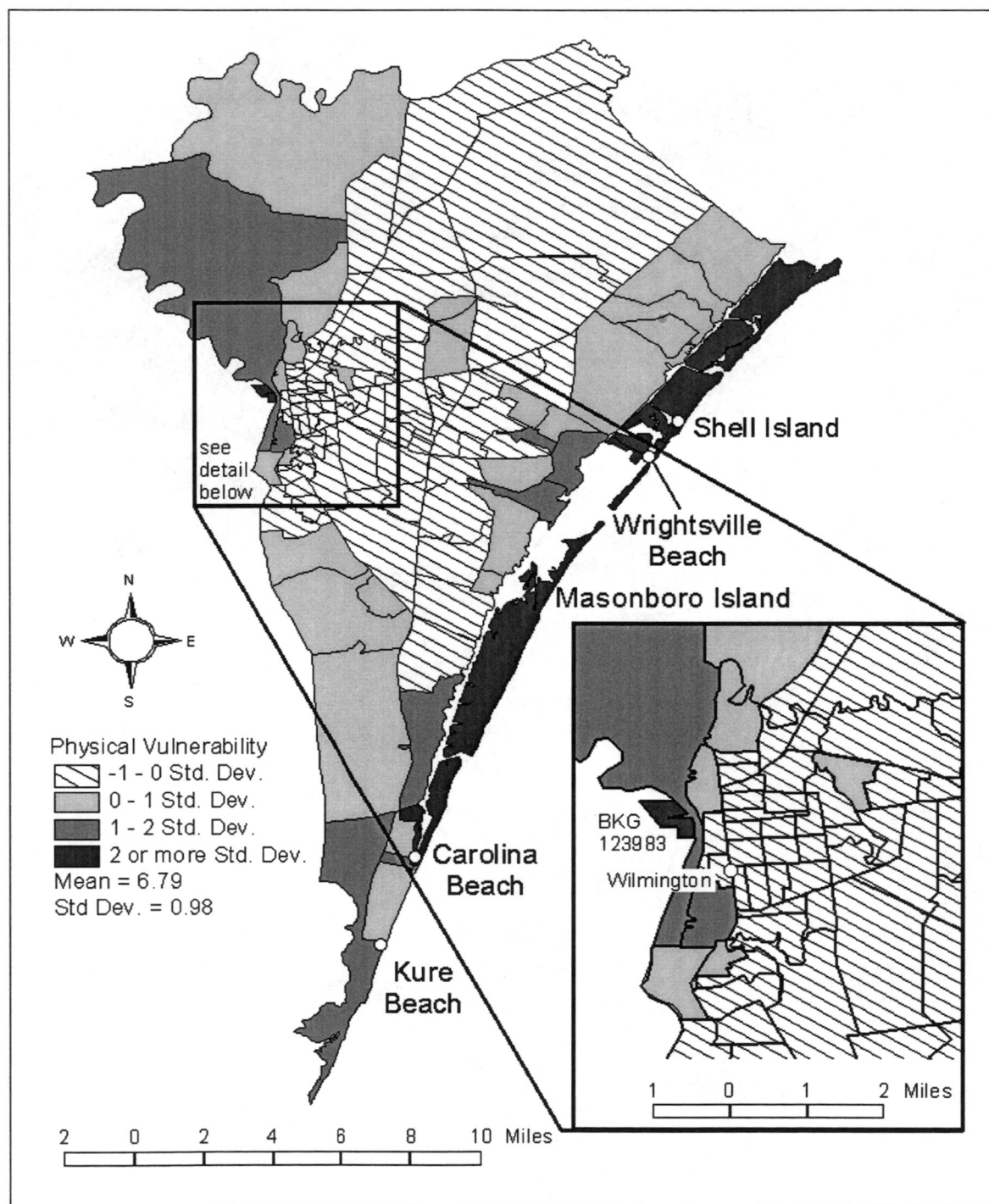
Figure 8. Physical Vulnerability of Brunswick County.

Beach (BKG 4028), and South Sunset Beach (BKG 5037). Other vulnerable areas include Belville, Oak Island, Long Beach, Varnamtown, Holden Beach, Sunset Beach, and Ocean Isle. These blockgroups in the northwest part of the county, Little Prong, Longwood, and Cedar Bay, are also physically vulnerable because they are located along the Waccamaw River. One blockgroup in the eastern part of the county is also among the most physically vulnerable. Most of the central and northern parts of the county have below average vulnerabilities.

New Hanover County. The mean PVI for New Hanover County is 6.79. In New Hanover County, blockgroups adjacent to water have the highest vulnerabilities (Figure 9). The blockgroups with the highest PVI scores are: Shell Island (BKG 118001), Wrightsville Beach (BKG 118002) Masonboro Island (BKG 118005), and BKG 123983 in western Wilmington. Mansonboro Island (BKG 18005) is the most physically vulnerable in the county and is uninhabited. Areas also with high PVI scores include some of the blockgroups along the Cape Fear River where the city of Wilmington is located.

Carteret County. The mean PVI for Carteret County is 8.1. In Carteret County, the areas with the highest VPI scores are located in the eastern half of the county and on the barrier islands (Figure 10). Many locations on the ocean side of the barrier island, including Atlantic Beach and the Cape Lookout National Seashore, are also among the most physically vulnerable blockgroups. The three blockgroups with the highest PVI scores are: Merrimon (BKG 1004), Davis (BKG 1005), Roe (BKG 1007). The western half of the county is the least physically vulnerable.

Figure 9. Physical Vulnerability of New Hanover County.



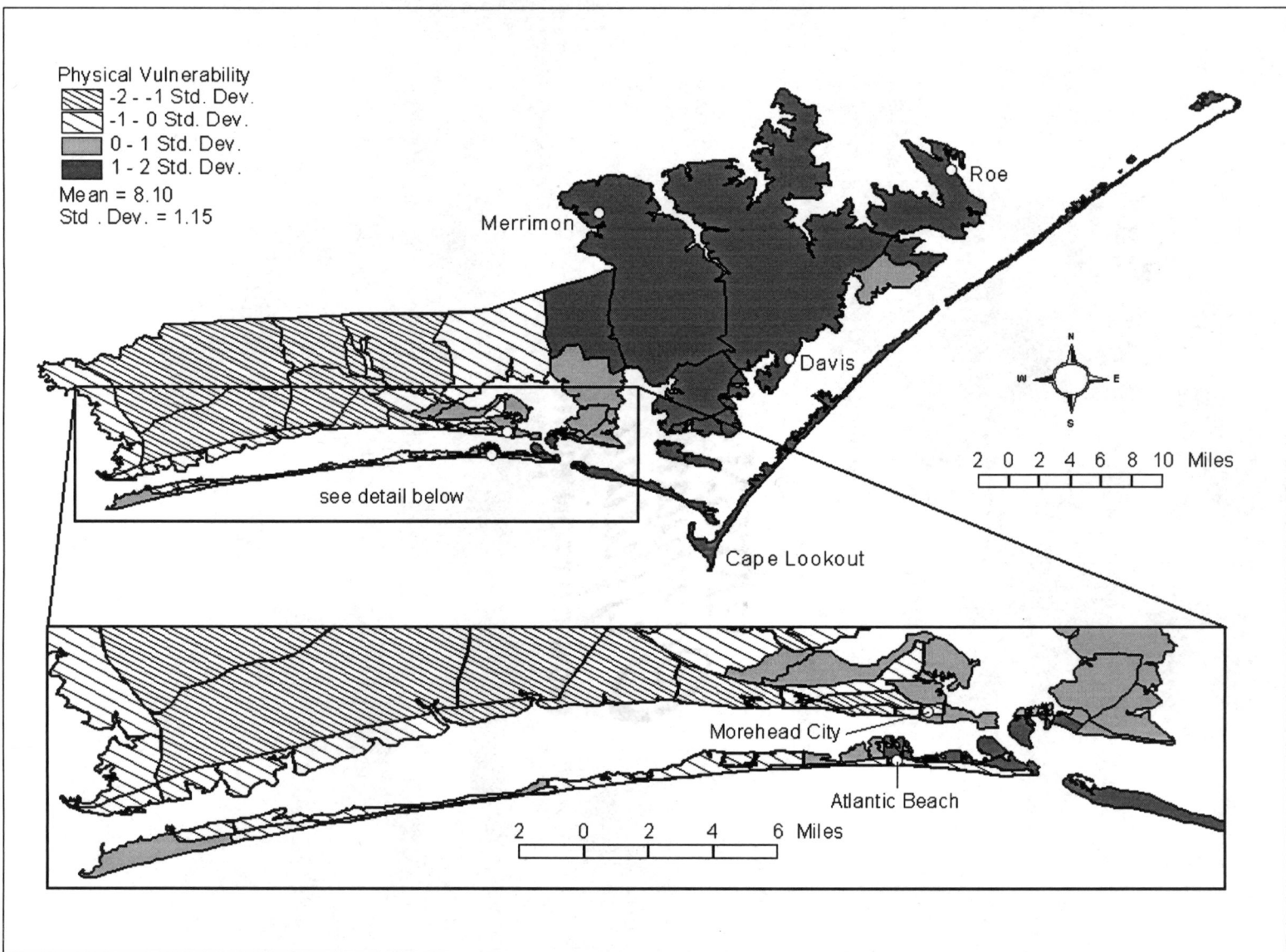


Figure 10. Physical Vulnerability of Carteret County.

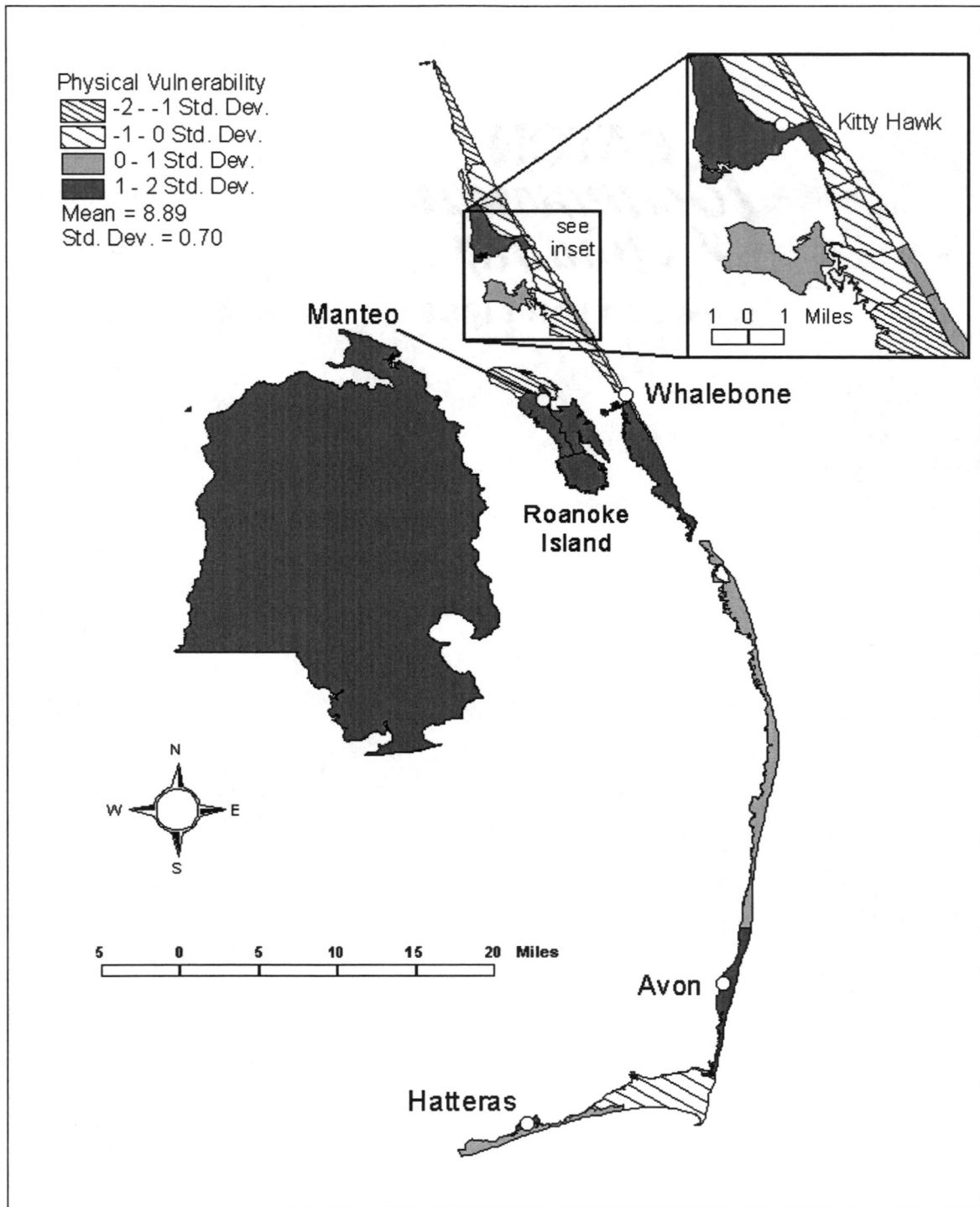
Dare County. Dare County has a mean PVI of 8.89 (Figure 11). The three blockgroups with the highest PVI scores are: Avon (BKG 5002), East Manteo (BKG 6002), and Mainland Dare (BKG 6005). Other blockgroups with high PVI scores are located in Kitty Hawk , on Roanoke Island, and on Hatteras Island.

Social Vulnerability (SVI).

The Social Vulnerability Index (SVI) is made up of components developed from census data, hotel data, and evacuation times (see Chapter 3). An average SVI score is obtained for each county. All the blockgroups mentioned have SVI's greater than one standard deviation from the mean of the county. To better explain the reasons for blockgroups having high SVI scores the table below explains some of the terms used in the explanation below.

Brunswick County. This county has a mean SVI of 7.19. In Brunswick County (Figure 12), blockgroups with a high SVI are located in the eastern part of the county along the Cape Fear River or in the northwest part of the county along the Waccamaw River. The blockgroups with the lowest SVI scores are found along the coast. The three blockgroups with the highest SVI scores are: North Belville (BKG 1983), South Belville (BKG 2001), and Little Prong (BKG 6001). North Belville is the most socially vulnerable blockgroup in the county because a high percentage of its population is of a susceptible age. South Belville's high score is related to the high percentage of new residents and to the large number of mobile homes. A large percentage of Little Prong's residents also live in mobile homes and have not completed high school.

Figure 11. Physical Vulnerability of Dare County.



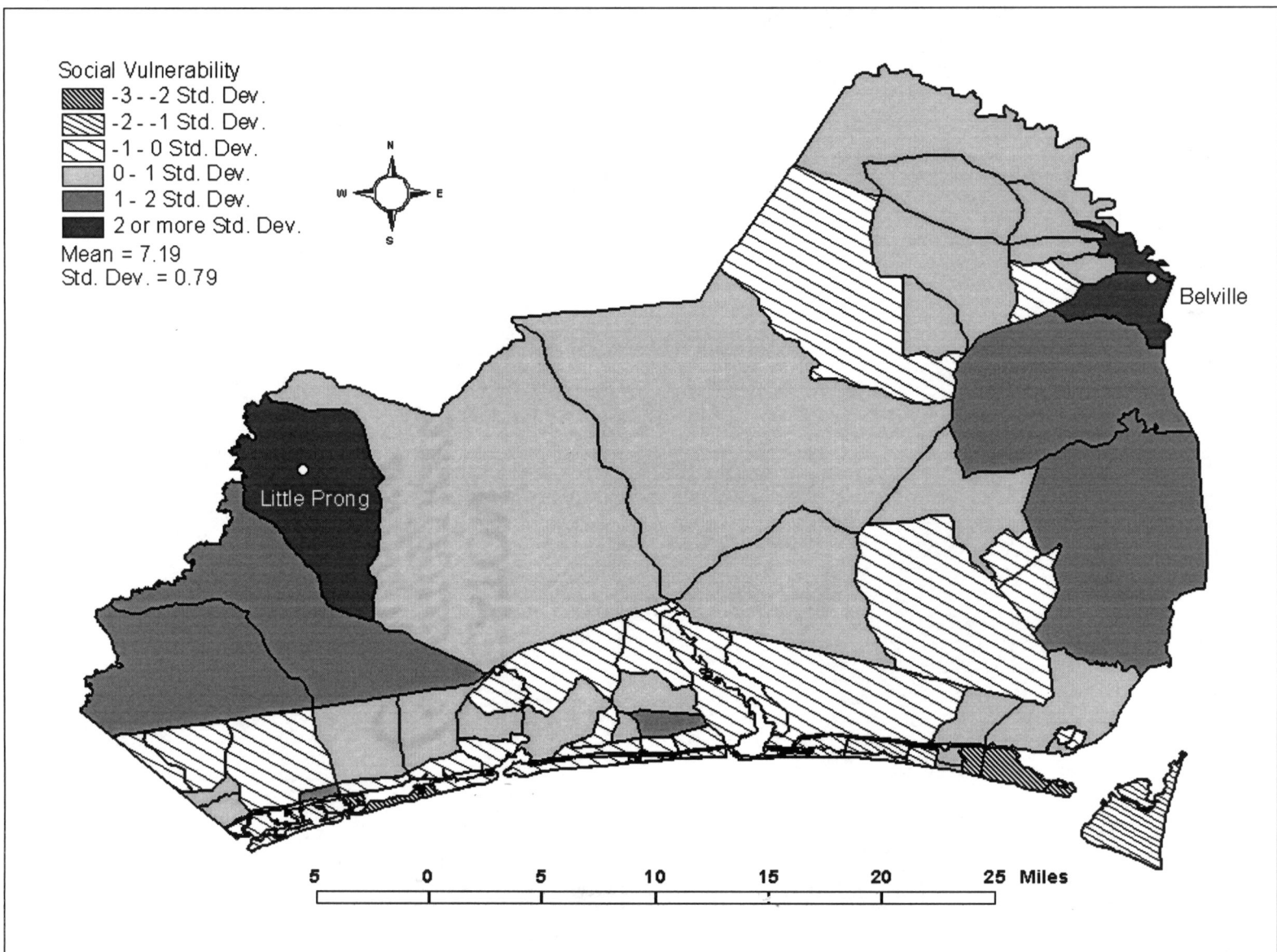
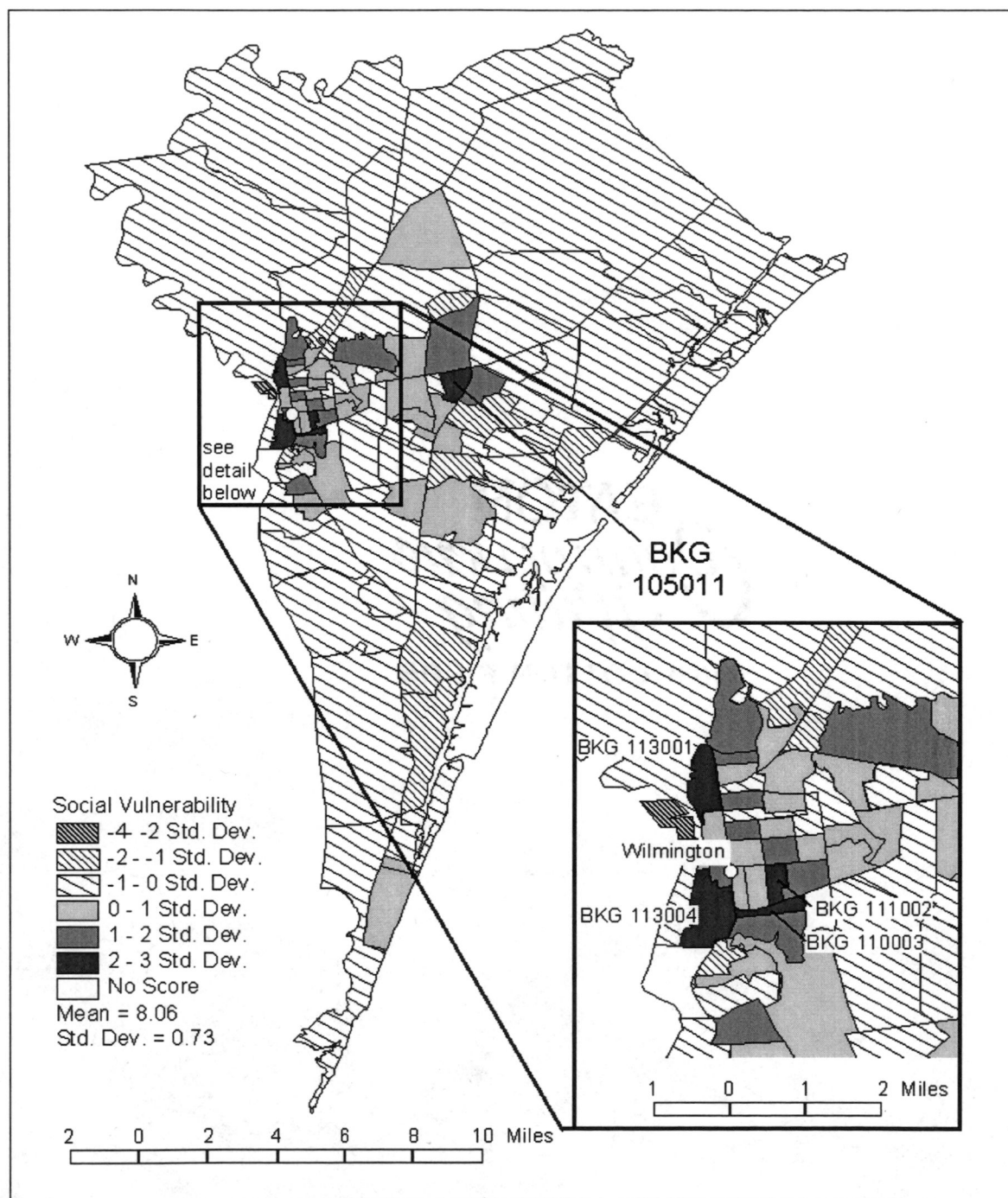


Figure 12. Social Vulnerability of Brunswick County.

New Hanover County. The mean SVI score for New Hanover County is 8.06. Most of the social vulnerability is concentrated around the city of Wilmington (Figure 13). Much of the coast is the least socially vulnerable. The blockgroups in the highest vulnerability category are: BKG 105011, BKG 111002, BKG 110003, and BKG 113001, and BKG 113004. BKG 111002 has the highest SVI score in this county. Nearly half of the blockgroup's population is made up of new residents and there are a relatively large percentage of female-headed households. This blockgroup also has a relatively high percentage of people at a susceptible age. Over 80 percent of the population of BKG 105011 are new residents. This blockgroup also has a large number of hotel rooms. BKG 105011 has a large number of hotel rooms and a relatively high percentage of multiple units. In BKG 110003, nearly 70 percent of the population, is made up of new residents and over 80 percent of the population consists of minorities. Three-fourths of BKG 113001's population is of susceptible age and about half of the population is made up of new residents. Over 70 percent of the population of BKG 113004 population consists of minorities and two-thirds of the population are new residents. There are three blockgroups in New Hanover County for which no social vulnerability score could be calculated because of insufficient census data. They are: BKG 109009, BKG 10001, and Masonboro Island (BKG 18005).

Figure 13. Social Vulnerability of New Hanover County.



Carteret County. Carteret County has a mean SVI score of 7.45. Carteret's most socially vulnerable blockgroups are scattered throughout the county (Figure 14). The blockgroups with the highest SVI scores in this county are: North Morehead City (BKG 04002), West Newport (BKG 07004), and West Atlantic Beach (BKG 12001). North Morehead City has high percentages of new residents and female-headed households. West Newport has a large percentage of people at a susceptible age and a large number of hotel rooms. West Atlantic Beach has many new residents and a large number of hotels.

Dare County. Dare County has a mean SVI score of 7.52 (Figure 15). The three blockgroups with the highest SVI scores are: West Manteo (BKG 6003), Wanchese (BKG 6004), and Mainland Dare (BKG 6005). West Manteo has the highest SVI score in the county. Nearly one-third of its population consists of ethnic minorities, and half of the population is new residents. Half of the population of Wanchese is made up of new residents and nearly half of the housing units are mobile homes. In Mainland Dare, nearly half of the housing units are mobile homes and the blockgroup has a low median household income. The southern Outer Banks, including Hatteras, and the Kill Devil Hills area have moderately high SVI scores. Most of the central and northern Outer Banks have low SVI scores.

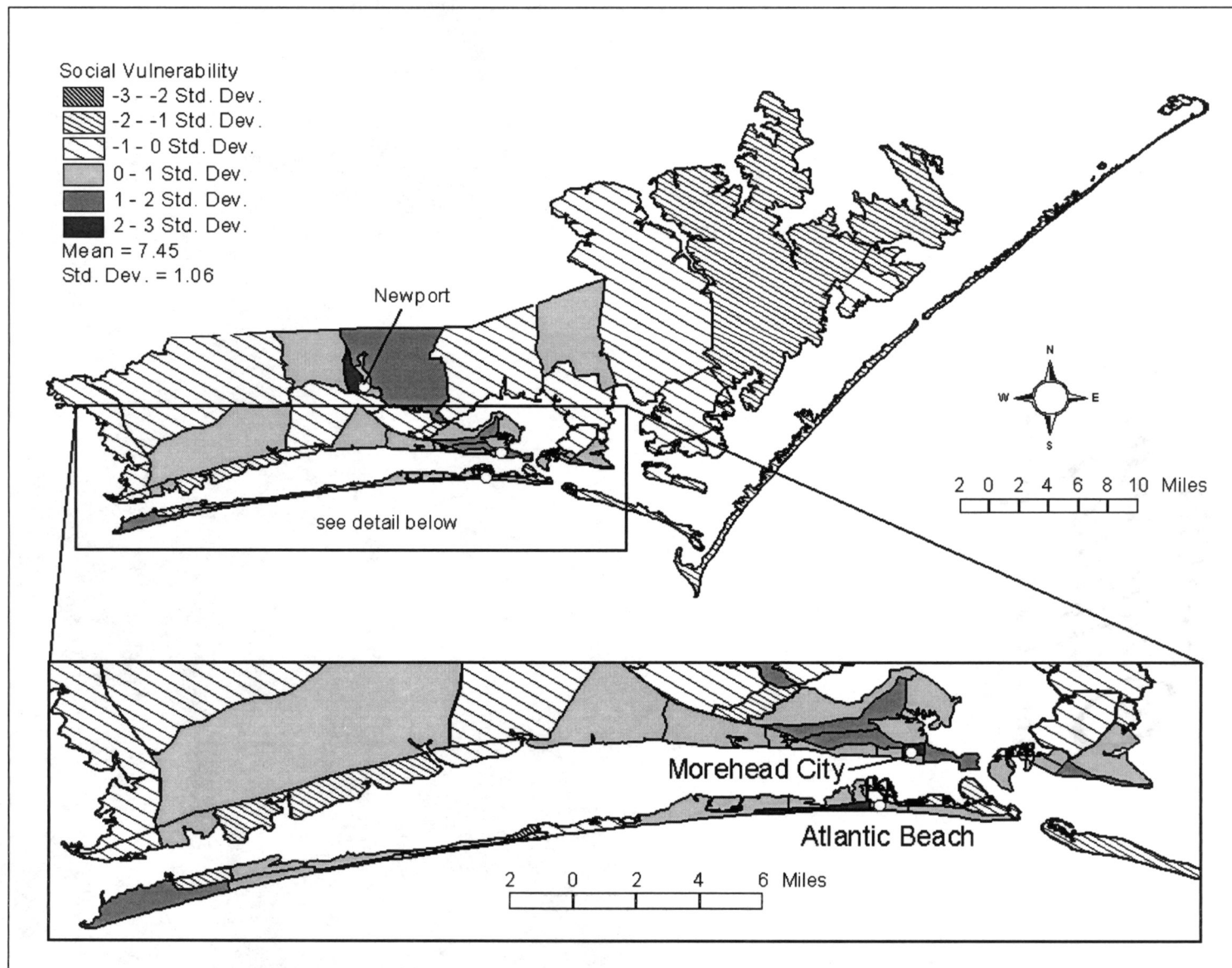
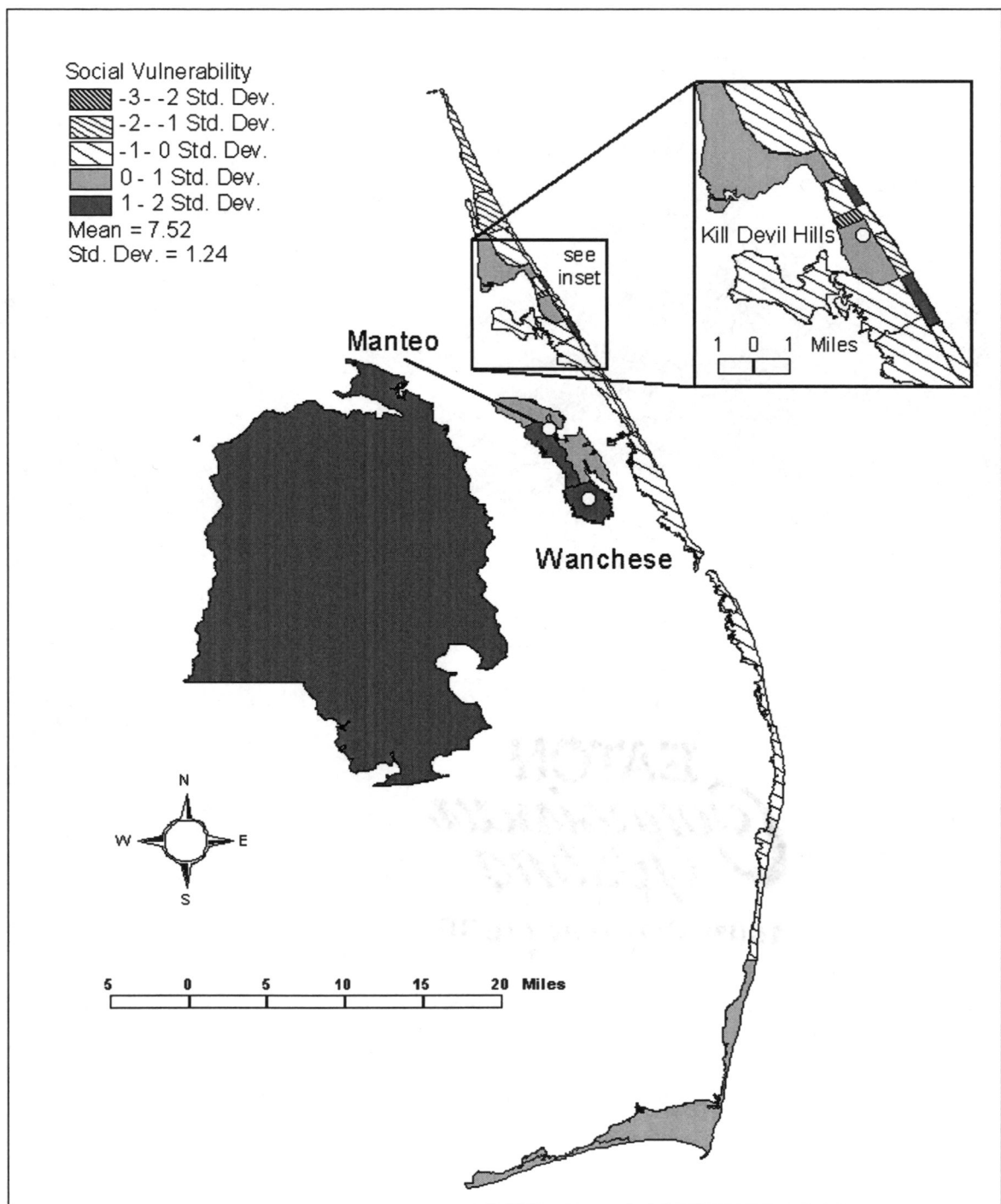


Figure 14. Social Vulnerability of Carteret County.

Figure 15. Social Vulnerability of Dare County.



Social vs Physical Vulnerability.

The relative importance of physical and social factors in determining vulnerability for each blockgroup can be established by subtracting the average physical vulnerability (PVI) score from the social vulnerability (SVI) score. A negative value indicated higher physical vulnerability and a positive value indicated higher social vulnerability. The results are provided in Table 11.

Table 11. Physical vs Social Vulnerability Results (Individual Counties).

	Physical		Social	
	# of BKGs	%of County	# of BKGs	% of County
Brunswick	32	45.1%	39	54.9%
New Hanover	19	17.6%	89	82.4%
Carteret	35	57.4%	26	42.6%
Dare	23	79.3%	6	20.7%
Total Sample	109	40.5%	160	59.5%

Brunswick County. In Brunswick County 39 of the 71 (or 55%) having higher SVI scores than PVI scores (Table 11). In general, blockgroups located along the ocean, the Cape Fear River and the Waccamaw River have higher PVI scores whereas, inland blockgroups have higher SVI scores (Figure 16).

New Hanover County. In New Hanover County, 89 of the 108 (or 82.4%) blockgroups have higher SVI scores (Table 11). These blockgroups are located around Wilmington and the center part of the county. Most of the blockgroups along the coast and in the northwest corner of the county are more physically vulnerable (Figure 17).

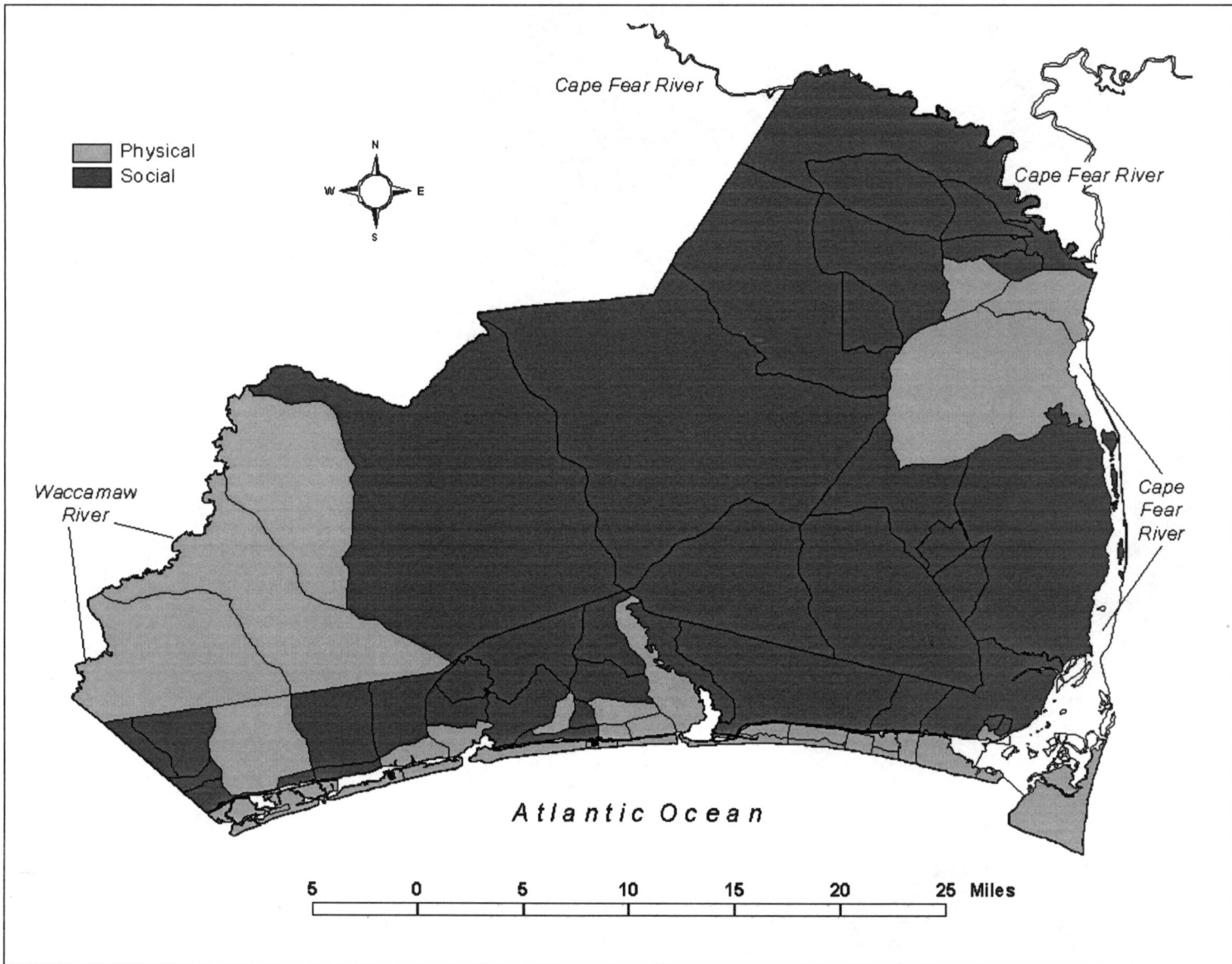
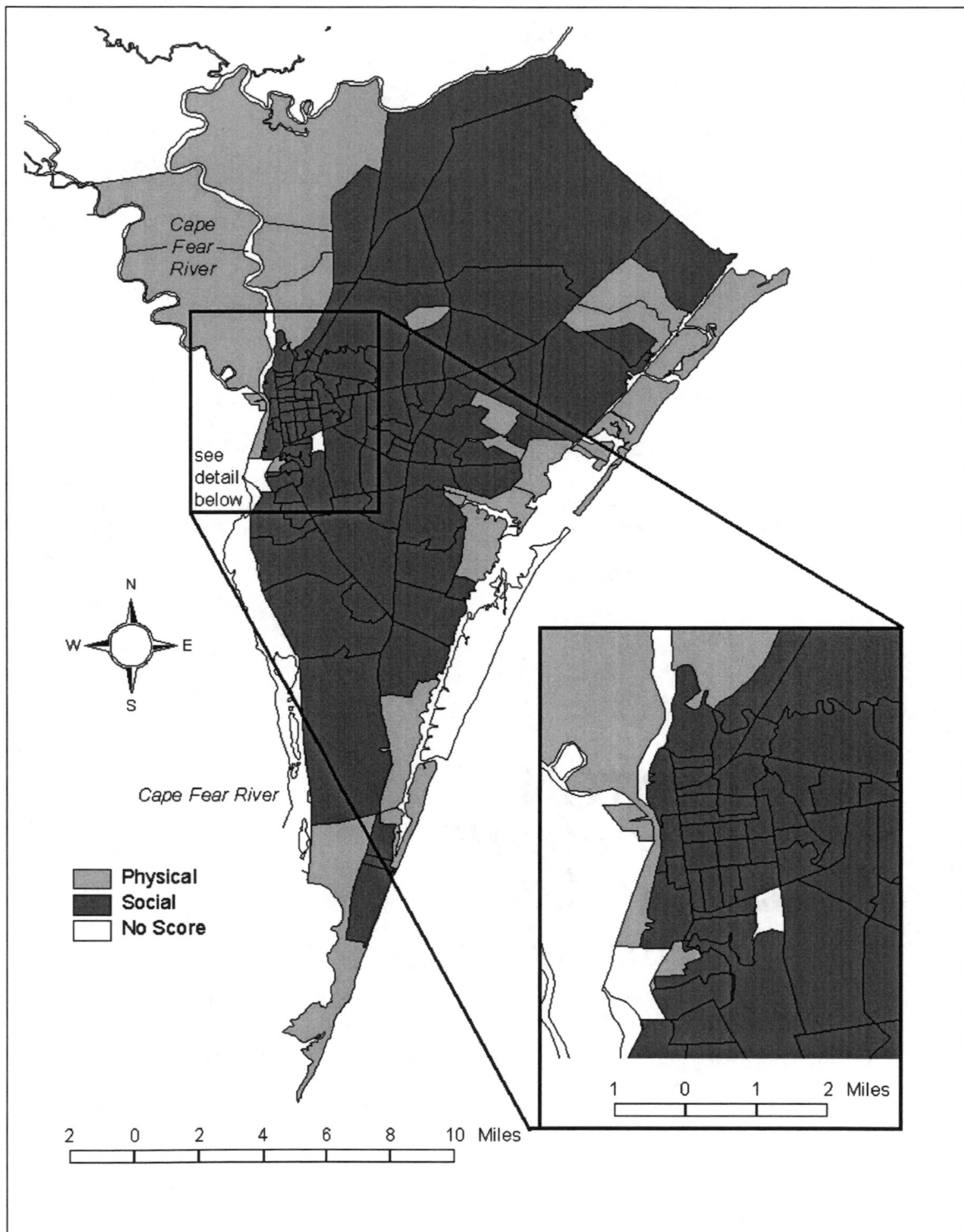


Figure 16. Social vs Physical Vulnerability for Brunswick County.

Figure 17. Social vs Physical Vulnerability for New Hanover County.



Carteret County. In Carteret County, 35 of the 61 (or 57%) blockgroups have higher PVI scores than SVI scores (Table 11). The eastern half of the county has higher PVI scores and the western half of the county has higher SVI scores. The eastern half of this county is very low in elevation and is more susceptible to storm surge. Half of the barrier islands of Carteret County have higher SVI scores and the other half have higher PVI scores. Many parts of the barrier islands of Carteret County have higher sand dunes. This allows these areas to have higher SVI scores than PVI scores (Figure 18).

Dare County. Twenty-three of the 29 (79%) blockgroups in this county have higher PVI scores than SVI scores (Table 11). The only areas where social factors contribute more to vulnerability than physical factors are on Roanoke Island and Cape Hatteras (Figure 19).

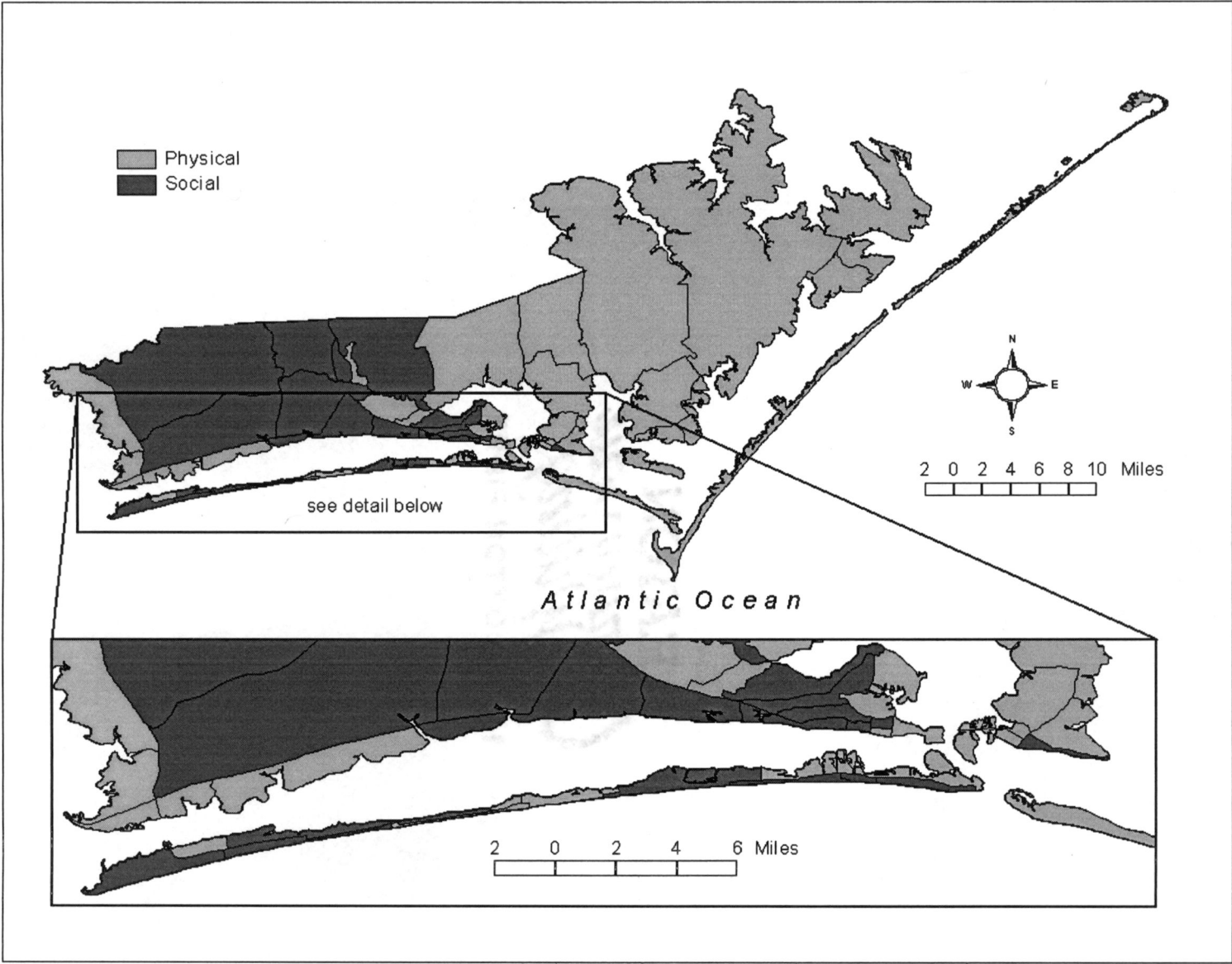
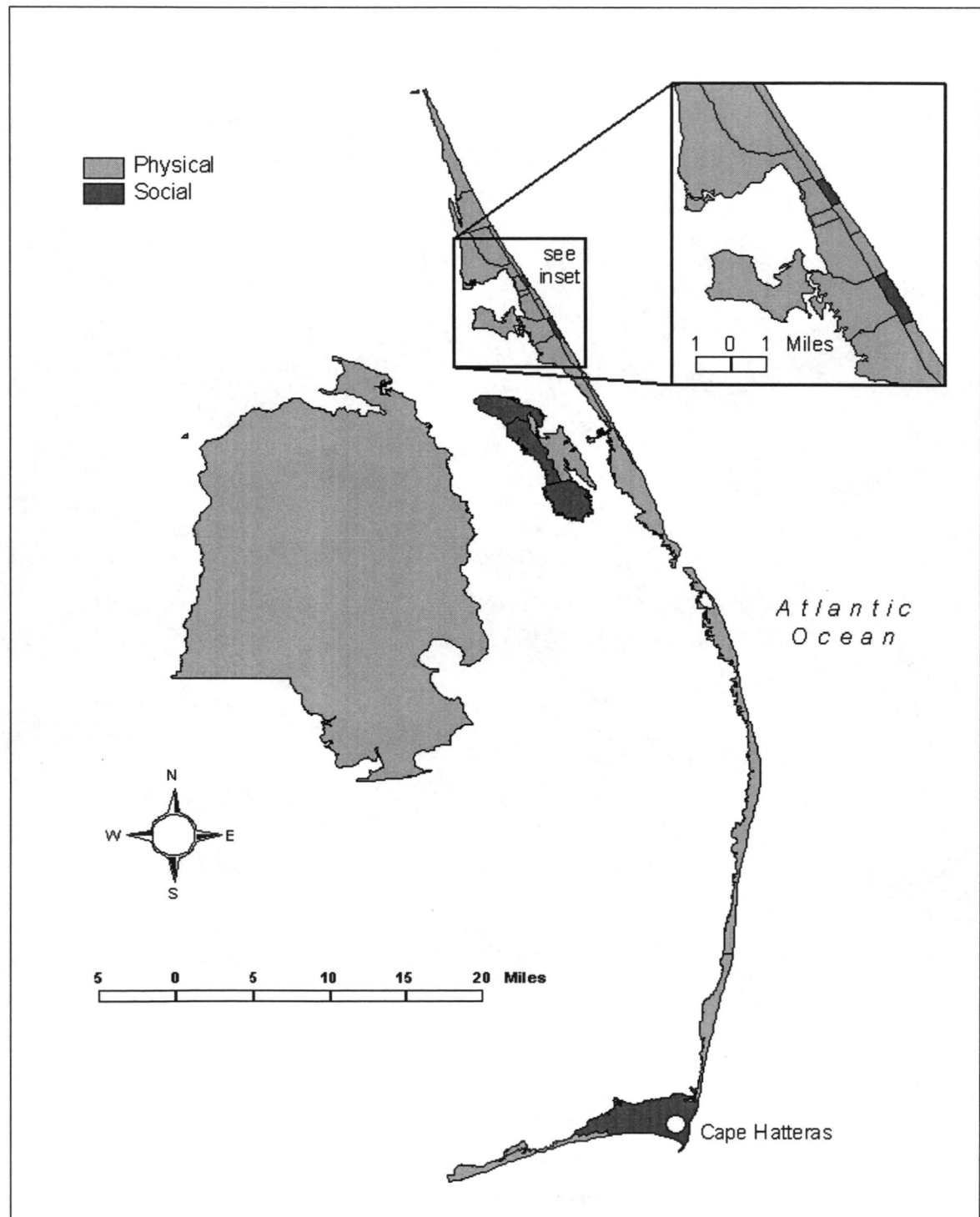


Figure 18. Social vs Physical Vulnerability for Dare County.

Figure 19. Social vs Physical Vulnerability for Dare County.



Total Vulnerability (TVI).

Each of six physical vulnerability scores (slow Categories 2-4 and fast Categories 2-4) was multiplied by the social vulnerability to attain six total vulnerability scores. They were then averaged together to produce one score for each blockgroup. These scores were then readjusted so that the highest TVI score would be 10.

Brunswick County. Brunswick County has a mean total vulnerability index (TVI) score of 6.65. The five blockgroups with the highest TVI scores in Brunswick County are: South Belville (BKG 2001), West Varnamtown (BKG 4012), Cedar Bay (BKG 5011), Longwood (BKG 5012), and Little Prong (BKG 6001) (Figure 20). South Belville lies along the Cape Fear and is across from Wilmington. This blockgroup has a high ethnic population and half of the population is made up of new residents. This blockgroup also has a high median household income level over \$65,000. This blockgroup also has an extremely high physical vulnerability score of 9.15 and a SVI score of 8.89. West Varnamtown, located in the center of the county near the coast, has a very high percentage of mobile homes in the blockgroup and a large number of hotel rooms. It also has a high PVI score of 8.85 and a SVI score of 8.10. The next three blockgroups are located in the northwest corner of the county. Many small tributaries and the Waccamaw River flow through this area. All three blockgroups have high PVI scores (Figure 8) and SVI scores (Figure 12). Cedar Bay has a high PVI score of 8.88 and a SVI score of 8.29. It has a large population without a high school education and nearly half of the housing units are mobile homes. Over one-third of the housing units in Longwood

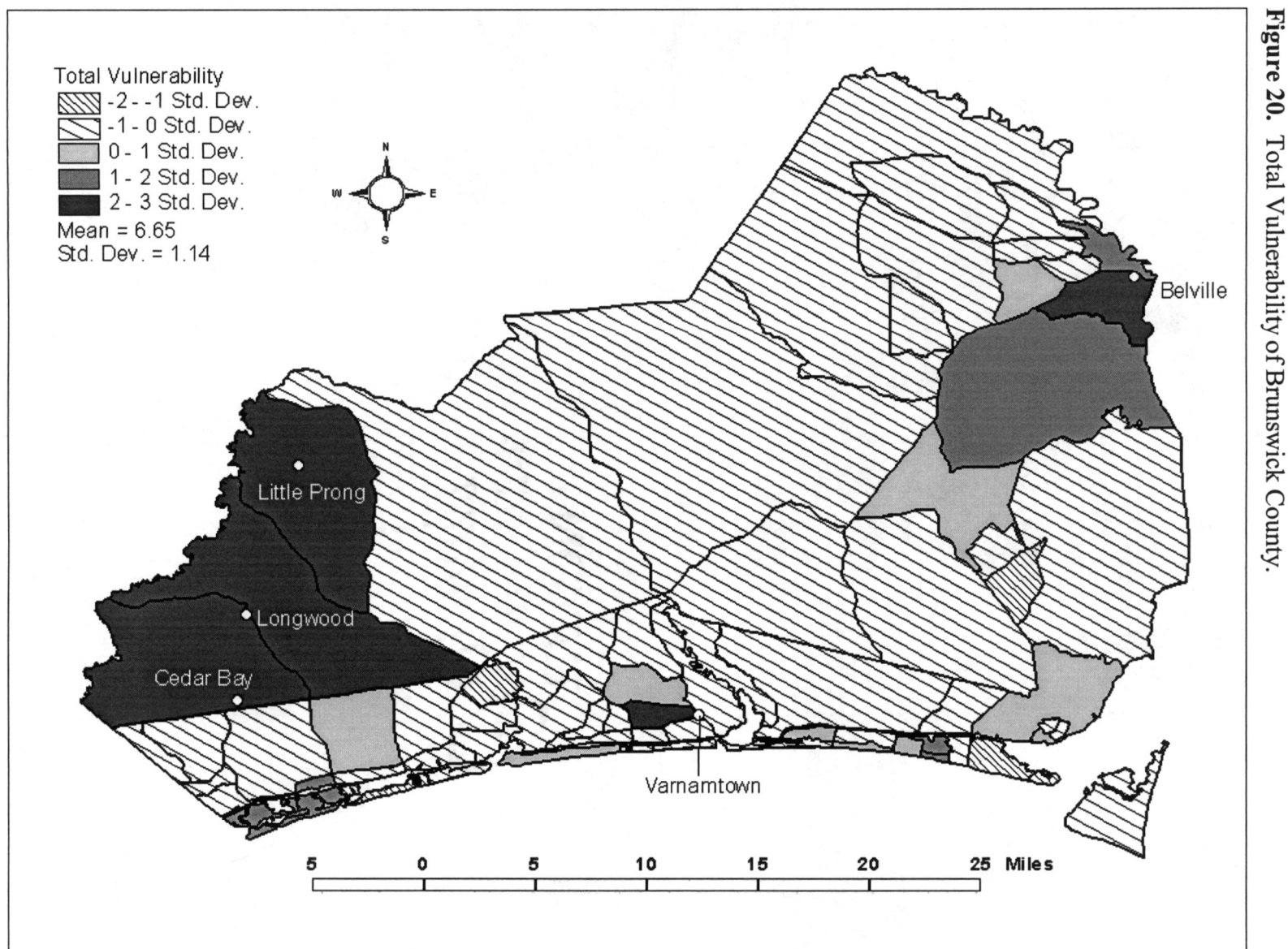


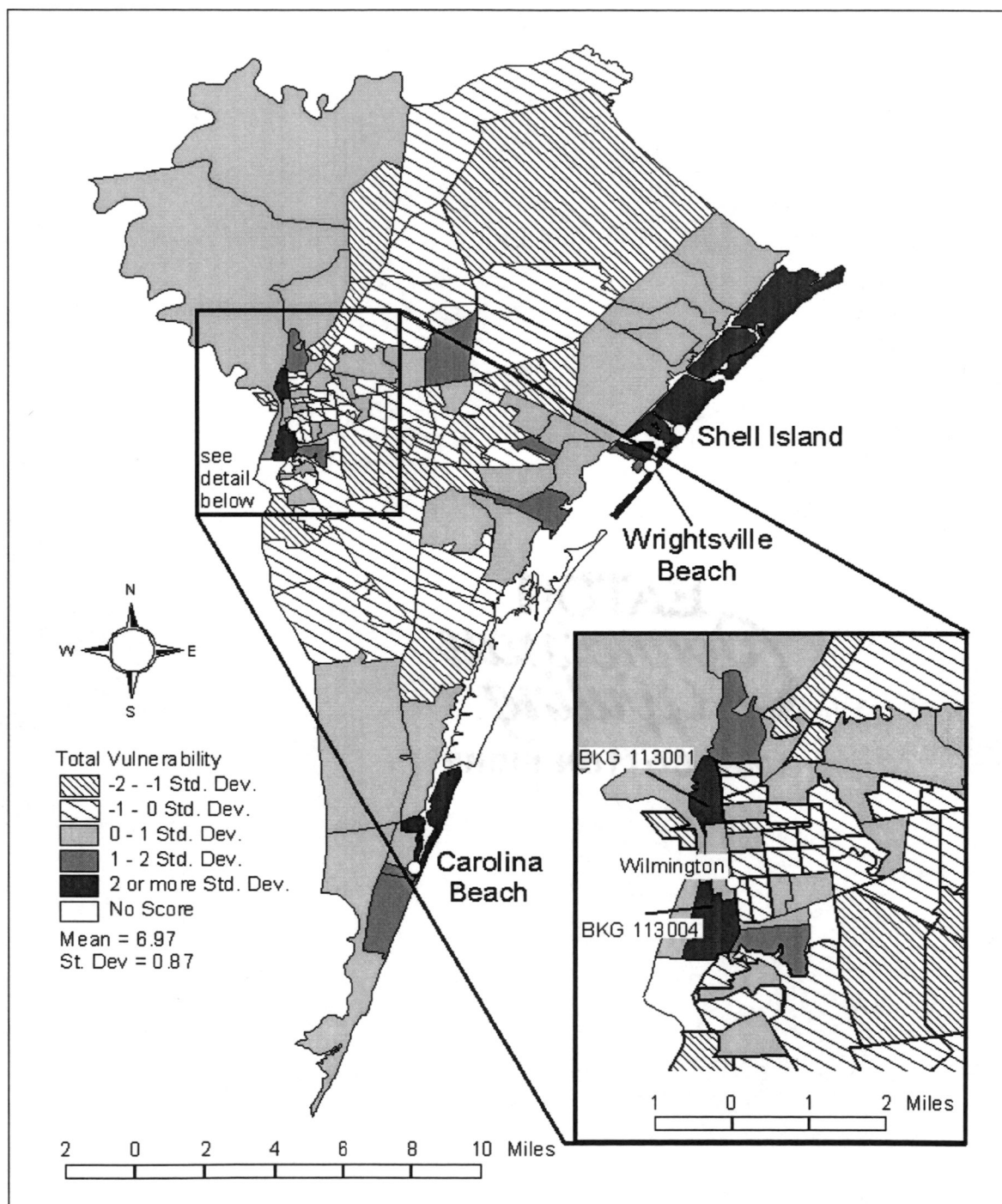
Figure 20. Total Vulnerability of Brunswick County.

and in Little Prong are mobile homes. Both also have a high percentage of the population without a high school education. In Longwood the PVI score is 8.91 and the SVI score is 8.00. The PVI score in Little Prong is 8.94 and the SVI score is 8.79.

New Hanover. New Hanover County has a mean TVI score of 6.97. Six blockgroups have the highest TVI scores compared to the mean of the county (Figure 21). They are: BKG 113001, BKG 113004, Shell Island (BKG 118001), North Wrightsville Beach (BKG 118002), South Wrightsville Beach (BKG 118004), and Carolina Beach (BKG 122001). These six blockgroups can be broken down into two groups. The first group consists of two blockgroups located in the city of Wilmington. One blockgroup is in northwest Wilmington (BKG 113001) and the other is in southwest Wilmington (BKG 113004). Both have high PVI scores due to their proximity to the Cape Fear River. BKG 113001 has a PVI score of 7.45 and BKG 113004 has a PVI score of 8.36. The SVI score is 9.96 in BKG 113001 and 9.58 in BKG 113004. Both blockgroups possess very low median household incomes under \$7,000. Other social factors that affect these blockgroups are the susceptible age of the residents and multiple units.

The second group are blockgroups with high TVI scores that border the ocean. These four blockgroups, Shell Island, North Wrightsville Beach, South Wrightsville Beach, and Carolina Beach, have median house values greater than \$90,000 and have relatively high median household incomes greater than \$34,000. These blockgroups have more property damage potential than the other two blockgroups. Shell Island has a PVI score of 9.76 and a SVI score of 7.57. North Wrightsville Beach has a PVI score of 9.76

Figure 21. Total Vulnerability for New Hanover County.



and a SVI score of 7.74. South Wrightsville Beach has a PVI score of 9.70 and a SVI of 7.96. Carolina Beach PVI score is 9.64 and SVI score is 7.61. There are three blockgroups in New Hanover County for which no overall vulnerability score could be calculated because of the lack of census data. They are: BKG 109009, BKG 110001, and Masonboro Island (BKG 118005).

Carteret. Carteret County has a TVI score of 7.48 (Figure 22). It has the highest TVI score of the four counties. However, it does not contain the extremes found in the other counties. Only one blockgroup was classified into the highest category of total vulnerability and it is South Lenoxville (BKG 03001). It is located along the southern coast of the county. This blockgroup has a high percentage of people at a susceptible age. In addition over one-third of the population recently moved to the blockgroup and 8 % of the households are headed by women. This blockgroup also has a high PVI score at 8.67 and a SVI score of 9.25. These blockgroups also had amongst the highest TVI scores in the county: BKG 3003 (North Beaufort), BKG 3007 (North River), BKG 4001 (Morehead City), and BKG 9006 (Lands End). BKG 3003 is found in north Beaufort and it has a PVI score of 8.76. The SVI score here is 8.35 because of its high percentages of people without a high school education and female-headed households with children. North Beaufort has a PVI score of 8.76 and a SVI score of 7.66. North Beaufort has high percentages of mobile homes and people without a high school diploma. North River has a PVI score of 9.56 and a SVI score of 7.66. The SVI score can be attributed to the

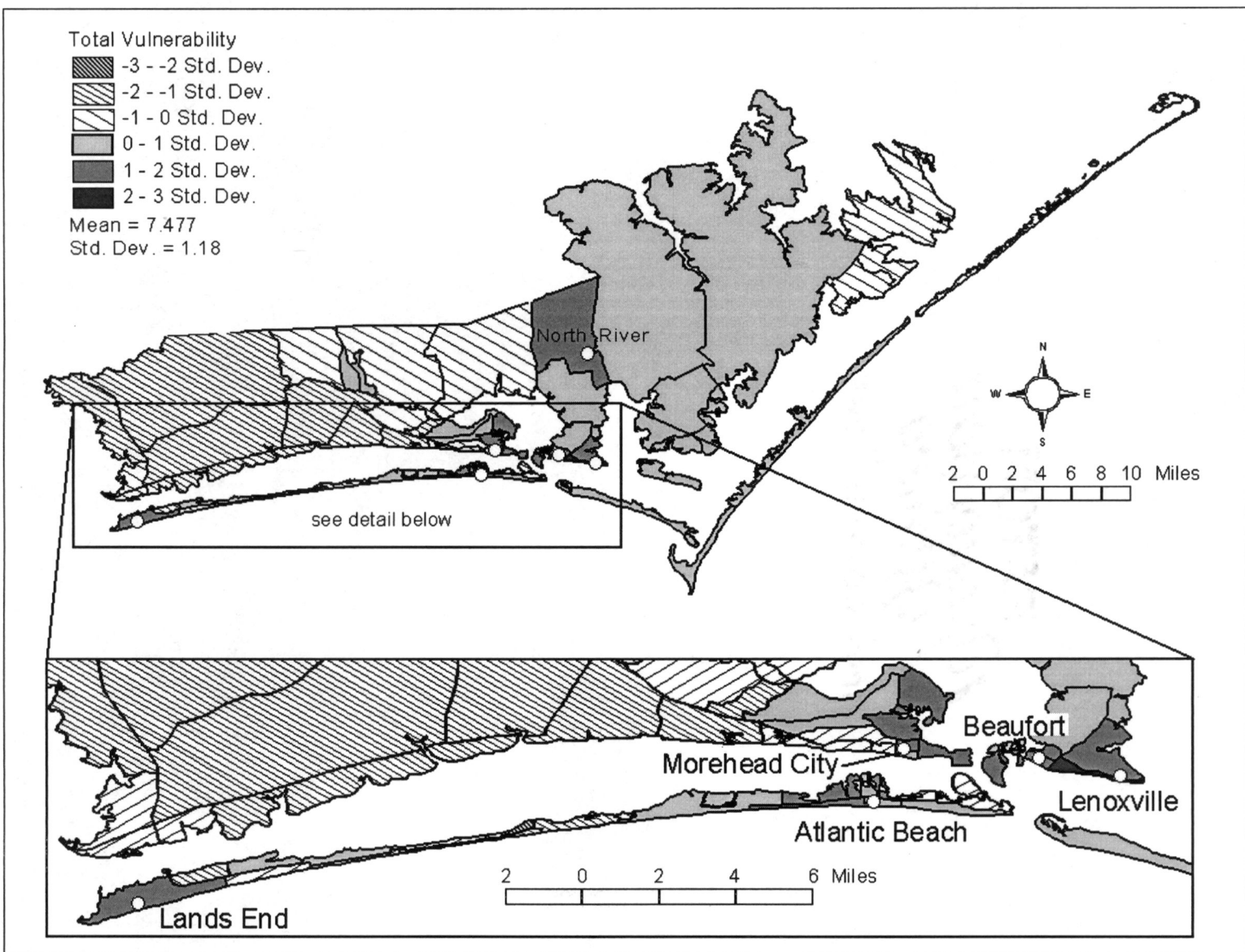
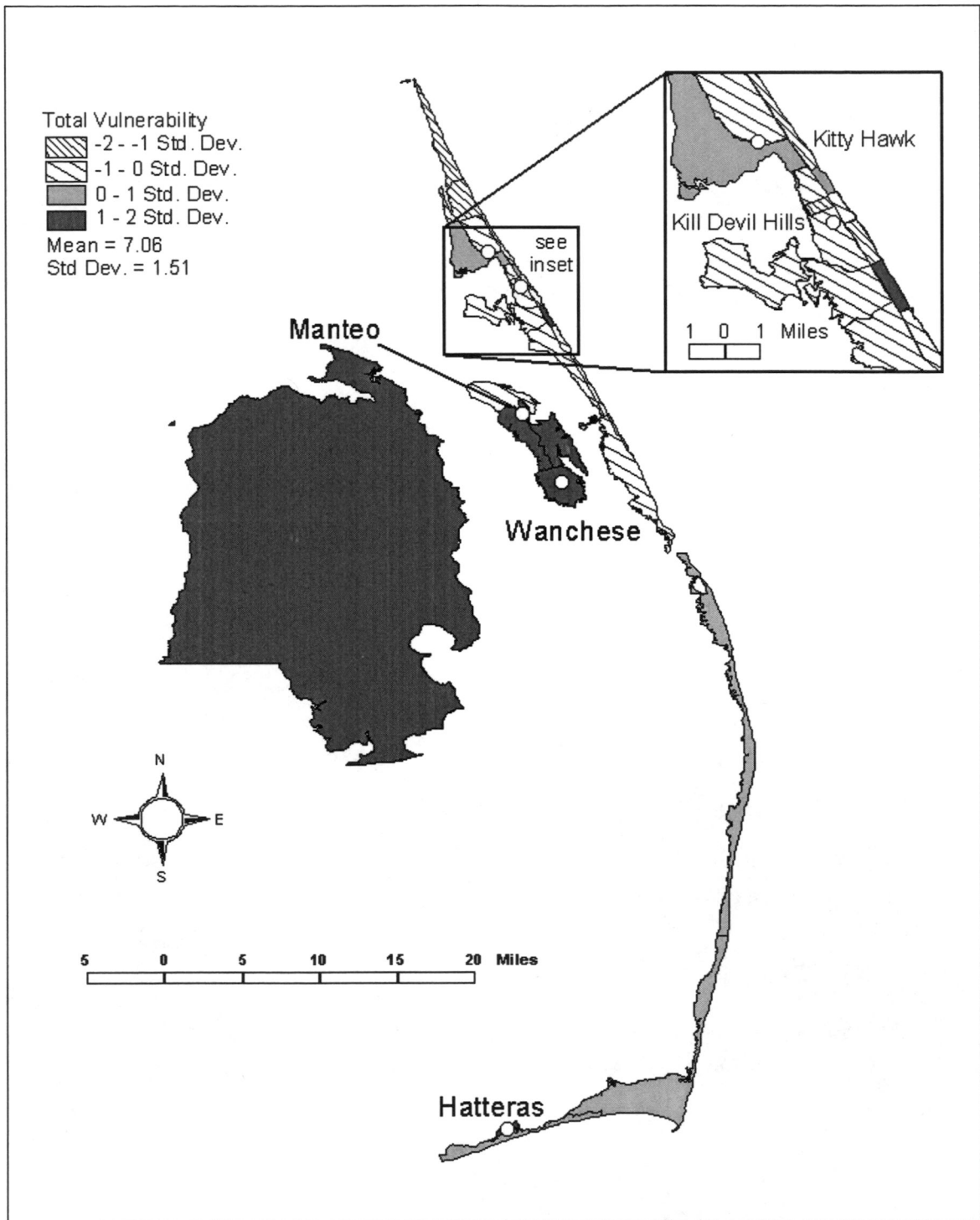


Figure 22. Total Vulnerability of Carteret County.

high percentage of female-headed households with children and the low median household income. Morehead City (BKG 4001) has high percentages of ethnicity and new residents. The PVI score for Morehead City is 8.58 and the SVI score 7.08. BKG 9006 (Lands End) has a PVI of 8.12. Here, a number of new residents and hotels contribute to the SVI score of 8.99.

Dare. Dare County has a TVI score of 7.06. The blockgroups with the highest TVI scores are: South Kill Devil Hills (BKG 3002), Hatteras (BKG 5005), East Manteo (BKG 6002), West Manteo (BKG 6003), Wanchese (BKG 6004), and Mainland Dare County (BKG 6005) (Figure 23). South Kill Devil Hills has the highest number of hotel rooms in the entire study at over 1200 rooms and contributes greatly to the SVI score of 9.50. This blockgroup has a relatively high percentage of multiple housing units. The PVI is also high at 8.80. Hatteras is in the southern part of the Cape Hatteras National Seashore. The SVI score is 9.05 because it has a very low median household income and nearly one-third of the population has not completed high school. This blockgroup is also very physically vulnerable with a score of 9.74. East Manteo, West Manteo, and Wanchese are three of the four blockgroups that make up Roanoke Island. East Manteo has a high percentage mobile homes and the median household income is moderately low at \$24,000. This blockgroup has a very high PVI score of 9.89 and a SVI score of 8.86. West Manteo has a PVI score of 9.78 and a SVI score of 9.78. Nearly one-third of the housing units are mobile homes. Wanchese has a high percentage of minorities and a large percentage of mobile homes. The PVI score is 9.66 and the SVI is 10. In Mainland

Figure 23. Total Vulnerability of Dare County.



Dare County, 27% of the households are headed by women and it has a low median income (just over \$18,000). This blockgroup also has a high PVI score at 8.95 and a high SVI score at 10. It also has the highest total vulnerability score in the county.

Between County Variability in Vulnerability

In the previous section, vulnerability scores were calculated for each individual county. This compared all the blockgroups within each county. The section that follows examines all the blockgroup data from the four counties together. Here, all the blockgroups are compared to a grand mean score. The score of each blockgroup is categorized according to its standard deviation from the grand mean. Most of the results for this evaluation are similar to the previous section. The blockgroups that were the most physically, socially, and totally vulnerable in the county analysis are similarly vulnerable in this analysis. For this reason, a comparison of the two sets of results is also given.

Physical Vulnerability

Table 12 and Figures 24-27 present the results for the total sample. The mean PVI score for the total sample is 7.30. Dare and Brunswick counties scored higher than the mean PVI score. Dare County is clearly the most physically vulnerable of the four counties. It has a PVI score of 8.30. Almost 45% of this county's blockgroups scored more than 1 standard deviation above the mean. It is no surprise that Dare County has the highest PVI score because all of its blockgroups, except one, border major water bodies. Carteret County is the least physically vulnerable and it has a PVI score of 6.55. None of Carteret County's blockgroups scored over 1 standard deviation above the mean. In fact, over 37% of the county scored more than 1 standard deviation below the mean. All of

Carteret's inland blockgroups scores were 1 standard deviation or more below the mean. No other blockgroups in the total sample scored more than 1 standard deviation below the means. Many of the blockgroups that make up the barrier islands in Carteret County have high sand dunes for protection against storm surge that can help account for their low scores.

In Brunswick County, the blockgroups with the highest PVI scores are located along the barrier island, the Waccamaw River, and the Cape Fear River (Figure 24). In New Hanover County, the blockgroups with the highest PVI scores are located along the east coast of the county (Figure 25). The difference between the highest PVI score of 8.3 and the lowest PVI score of 6.55 is 1.75. This difference is much greater than the difference between the highest and lowest SVI scores.

Table 12. Physical Vulnerability Results for Total Sample.

	Physical Vulnerability Mean Score Total Sample	# of BKGs > +1 std. dev.	% of County	# of BKGs < -1 std. dev.	% of County Or Total Sample
Brunswick	7.82	20	28.2%	0	0%
New Hanover	7.11	10	9.0%	0	0%
Carteret	6.55	0	0%	23	37.7%
Dare	8.30	13	44.8%	0	0%
Total Sample	7.30	43	15.8%	23	8.5%

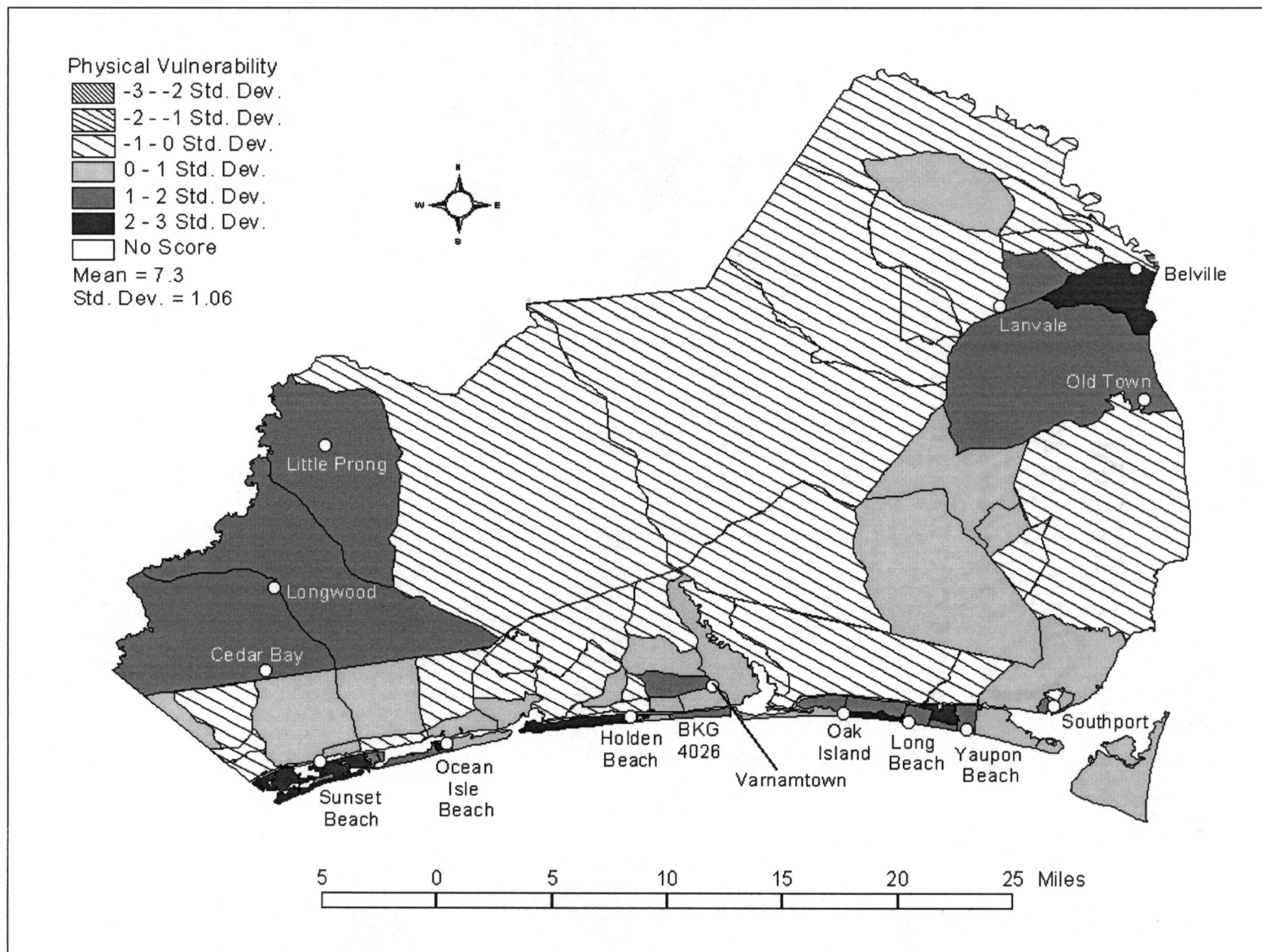
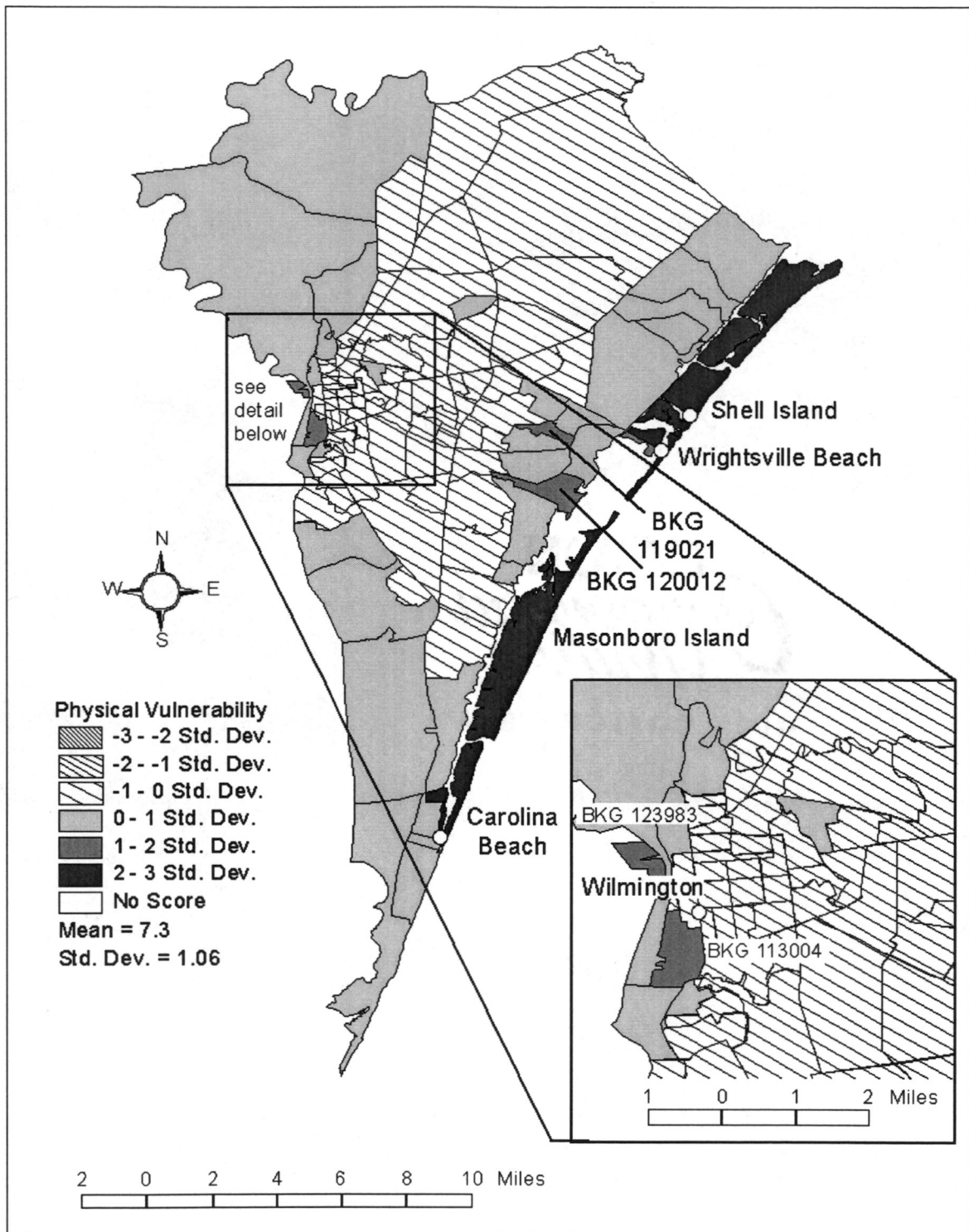


Figure 24. Physical Vulnerability for Brunswick County.

Figure 25. Physical Vulnerability for New Hanover County.



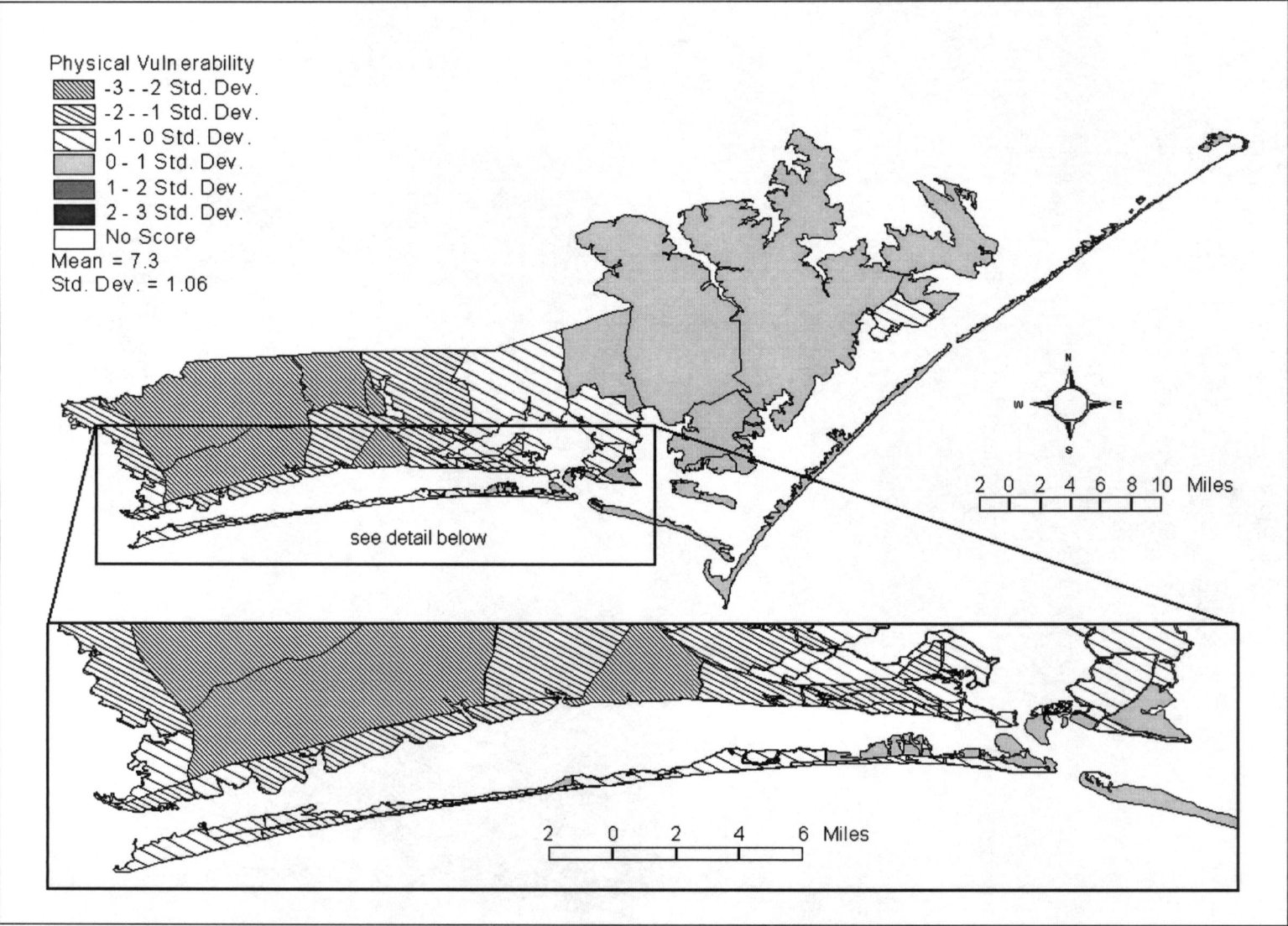
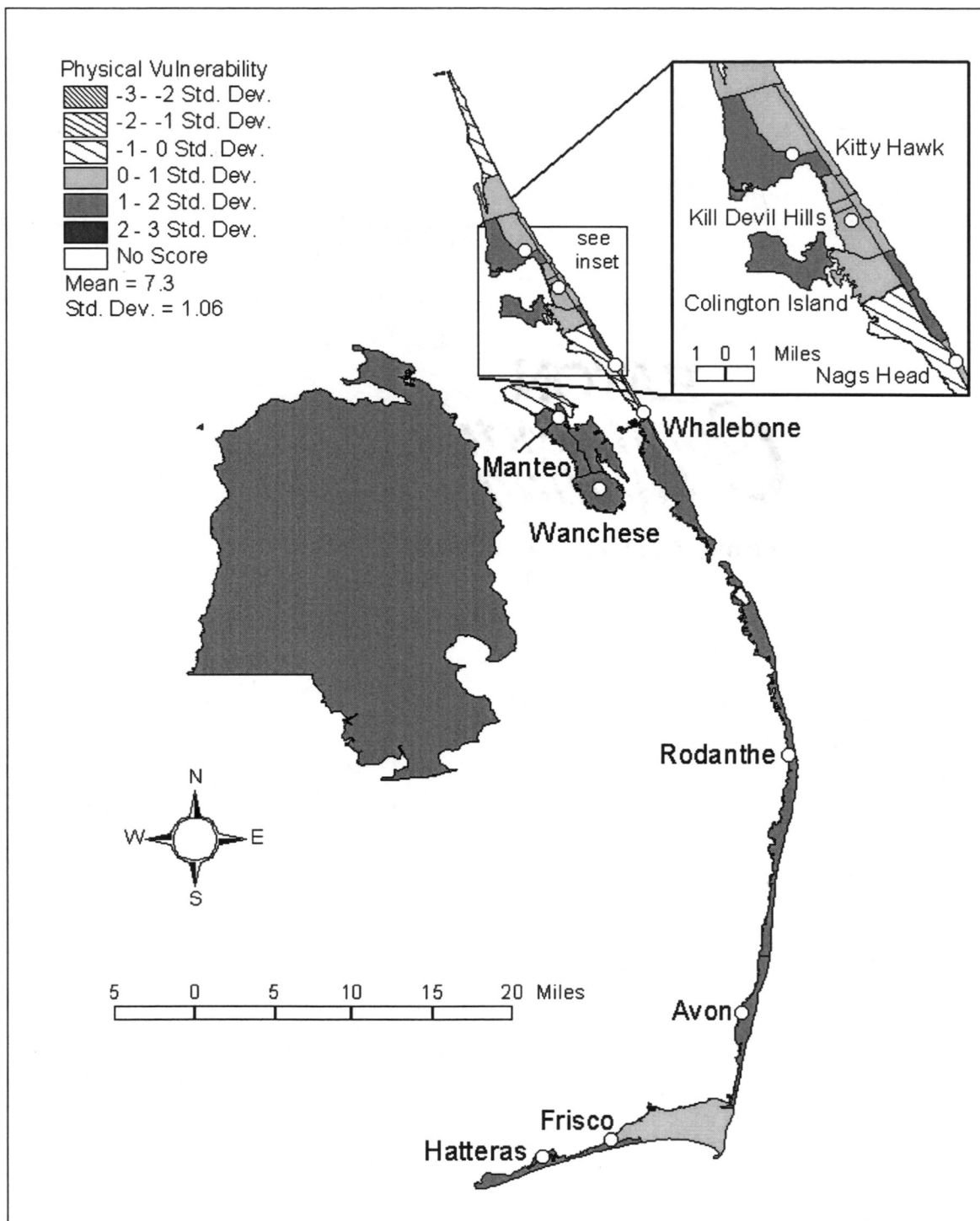


Figure 26. Physical Vulnerability of Carteret County.

Figure 27. Physical Vulnerability of Dare County.



Social Vulnerability.

The mean SVI score for the total sample is 6.83 (Table 13). Dare and New Hanover counties scored above the mean. Dare County has the highest SVI score at 7.07. Brunswick County has the lowest SVI score at 6.69. The difference between the highest and lowest SVI scores is only 0.38, which is much lower than the PVI difference. The extremes of social vulnerability are found in New Hanover County. New Hanover has the highest percentage of blockgroups with SVI scores greater than 1 standard deviation (21.5%). New Hanover County also has the highest percentage of blockgroups scores more than 1 standard deviation below the mean (13.1%). Fewer extremes are found in Carteret County where 4.9% of the blockgroups had SVI scores more than 1 standard deviation above the mean and only 3.3% with scores more than 1 standard deviation below the mean.

Table 13. Social Vulnerability Results for Total Sample.

	Social Vulnerability Mean Score Total Sample	# of BKGs >+1 std. dev.	% of County	# of BKGs < -1 std. dev.	% of County or Total Sample
Brunswick	6.69	3	4.2%	12	1.4%
New Hanover	6.94	23	21.5%	14	13.1%
Carteret	6.80	3	4.9%	2	3.3%
Dare	7.07	5	17.2%	1	3.4%
Total Sample	6.83	34	31.8%	29	10.8%

Figure 28. Social Vulnerability of Brunswick County.

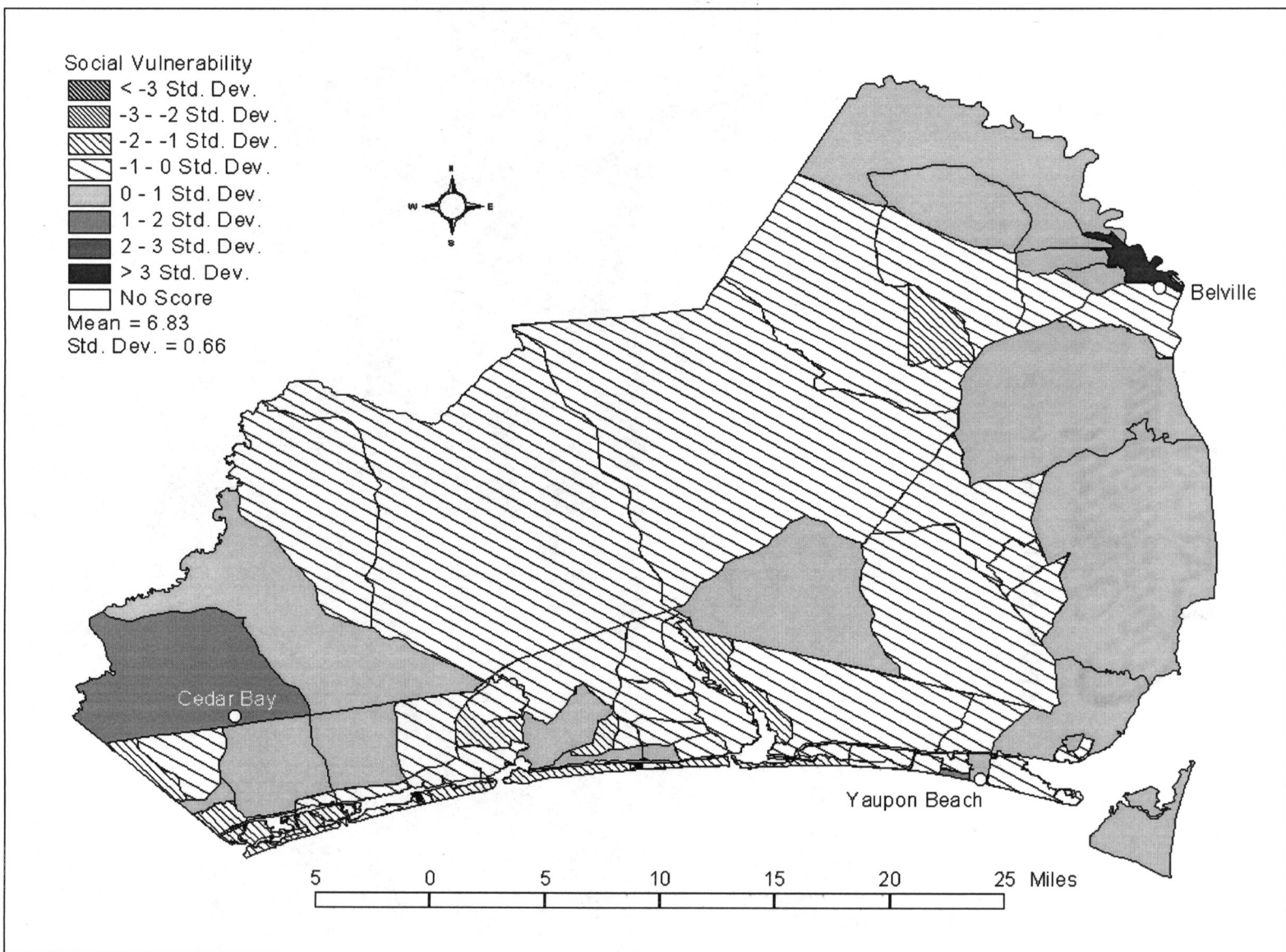


Figure 29. Social Vulnerability of New Hanover County.

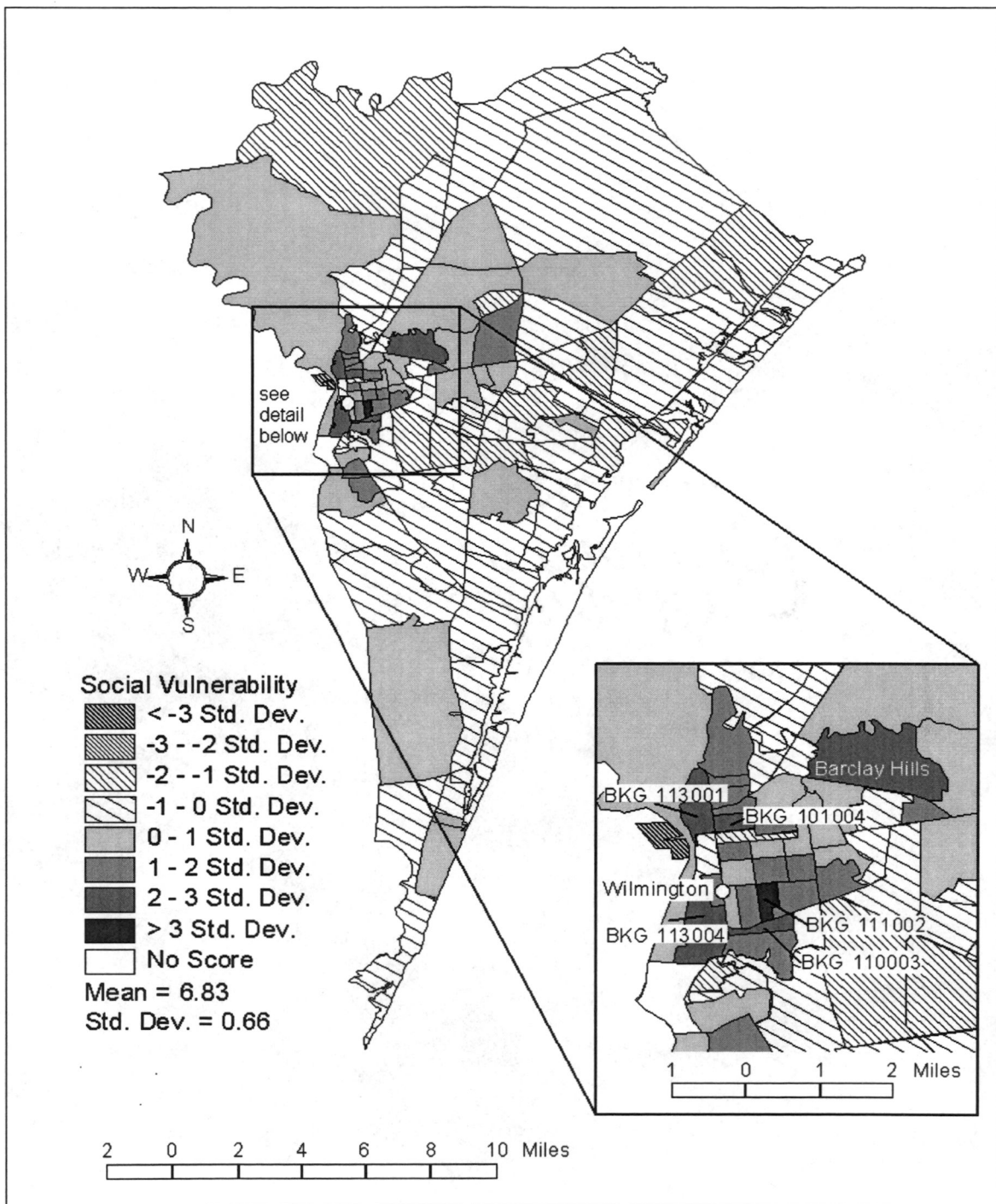


Figure 30. Social Vulnerability of Carteret County.

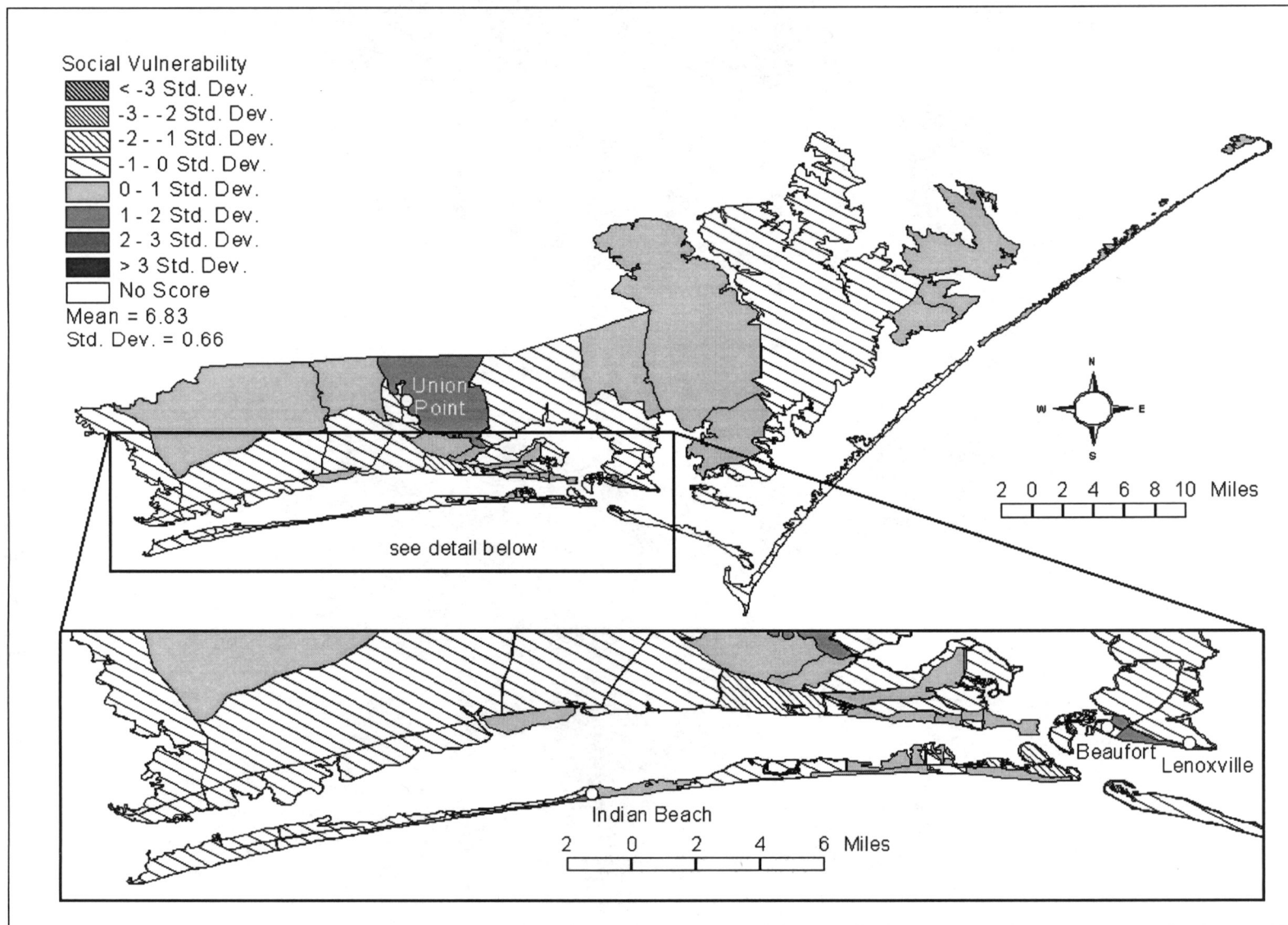
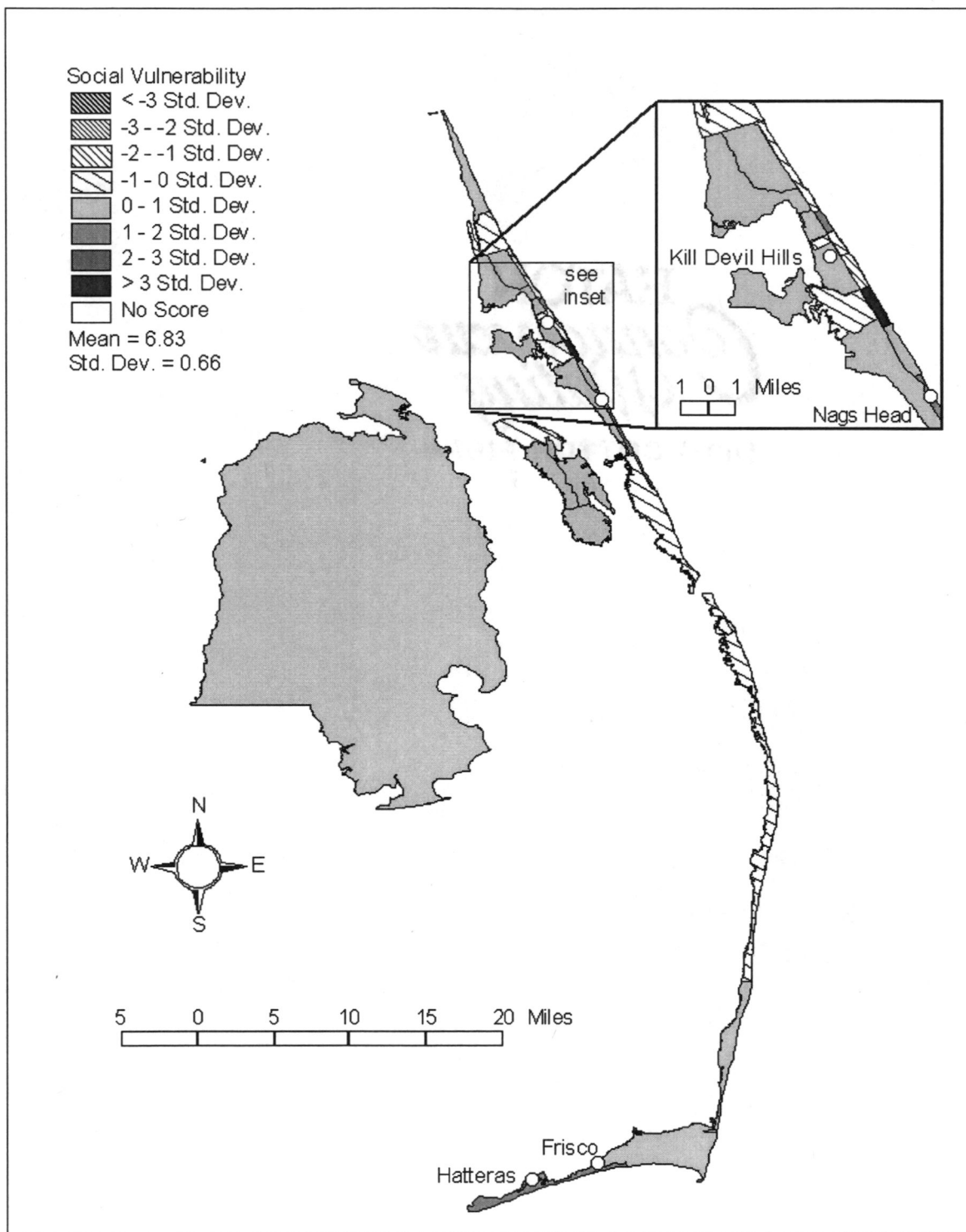


Figure 21. Social Vulnerability of Dare County.



Social vs Physical Vulnerability.

The physical vulnerability score was subtracted from the social vulnerability score to see if one was more important than the other for the entire data set and the results can be seen in Table 14. These results are different than in the individual county section. In the individual county section, social vulnerability dominated. Here, physical vulnerability is the more dominant of the two. In Brunswick County (Figure 32), 60 of the 71 blockgroups proved to be more physically vulnerable. This is no surprise because this county borders the ocean and the Cape Fear River. It also has many small streams and rivers that cut paths across the interior of the county. In New Hanover County (Figure 33), 52 of the 108 blockgroups are more socially vulnerable than physically vulnerable. Blockgroups with higher PVI scores are located along the coast, but SVI scores are higher in and around Wilmington. The rest of the socially vulnerable blockgroups are in the northeast part of the county. In Carteret County (Figure 34) there is a distinct difference between the eastern and the western parts of the county. The eastern part is more physically vulnerable and the western half is more socially vulnerable. Thirty-seven of the 61 blockgroups in this county are more socially vulnerable. However, the land area each one covers is about half each. In Dare County (Figure 35) physical vulnerability dominates as 28 of the 29 blockgroups are more physically vulnerable.

Table 14. Physical vs Social Vulnerability Results (Total Sample).

	Physical		Social	
	# of BKGs	%of County	# of BKGs	% of County
Brunswick	60	84.5%	11	15.5%
New Hanover	56	51.9%	52	48.1%
Carteret	24	39.3%	37	60.7%
Dare	28	96.6%	1	3.4%
Total Sample	168	62.5%	101	37.5%

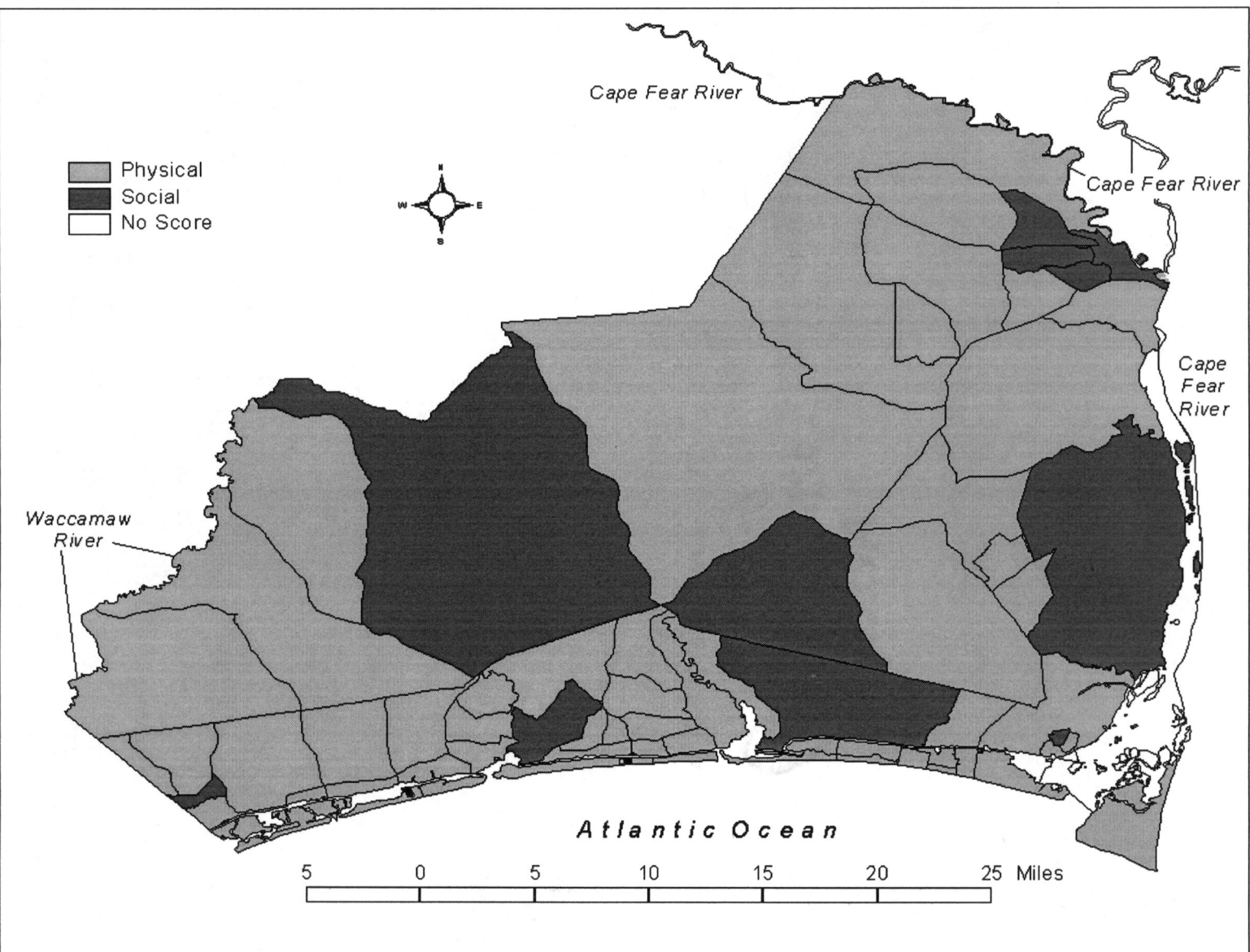


Figure 32. Social vs Physical Vulnerability for Brunswick County.

Figure 33. Social vs Physical Vulnerability for New Hanover County.

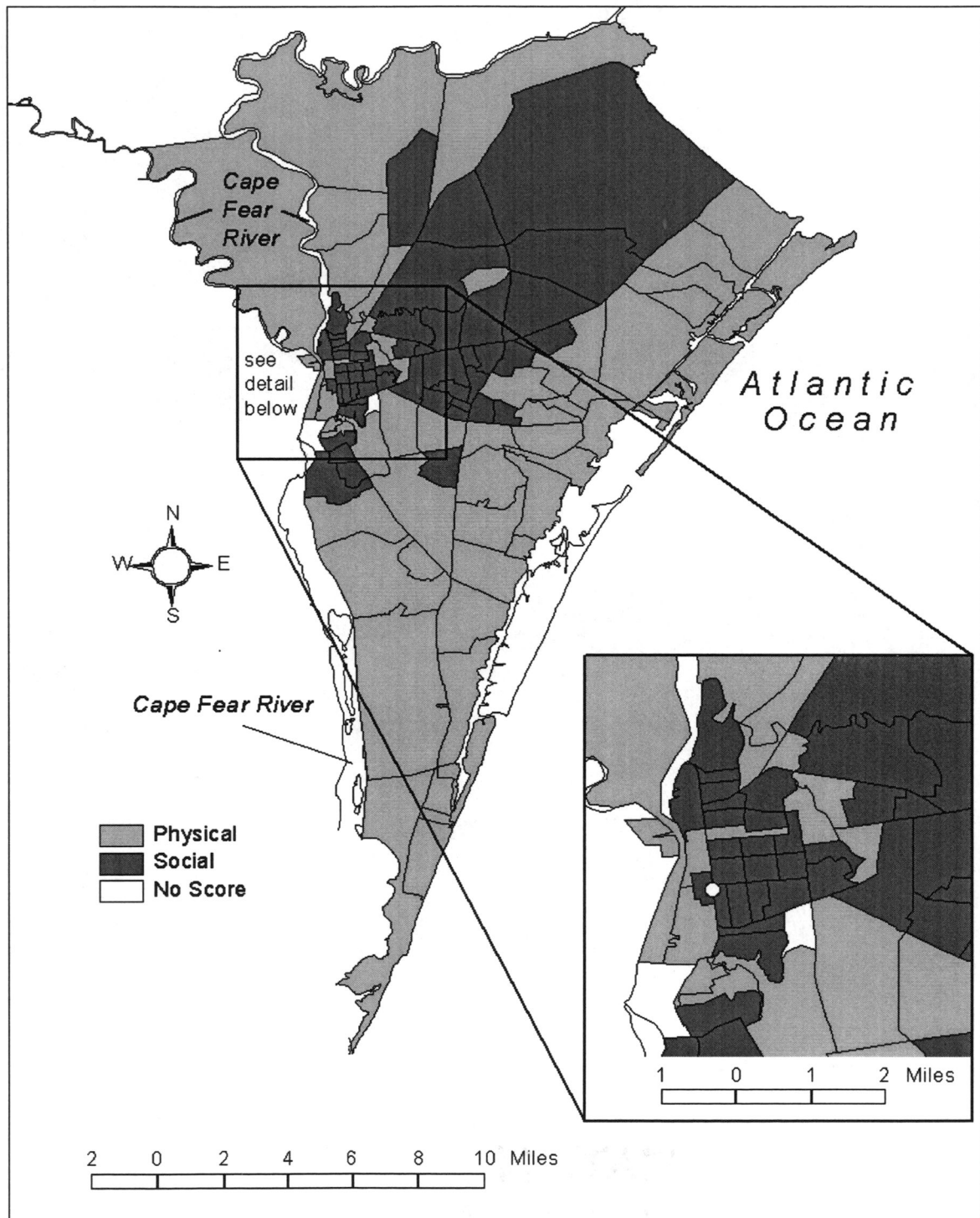


Figure 34. Social vs Physical Vulnerability for Carteret County.

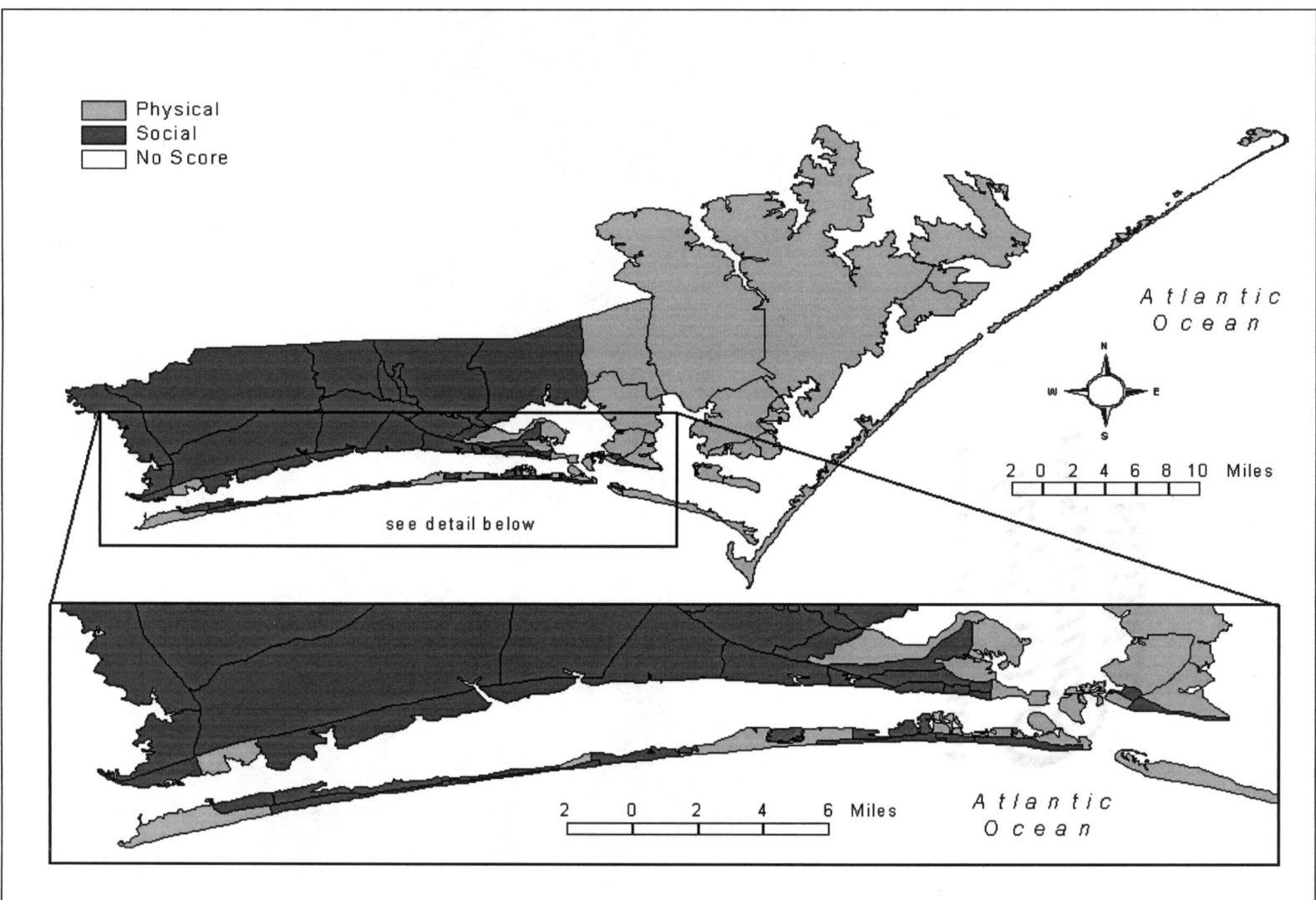
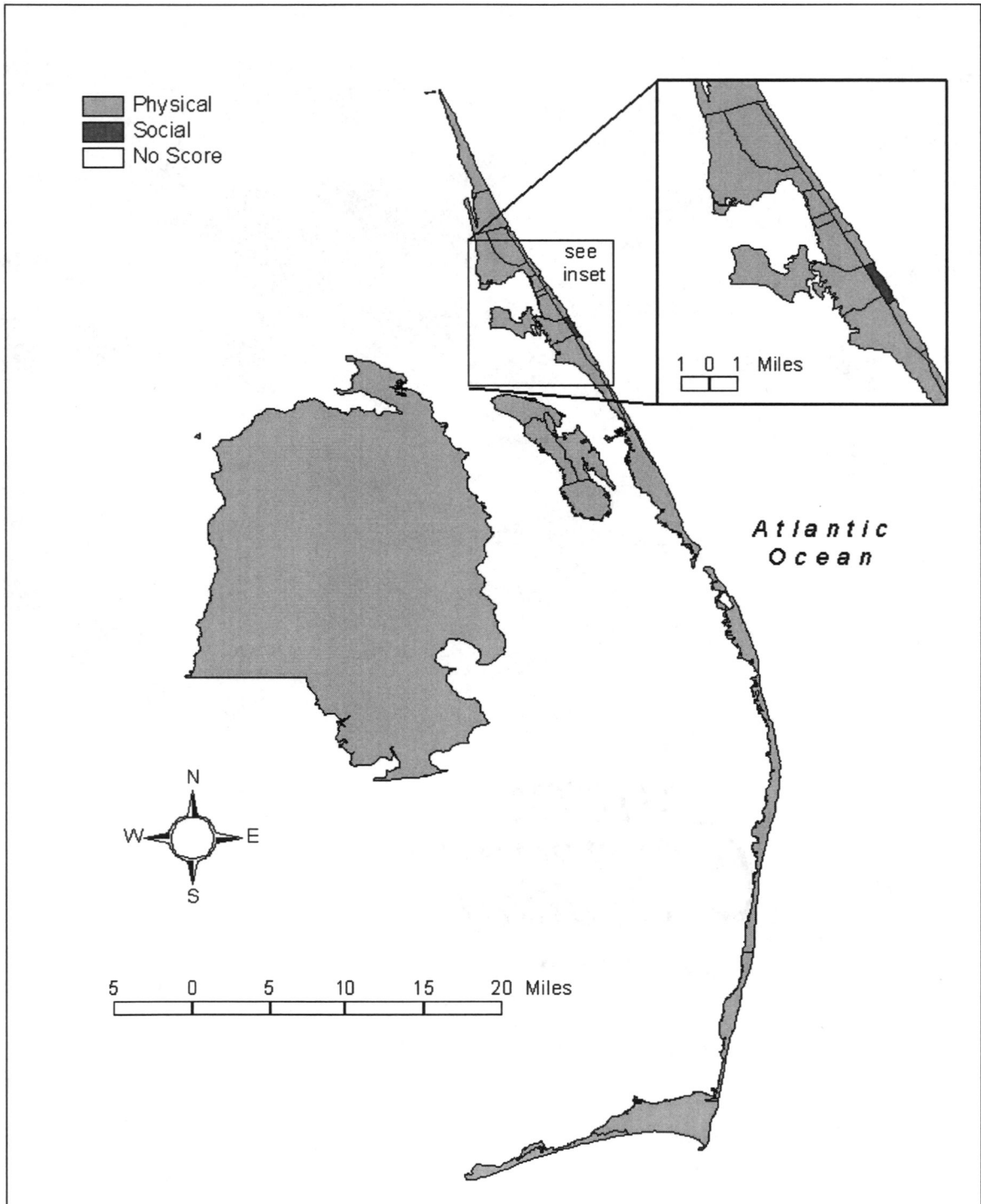


Figure 35. Social vs Physical Vulnerability for Dare County.



Total Vulnerability.

Forty-three blockgroups have TVI scores 1.0 or more standard deviations above the mean (Table 15). Fifteen are located in Brunswick County, fifteen are in Dare County, eleven are in New Hanover County, and two are located in Carteret County. Thirteen percent of the blockgroups in the total sample scored more than 1 standard deviation below the mean. Figures 36-39 present maps of the four counties using the total sample.

The mean TVI score is 6.55 for the total sample. Both Dare and Brunswick counties scored higher than the mean. Dare County is the most vulnerable of the four counties with a TVI score of 7.65. As seen in the physical and social vulnerability sections, Dare County had the highest PVI and SVI scores (Tables 12 and 13) so it is no surprise that it has the highest TVI score. Carteret County is the least vulnerable as it scored 5.87. The difference between the highest TVI score of 7.65 and the lowest TVI score of 5.87 is 1.78. This difference is greater than the 0.83 difference in TVI scores in the individual county comparison.

Table 15. Total Vulnerability Results for Total Sample.

	Brunswick		New Hanover		Carteret		Dare		Total Sample	
	# of BKGs	% of Cty	# of BKGs	% of Cty	# of BKGs	% of Cty	# of BKGs	% of Cty	# of BKGs	% of County
< -1 Std. Dev.	3	4.2%	12	11.1%	21	34.4%	0	0%	36	13.3%
1 > Std. Dev.	15	24.6%	11	10.2%	2	3.3%	15	41.4%	43	16.0%
Total Vulnerability Mean Score Total Sample	6.89		6.42		5.87		7.65		6.55	

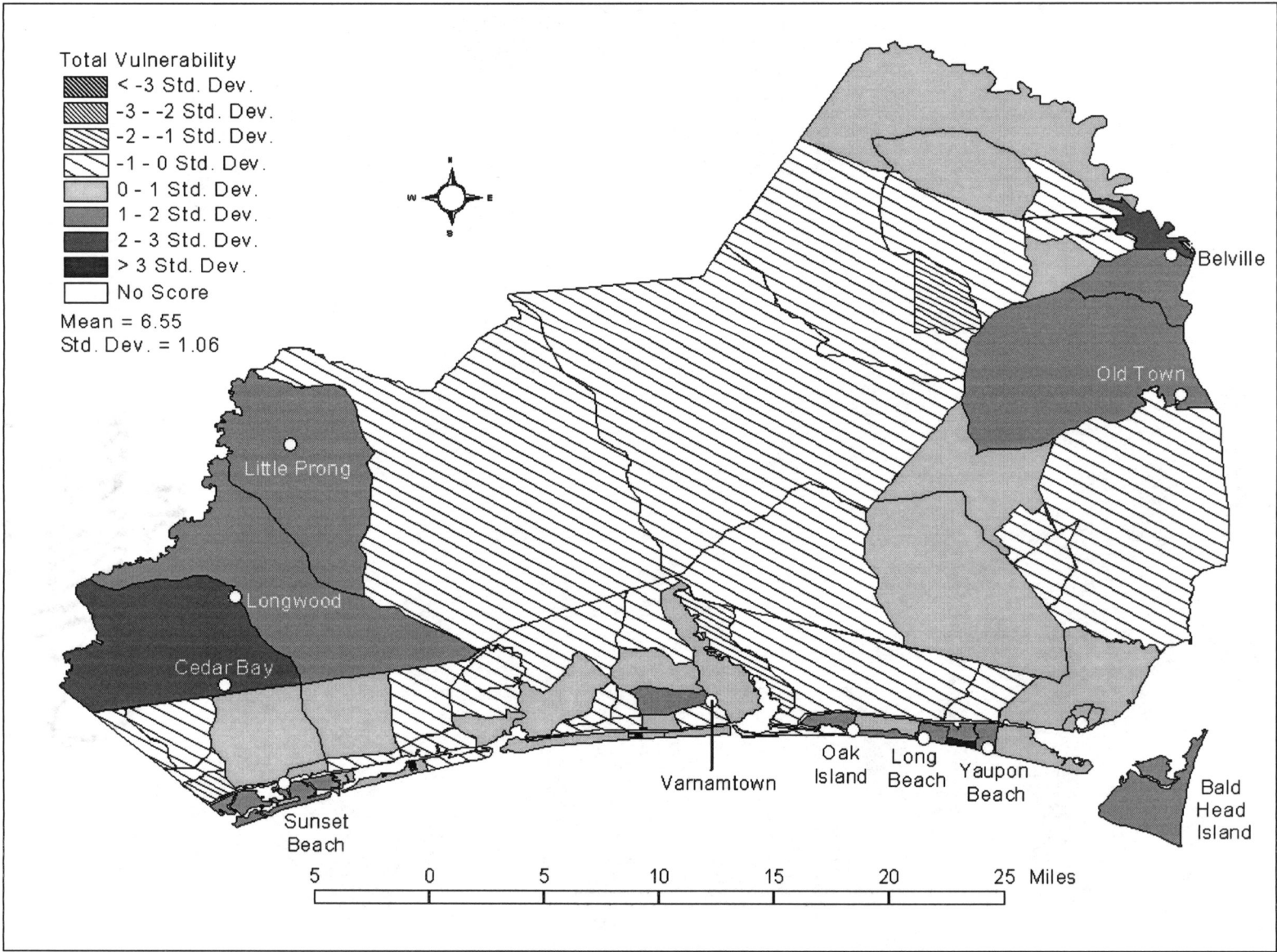


Figure 36. Total Vulnerability of Brunswick County.

Figure 37. Total Vulnerability of New Hanover County.

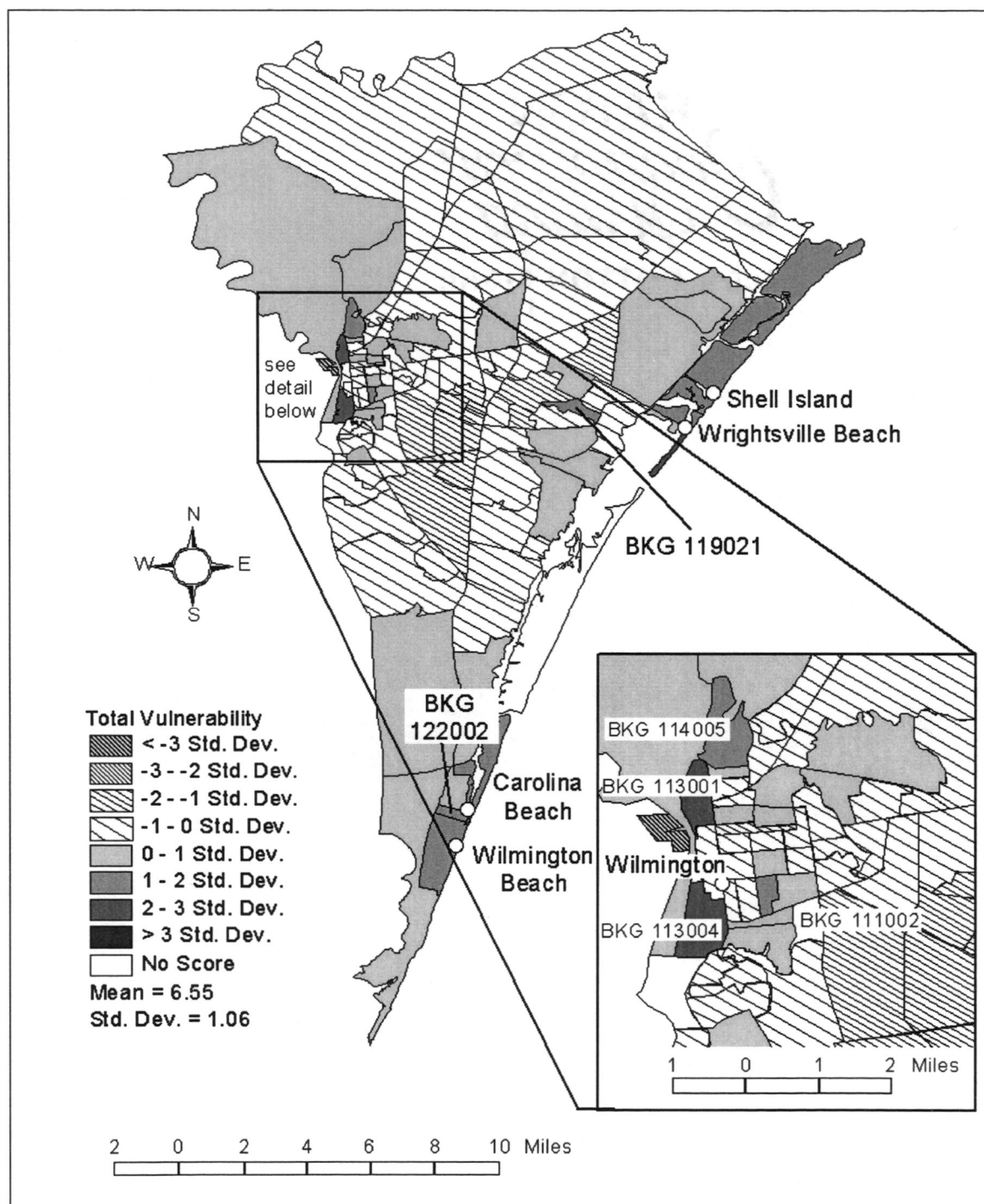


Figure 38. Total Vulnerability of Carteret County.

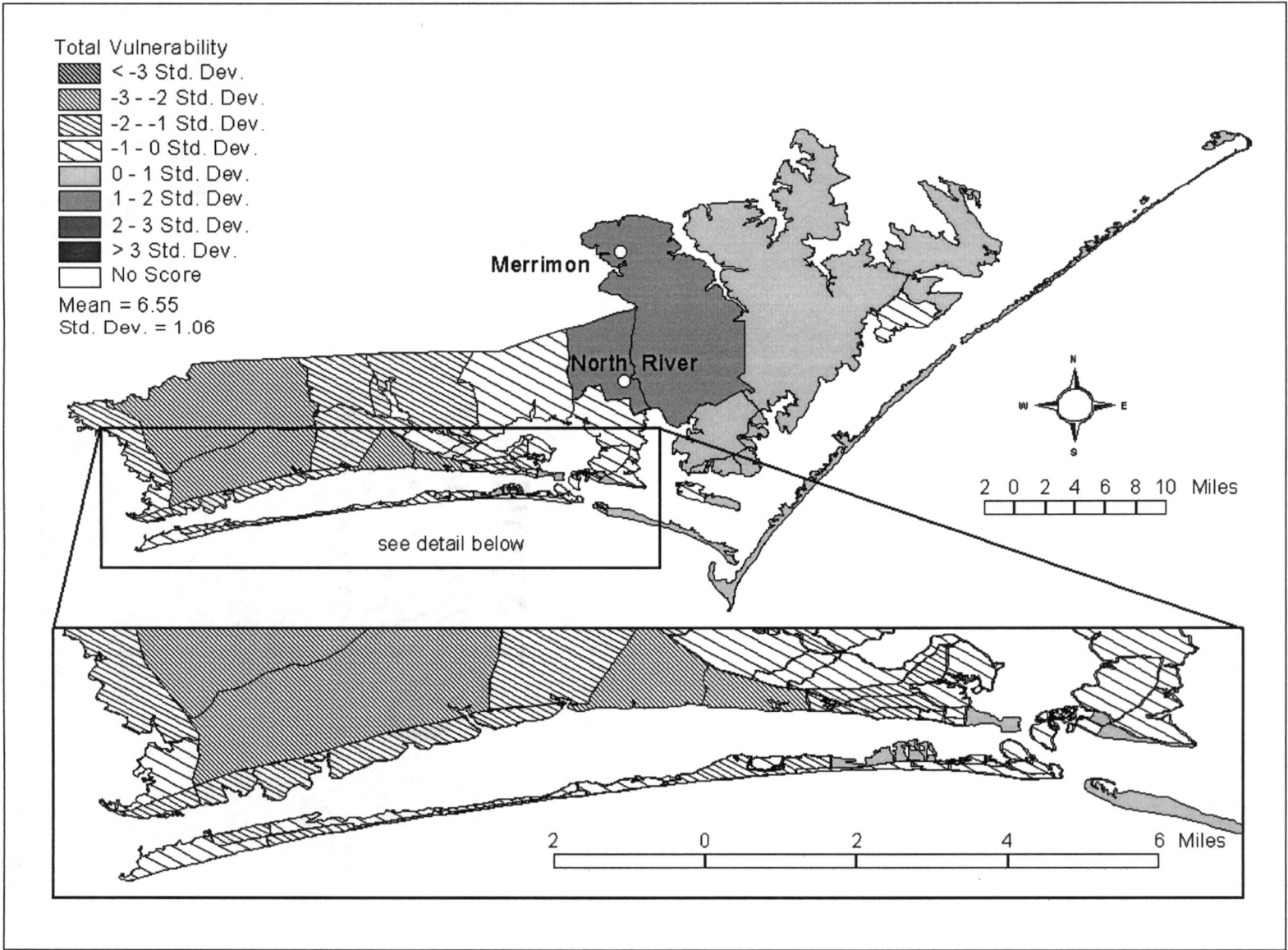
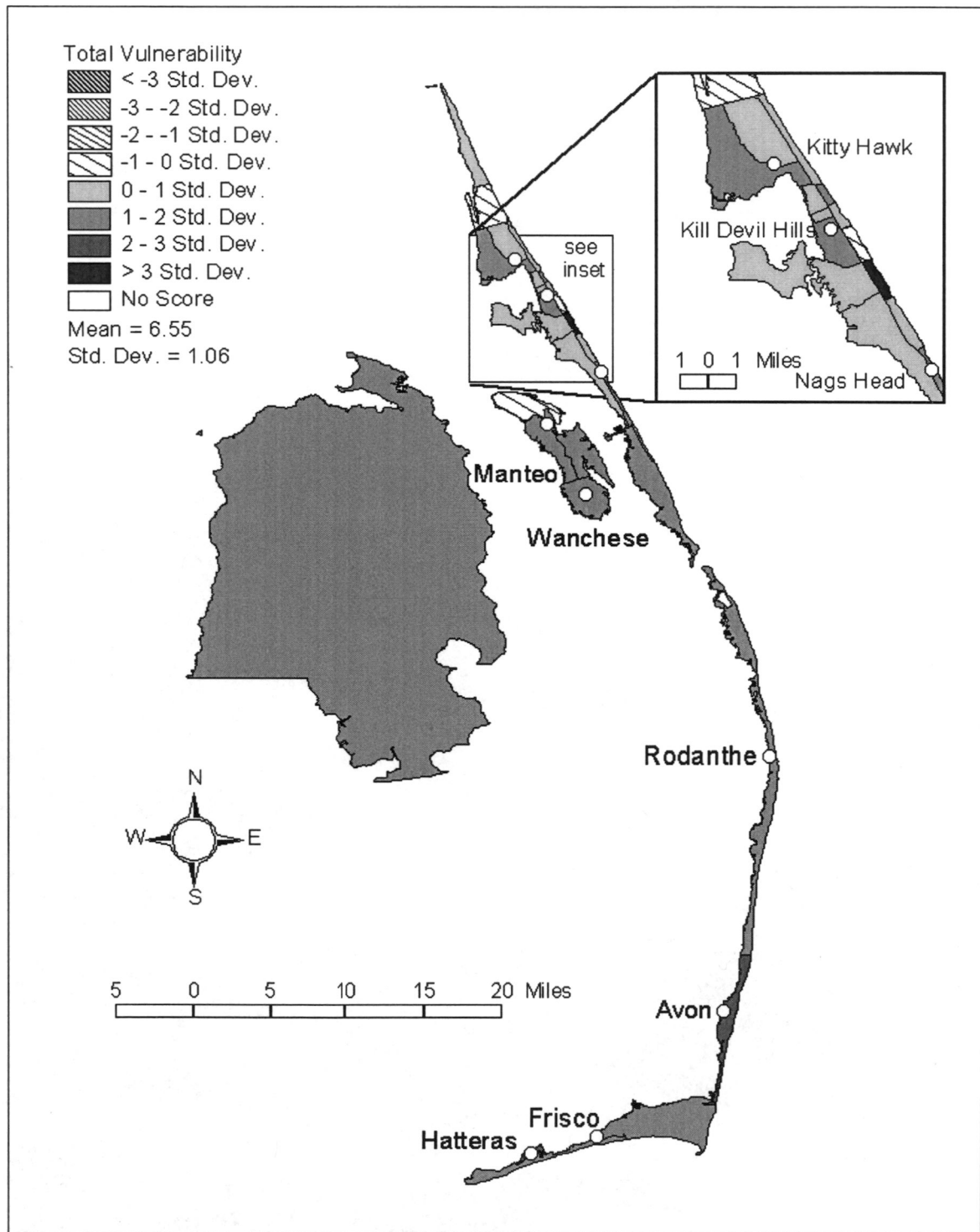


Figure 39. Total Vulnerability of Dare County.



CHAPTER 5

DISCUSSION

Introduction

This chapter begins with an examination of total vulnerability. The total vulnerability within each county is examined first. Followed by a discussion of the total vulnerability between the counties. Physical and social vulnerability are then examined on the individual county level and between the counties. Next, an evaluation of the index used in this study is presented. The relative importance of physical and social vulnerability is examined. Finally, there is an analysis of factors that are important in reducing vulnerability in blockgroups with low scores.

Total Vulnerability

The blockgroups with the highest TVI scores in each county are located next to major water bodies. This is true for both the individual county results and the results between the counties. The ocean, sounds, and major rivers (Cape Fear and Waccamaw Rivers) in the study area play a very important role in the total vulnerability because they contribute to high PVI scores and therefore contribute to higher TVI scores. TVI scores proved to be high in blockgroups with extremely high SVI scores too. This meant that physical vulnerability only had to have a moderate impact on the blockgroup in order to get high TVI scores.

The blockgroups with the highest TVI scores are the blockgroups where both physical and social vulnerability have the most influence and therefore contribute to high TVI scores. When examining each individual county, Carteret has the highest mean TVI

score (Figures 20-23). Brunswick had the lowest TVI (Figures 20-23). However, this does not mean that Carteret is the most vulnerable of the four counties. When comparing the data of all the blockgroups in the study, Carteret is the least vulnerable of all four counties (Table 15). Carteret County had only 3.3% of its blockgroups score greater than 1 standard deviation above the mean and 34.4% of its blockgroups scored more than 1 standard deviation below the mean. Dare is the most vulnerable of the four counties (Table 15). As can be seen in Figures 36-39, the total vulnerability is concentrated mostly in Dare County.

Components and Variables Important to Total Vulnerability.

To see which components and variables are the most important to total vulnerability, T-Tests were run to see if any significant difference could be found in the variables and the components. Out of 272 blockgroups, there are 43 whose TVI scores exceed the mean by 1 or more standard deviation. First, the mean component scores for the study area and the 43 most vulnerable blockgroups are given below in Table 15. The T-Tests results for the two groups are also in Table 16. The age, hotel, and newcomer components were found to be statistically different.

A breakdown of the variables that were included in the components is given in Table 7 back in Chapter 3.

Table 16. Component Scores.

Component	Total Sample Mean	43 Most Vulnerable Mean	T-Test
Population	4.05	3.88	
Age	4.99	5.50	*
Education	5.10	5.11	
Income	8.20	8.36	
Hotel	3.11	3.80	*
Newcomers	2.76	3.41	*

* Indicates a statistical difference was found at .05 level.

The components are based on individual socio-economic variables. The socio-economic data for the 43 blockgroups with TVI scores greater than 1 standard deviation were separated from the total sample, and the two groups were tested for statistical difference to see which variables can attribute to total vulnerability (Table 17).

Table 17 Variable Scores.

Variable	Total Sample	43 Most Vulnerable	T-Test
	Mean	Mean	
1990 Population	910	684	*
1990 Population Density per Sq. Mile	1144.9	852.9	
% of Ethnicity	18.5%	18.2%	
% Under Age 5	5.6%	6.7%	
% Age 65 and Up	15.0%	15.5%	
% of Foreign Entry	3.5%	1.3%	*
% of Population Moving into Buildings	35.0%	28.7%	*
% of Female Headed Households	5.0%	5.2%	
% of Female Headed Households with Child	3.5%	3.6%	
% without High School Diploma	18.0%	19.7%	
% of Households with 50 or more units	1.4%	2.9%	
% of Mobile Homes	20.1%	16.1%	
Evacuation Time	2.1 hours	2.6 hours	*
Number of Hotel Rooms	45	125	*
Median Year Structure Built	1949	1973	
Median House Value	\$79,209	\$99,897	*
Median Household Income	\$26,567	\$29,630	
Average Percentage of Flooding	29.3%	57.7%	*
Average Social Vulnerability Score	6.83	7.27	*
Average of all Physical Vulnerability Scores	7.30	8.77	*
Average of all Total Vulnerability Scores	6.55	8.32	*

* Indicates a statistical difference was found.

Physical Vulnerability

Blockgroups that bordered the Atlantic Ocean, the Albermarle and Pamlico Sounds, and the Cape Fear and Waccamaw Rivers prove to be the areas where physical vulnerability was at its highest (Figures 8-11 and 24-27). This physical vulnerability is the primary reason why these locations have high TVI scores. Dare County has the highest physical vulnerability score at the individual county level (Figures 8-11). When

examining between county data (Figures 24-27), Dare County is clearly the county where physical vulnerability has the greatest influence. Dare County also has the most blockgroups with the highest PVI scores when examining between the counties (Table 11). The PVI scores explain why Dare County has so many blockgroups with high TVI scores. Carteret is less influenced by physical vulnerability. As mentioned before, many areas along the coast that are not physically vulnerable have high sand dunes for protection. This can explain why much of Carteret's blockgroups on the barrier island do not have high PVI scores. Also, many of Dare County's blockgroups have high PVI scores. However, a blockgroup such as Cape Hatteras, has a higher elevation than the surrounding blockgroups and therefore are not as affected by storm surge. The higher elevation of some blockgroups helps to reduce their physical vulnerability.

Effects of Magnitude and Speed on Vulnerability.

Hurricane magnitude and forward speed would appear to affect vulnerability. Category 2 hurricanes strike more often than Category 3 and 4 storms but the later would have greater storm surge. Faster hurricanes would be expected to do more damage to coastal areas because of the higher winds. The higher winds would diminish farther inland than with a slower storm. Slower moving hurricanes will have more time to cause more inland flooding. To determine if these differences in the physical characteristics of storms produce significant differences in vulnerability T-Test were run comparing magnitude and speed. First, an average score was determined for Category 2, 3, and 4 hurricanes. An average score for fast moving Category 2, 3, and 4 hurricanes and slow moving Category 2, 3, and 4 hurricanes were also calculated. T-Tests were run to see how

significant the magnitudes and speeds were to the vulnerability in these counties. The results are in Table 18.

Table 18. T-Test Results

	Total Sample	Brunswick	New Hanover	Carteret	Dare
Category 2 vs 3	*				*
Category 2 vs 4	*	*	*	*	*
Category 3 vs 4	*	*	*	*	*
Slow vs Fast				*	

* Indicates a statistical difference at the 95% confidence level.

Three out of the four counties have no significant difference between Category 2 and 3 hurricane because the frequency for Category 3 hurricanes is lower than Category 2 hurricanes in all the counties except Dare. Category 2 and 3 hurricanes strike Dare County equally (Table 3). The effect of higher magnitude associated with Category 3 storms is offset by the higher frequency of Category 2 storms in the other counties. However, category 2 and 4 storms are significantly different despite differences in frequencies because of the magnitude differences are much greater. Pielke and Pielke (1997a) demonstrate that there is a logarithmic increase (Figure 7) in hurricane destructive power associated with higher category storms.

Fast moving hurricanes tend to make coastal blockgroups more vulnerable because higher winds produced by the combination of the forward speed of the hurricane and the wind speed of the storm. Slower moving hurricanes tend to make inland

blockgroups more vulnerable because the hurricane has more time to rain on a blockgroup. Carteret County is the only county in the study area that can expect a significantly different amount of flooding and damage from faster moving storms than slower moving storms. This is because Carteret has over two-thirds of its blockgroups adjacent to ocean or estuary water where higher storm surge associated with fast moving storms makes these more dangerous events. In Brunswick and New Hanover Counties, appears to shift some of the vulnerability from coastal to inland blockgroups. Dare County suffers equally as much from fast and slow hurricanes because every blockgroup, except one, is adjacent to water. When examining the total sample, there is a significant difference between each category. This can best be explained by the fact that physical vulnerability takes on a more important role in the total sample than in the individual county comparison (Tables 11 and 14).

Social Vulnerability

In both New Hanover and Brunswick counties, high social vulnerability is concentrated around the city of Wilmington. New Hanover has the highest SVI score when examining each individual county. Some of Wilmington's inner city blockgroups have the highest SVI scores in the study area. Most of these blockgroups are small in size in terms of land area they cover and have a high population density. Many new residents, people of a susceptible age, minorities, and multiple housing units are found in these blockgroups. New Hanover and Dare Counties are also the two counties where the majority of high SVI scores are found. Dare County can attribute much of its

vulnerability to hotels, evacuation times, new residents, and people of a susceptible age. The blockgroups with very high SVI scores also tend to have high TVI scores.

Social Vulnerability, 1990 Total Population, and 1990 Population Density.

The blockgroups that scored greater than 1 standard deviation (36 blockgroups) on their social vulnerability index (SVI) scores were examined to see how their social vulnerability compared to their total population. For the study area, the mean blockgroup population is 910. The mean population for the 36 blockgroups with the highest SVI scores is 709. Total population in these 36 blockgroups range from 55 to 2948. The population density in these 36 blockgroups ranges from 26.6 to 10,934. The mean population density for the total sample is 1145 people per sq. mile whereas for the 36 blockgroups with the highest SVI scores the density is 2846 people per sq. mile. Blockgroups with a smaller total population or higher population densities tend to be slightly more socially vulnerable than blockgroups with larger populations and smaller densities.

Evaluation of Vulnerability Index

Clark et al. (1998) and Cutter et al. (2000) are the only other studies similar to this one. Both studies point out the different kinds of vulnerabilities. Each of these studies however takes a different approach to measuring vulnerability. Clark et al., (1998) use only the 100 and 500-year floodplains from FEMA's Insurance Rate Maps of flood zones as its only physical factor. Therefore their only physical factors are river flooding and frequency. This study does not consider wind damage at different magnitudes and speeds. It is also concerned with nor'easters instead of hurricanes. The

results indicated that physical and social vulnerability varies spatially. They found areas along the coast to be the most physically and socially vulnerable. They also found that blockgroups where medium or high levels of social and physical vulnerability coincide are the most vulnerable. The areas of highest vulnerability are also those along the coast.

In comparison, this study makes a distinction between the different magnitudes and speeds of storms. This study concentrates on hurricanes instead of nor'easters. It is also concerned with storm surge from hurricanes. This study also combines both physical and social vulnerability into total vulnerability. A different set of weights was developed for this study than that which was used in the Clark et al study.

Cutter et al. (2000) differs from the Clark et al. (1998) study in several ways. Cutter et al. (2000) uses the same flood zones used by Clark et al. (1998). In their study they identify areas that are socially, physically, and technologically vulnerable within Georgetown County, South Carolina but use no weights. Areas next to the ocean and rivers are the most physically vulnerable. Roads, where chemical releases have occurred, are the most technologically vulnerable. The areas with the highest social vulnerabilities are scattered throughout the county. The results from this study found a high degree of spatial variability in overall hazard vulnerability. They found also that the most vulnerable biophysical places do not always coincide with the most vulnerable populations. They found that the most vulnerable places are the result of a combination of medium levels of biophysical vulnerability with medium to high levels of social vulnerability. The areas where physical, social, and technological vulnerabilities score medium or high are the most vulnerable areas in the county.

A distinction has been made between different speeds at which hurricanes move in this study that was not done in the Cutter et al. (2000) study. This study considers the destructive power of wind. Both studies combine physical and social vulnerability into one total vulnerability score. Technological hazards have been ignored in this study, but were considered in the Cutter et al study.

There are several advantages to this index. It clearly indicates the extremes of vulnerability. The blockgroups with very high and very low PVI, SVI, and TVI scores are easily identified. Countless variables can be used in the index. This index requires both physical and social vulnerability scores to be moderate or high in order to get a high total vulnerability.

There are also major disadvantages to this index. One problem involves adjusting the scale to a 10 scale. This problem is best seen when looking at the total vulnerability score of Carteret County at the individual county level. Carteret County has the highest TVI score of the four (Figures 20-23). However, when comparing Carteret County to the entire sample it is found that Carteret County has the lowest TVI score of any county. This can best be explained in the following manner. Before the scores are adjusted to the 10 scale, they might actually range from 8 to 12. If a county's highest blockgroup score is around 8 (as in Carteret), and then they are adjusted to the 10 scale, this actually increases all the vulnerability scores for every blockgroup score in the county. If a county's highest blockgroup score is around 12, and then is adjusted to the 10 scale, it actually reduces all the vulnerability scores for every blockgroup in the county. This seems to explain what has happened to make Carteret County the most vulnerable of the four at the individual

county level. This scaling system should not be used to make county comparisons when examining the county's data individually. If the need is to compare several counties then all of the data needs to be examined at one time. This issue of adjusting to a 10 scale might be a factor in computing average PVI and SVI scores for individual county level also.

Another problem with this index concerns water depth. The flood data does not indicate how much flooding occurs in a blockgroup. All it states is the percentage of the blockgroup that is flooded. It is very possible that some blockgroups are flooded with two inches of water while another blockgroup is flooded with two feet of water. And the damage potential from flooding from two feet of water is greater than just two inches of water.

Another disadvantage of this index is the inability to measure resistance and recovery. Back in Chapter 1, vulnerability was defined as the "characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard." The resistance and recovery phases have been left out of the index. For example, some of the blockgroups identified with high TVI scores are blockgroups with high median household incomes. It should be much easier for a blockgroup that has a high median household income to prepare and recover from a hurricane than a blockgroup that has a low median household income. Perhaps income should be considered as a separate component from the rest of the social variables. This would then allow income to have more impact on the index that would allow for a better representation of resistance and recovery.

Importance of Social and Physical Vulnerability

Social vulnerability is an important factor to a disaster as it can amplify or reduce physical vulnerability. As just mentioned, individuals with higher household income should be able to prepare and recover more easily than individuals with lower household incomes. Perhaps income should be treated separately and not thrown into a component like the other variables. This also can bring up the issue of how variables and components are weighted. Perhaps income should receive its own weight that would reflect the ability to resist and recover. However, literature on weights is very scarce making a set of weights difficult to develop. Nevertheless, income is not the sole factor in determining social vulnerability as this study has shown. Many other variables have proven to be important in this study and in the literature.

An interesting finding in this study concerns social vulnerability. There are two types of social vulnerability in these counties found in this study. The first type includes blockgroups that owe their social vulnerability to human factors such as low median household income, age, ethnicity, or a high percentage of new residents living in the blockgroup. These blockgroups tend to be scattered throughout the interior of the county or inside major cities such as Wilmington. A good example of this type of blockgroup is BKG 113004 within the city of Wilmington (Figure 29). This blockgroup has relatively high percentages of ethnicity and people under age 5. Two-thirds of the population is composed of new residents. The median household income is also very low at around \$5,000 in this blockgroup.

The second type of social vulnerability is related to structural characteristics of the blockgroup. These blockgroups tend to have higher median household incomes, higher house values, and a large number of hotel rooms. In these blockgroups, there is a greater potential for property damage resulting in high financial loss. Most of these blockgroups are found along the coast, particularly on barrier islands. The best example of this type of blockgroup is Wrightsville Beach (Figure 29). It has a relatively high median household income and the median house value is almost \$200,000. There are also 262 hotel rooms in this blockgroup.

Another interesting finding is the importance of physical vulnerability. Some of the literature (Morrow, 1999) suggests that social vulnerability is the more important of the two. Morrow states that “disaster vulnerability is socially constructed” and that vulnerability “arises out of the social and economic circumstances of everyday living.” This would be true if the physical characteristics are the same everywhere. If the physical characteristics are the same, then social vulnerability will determine who is the most vulnerable. This is probably true for tornadoes. Everybody affected by a tornado would feel approximately the same amount of wind and therefore the social vulnerability is the determining factor. However, physical characteristics are not the same for some events. Hurricane storm surge and river flooding can vary dramatically within a county. Therefore, this study finds that the physical characteristics of hurricanes are slightly more important than the social vulnerability. On the individual county basis, Brunswick, Carteret, and Dare actually scored a higher mean PVI than SVI. Dare County is the most physically vulnerable of the four counties once again proving the importance of physical

vulnerability because Dare County is also totally the most vulnerable county of the four. Social vulnerability is greater in New Hanover County, perhaps because of its larger population. When examining the total sample of data, the mean SVI score for each county was approximately the same. The difference between the highest SVI score and the lowest score is 0.38 (Table 12). In contrast, the PVI score varied more for each county as the difference between the highest mean PVI score and the lowest is 1.75 (Table 11). It also finds that when comparing the total sample that the mean PVI score is higher than the mean SVI score. In fact, 67 more blockgroups in the study area have higher PVI scores than SVI scores (Table 13). Clearly, physical vulnerability needs more attention than what some of the literature has suggested. Finally, Cutter et al. (2000) found that only a moderate physical vulnerability score and a moderate to high social vulnerability score were needed to produce a high final vulnerability score.

Reducing Vulnerability

There are several factors that can reduce vulnerability. The blockgroups that had the lowest TVI scores had all these factors in common. First, they have a low PVI score. To reduce physical vulnerability people should live where physical vulnerability is not a major factor is important. Staying away from the coast and from rivers will reduce the risk of flooding from hurricanes. To reduce physical vulnerability, people should consider living more inland and out of at least the 100-year floodplain. If people decide to live along the coast, then they should live on the highest elevated areas of the coast to reduce the risk of flooding. Buildings could also be put on pilings to raise them above flood waters. Building codes that would reduce the damage that housing units might

suffer should be considered. Houses should be built to withstand at least a Category 3 hurricane because the probability of being struck by one is very realistic. Flood insurance could also be used to repair the damage caused by storms. All of the blockgroups with low SVI scores have among the lowest evacuation times in they study area (Table 16). Most of these blockgroups have people with a good education and a moderate household income level. Smaller families, those without many children or seniors to look after, are blockgroups that tend to be less vulnerable. This seems to suggest also that these blockgroups have an easier access to transportation out of the hurricane warning areas to safer areas.

CHAPTER 6

CONCLUSION

The primary purpose of this thesis was to construct a vulnerability index to determine the most vulnerable blockgroups and see how vulnerability varies spatially. This was first done by comparing all the blockgroups at the county level and then comparing the counties to each county. The relative importance of social and physical vulnerability has been determined. This chapter is divided into two sections. The first one is a summary of the research findings. The last section deals with recommendations for improving this study.

Summary of Research Findings

- The most physically, socially, and totally vulnerable blockgroups in the four counties have been identified. Blockgroups that border major rivers or the ocean are more vulnerable than landlocked blockgroups because of the interaction of both physical and social vulnerability. It takes a combination of physical and social vulnerability to produce a vulnerable population to hurricanes. Dare County is the most vulnerable county in the study because physical and social vulnerability intersect the most in this county.
- Physical and social vulnerability vary spatially as it has in previous research. Yet physical and social vulnerability do not always coincide in the same spatial location. Physical vulnerability does seem to be more important than some previous research has suggested. Physical vulnerability scores tend to be higher

for most blockgroups than social vulnerability. In the addition, the major reason why Dare County is so vulnerable is because of its physical vulnerability.

- The multiplication of physical and social vulnerability required that physical and social vulnerability indices be at the higher end of the range to produce a high overall vulnerability score.
- Speeds at which hurricanes travel have no significance on the overall vulnerability of a county. Scores for Category 2 and 3 hurricanes were because of the high frequency associated with Category 2 storms offsets the destructive power of wind from a Category 3.
- There are two types of social vulnerability. One is human social vulnerability and the other is structural social vulnerability.
- This study can be useful in emergency management by predicting which areas of a county are most likely to suffer the most from a hurricane disaster. This knowledge would help managers focus pre-disaster mitigation efforts on these areas. If a vulnerable blockgroup has been identified as having a large percentage of people age 65 and over, then steps need to be taken to ensure these people are able to evacuate the area. If a vulnerable blockgroup has been identified as having a low median household income then in this case steps should be done to make sure that the population living there has transportation to leave and get to a shelter. If there are new residents to the area, they should be advised of the seriousness of hurricanes if they are unaware of them. If these new residents happen to be foreign, perhaps some language program is necessary for them to

understand the importance of hurricanes. By looking at the vulnerable population, steps can be made by emergency management to reduce the vulnerability of a population. Managers would also be able to respond to these areas for post disaster relief.

Recommendations

- More time and literature needs to be done to develop a better weighting system. The meager amount of literature that exists for creating weights for vulnerability indexes makes coming up with a weighting system difficult. Perhaps hotels and evacuation time have been weighted too much. These two factors can be considered short-term vulnerability. Once a hurricane strikes these two variables are no longer important. Maybe vulnerability needs short and long-term components.
- Some research (Peacock et al. 1997) suggests that some people are more likely to evacuate than others. These people and blockgroups should be identified and efforts to convince them to evacuate should be intensified. This would reduce vulnerability.
- Another improvement that could be made is the collection of data. For this thesis 1990 census data were used. The 2000 census data are now available and a new analysis could be done to update the vulnerability index. It would make for an interesting comparison and would also indicate if areas are becoming more or less vulnerable.

- There are 21 counties in North Carolina that border the coast and sounds that are vulnerable to hurricanes. All of these locations should be subject to this kind of vulnerability analysis, not just those examined here. Even though Carteret County was found to be relatively the least vulnerable of the four counties, it still might be one of the more vulnerable counties if all the coastal counties of North Carolina are examined.
- Only direct strikes are considered in this study. Hurricanes that do brush the coast can also cause damage. Indirect strikes should be accounted for in some method.
- The variables determined by this thesis to be the most important to vulnerability are: flooding, age, new residents, and hotels. Although, these variables are the most important to this study area, they would not necessarily be the most important in other areas. Broader analysis would reveal which variables contribute most to vulnerability.
- Another item that should be considered is coastal erosion. Many blockgroups suffer from erosion problems. It is necessary to identify the blockgroups that have more erosion or deposition on them. Many houses along the coast might fall into the ocean because of erosion and major changes in the shoreline can result from hurricanes.
- This study could be expanded by including other hazards and their unique characteristics. The methodology used here could be applied to other hazards. As social conditions remain constant, only the physical conditions would change.

Hazards such as nor'easters, tornadoes, and floods could be evaluated in a similar fashion if physical data on magnitude and frequency were available. Technological hazards could be included as Cutter et al (2000) do in their study.

- Hurricane season is June 1st to November 31st. However, hurricanes strike more frequently during certain months such as September than they do in June. There are also more tourists visiting these counties in warmer summer months than in November. Perhaps the index could be adjusted for each month.
- One flaw concerns flooding. The flood data does not indicate how much flooding has occurred in terms of height. Two blockgroups may be considered completely flooded from a certain category of hurricane. However, one of these blockgroups may be flooded with only a couple of inches of water, while the other blockgroup may suffer from a couple of feet of flooding. More damage should occur in the blockgroup where there is more flooding. Perhaps digital elevation models could be used to determine how high flooding could be expected in blockgroups.
- The other major flaw in the index is adjusting the all the scores to a 10 scale. Perhaps the data should not be adjusted in some cases.
- The worse case scenario should be used by planners in the event of an approaching hurricane.
- This index should be compared to an actual hurricane event to see if the results presented here are similar to an actual event.

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