Sea, Storms, & Tourism: A Case Study of the Hazards and Vulnerabilities of Cape Cod, MA

by

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ABSTRACT

Drawing from the fields of coastal geography, political ecology, and institutions, this dissertation uses Cape Cod, MA, as a case study, to investigate how chronic and acute climate-related coastal hazards, socio-economic characteristics, and governance and decision-making interact to produce more resilient or at-risk coastal communities. GIS was used to model the impacts of sea level rise (SLR) and hurricane storm surge scenarios on natural and built infrastructure. Social, gentrification, and tourism indices were used to identify communities differentially vulnerable to coastal hazards. Semi-structured interviews with planners and decision-makers were analyzed to examine hazard mitigation planning.

The results of these assessments demonstrate there is considerable variation in coastal hazard impacts across Cape Cod towns. First, biophysical vulnerability is highly variable with the Outer Cape (e.g., Provincetown) at risk for being temporarily and/or permanently isolated from the rest of the county. In most towns, a Category 1 accounts for the majority of inundation with impacts that will be intensified by SLR. Second, gentrification in coastal communities can create new social vulnerabilities by changing economic bases and disrupting communities' social networks making it harder to cope. Moreover, higher economic dependence on tourism can amplify towns' vulnerability with reduced capacities to recover. Lastly, low political will is an important barrier to effective coastal hazard mitigation planning and implementation particularly given the power and independence of town government on Cape Cod. Despite this independence, collaboration will be essential for addressing the trans-boundary effects of coastal hazards and provide an opportunity for communities to leverage their limited resources for long-term hazard mitigation planning.

This research contributes to the political ecology of hazards and vulnerability research by drawing from the field of institutions, by examining how decision-making processes shape vulnerabilities and capacities to plan and implement mitigation strategies. While results from this research are specific to Cape Cod, it demonstrates a broader applicability of the "Hazards, Vulnerabilities, and Governance" framework for assessing other hazards (e.g., floods, fires, etc.). Since there is no "one-size-fits-all" approach to mitigating coastal hazards, examining

vulnerabilities and decision-making at local scales is necessary to make resiliency and mitigation efforts specific to communities' needs.

DEDICATION

I dedicate this dissertation to my parents, Jack and Karen Gentile. Thank you for your never-ending love and support, which has been a source of strength to draw from throughout this process. You are my rock and I am so blessed to have you in my life.

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CHAPTER 1

INTRODUCTION

Over the last three decades, research efforts, policy-making, and the media have been increasingly focused on the complexities of climate change and its impacts. As a hotly contested topic, climate change has become *the* buzzword: a warning, a prediction of doom[1] that is increasingly associated with large-scale environmental hazards and disasters. Within the last ten years alone numerous devastating coastal disasters have occurred including the August 2005 Hurricane Katrina that decimated parts of Louisiana and Mississippi U.S. (1,300 fatalities, $125 billion USD in losses), the 2011 Japanese Earthquake and Tsunami (15,883 fatalities, estimated $300 billion USD in losses), the October 2012 Hurricane Sandy (117 fatalities, $68 billion in losses), and the November 2013 Typhoon Haiyan in the Philippines (~6,000 dead and $700 million in damages). These events have served as warning events for coastal regions, spurring scientific research and policy efforts to determine communities' vulnerabilities and to develop coping and mitigation strategies.

Hazards and vulnerability research has grown from two specific domains: hazards/disasters/risk research and climate change research. Hazards/disasters/risk research has focused on acute events by identifying factors for disaster risk reduction and evaluating their effectiveness whereas climate change research has focused on future conditions by developing and evaluating adaptation approaches (Romieu et al., 2010). Even though these two traditions evolved separately, current research efforts recognize that climate change and coastal hazards are intricately connected. In particular, there is increasing evidence that climate change will have multiple effects on coastal systems (Church et al., 2013), particularly the way sea level rise may increase the magnitudes of hurricane storm surge (Frazier et al., 2010; Shepard et al., 2012). Lichter & Felsenstein (2012) noted that many sea level rise impact studies have been at the global or national spatial scales (Anthoff et al., 2010; Hinkel & Klein, 2009) with the regional and local levels being overlooked. These differences in scales need to be minimized considering how the local and regional levels directly experience the losses and costs of climate-related coastal

[1] See Bettini (2013) for a review of the "doom and gloom narratives" of climate change.

hazards. This dissertation addresses, empirically, this scalar gap between vulnerability assessments and decision-making, by conducting a case study in Cape Cod, MA of coastal hazards and vulnerability at the community level in an understudied region of the United States.

Drawing from the fields of coastal geography, political ecology, and institutions, this research is a case study on Cape Cod, MA that investigates the ways chronic and acute climate-related coastal hazards (i.e., hurricane storm surge and sea level rise), socio-economic characteristics, and governance and decision-making processes interact to produce more resilient or at-risk coastal communities. Broadly, vulnerability refers to the potential for loss and is characterized by certain conditions of exposure (e.g., biophysical, communities, ecosystems, and geographical areas), sensitivity (i.e., social context), and capacities (i.e., abilities to reduce, manage, and plan for hazards impacts) (Polsky et al., 2007).

The high population densities and extensive infrastructure of coastal areas requires a more holistic, multi-disciplinary approach to assessing and managing coastal hazards. In the early hazards and disasters literature (See White, 1974), planning and decision-making focused extensively on the biophysical (e.g., geographical, ecological, and physical forces) context. More recent research efforts, though still understudied, have sought to consider the socio-economic context in which hazards occur (Cutter et al., 2003; Frazier et al., 2010; Kleinosky et al., 2006; Shepard et al., 2012). Both biophysical conditions and social characteristics are important components of vulnerability and are influenced by the broader institutional, decision-making context. Initiatives to improve adaptive capacities and resiliency are expected to occur at the community scale (Ford & Smit, 2004; Kelly & Adger, 2000) since the institutional (e.g., political, policies) context oftentimes governs how more or less sensitive a community is to coastal hazards. This dissertation seeks to contribute to the political ecology of hazards and vulnerability literature by a) considering climate change as a characteristic of coastal hazards and place-based vulnerability and b) by linking institutional and governance theory and practice with communities' capacities for planning, response, and recovery. Therefore, the overarching objective guiding this research is to determine how these capacities are shaped and constrained by socio-economic and biophysical conditions and how institutional decision-making can either improve communities' resiliency or perpetuate vulnerabilities to climate-related coastal hazards.

1.1 Research Problem and Questions

Why is it important to study communities' biophysical and social vulnerabilities as well as their coastal hazard governance processes? Coasts are dynamic systems that are influenced by geomorphological and oceanographical factors that change across various temporal and spatial scales (Cowell et al., 2003). They refer to those areas where sea meets land and also include the human-environment interactions that occur. These areas provide invaluable ecosystem goods and services including natural infrastructure (e.g., wetlands, dunes, etc.) protection against coastal hazards, water filtration, natural resources, transportation avenues, and recreational opportunities. As a result of these benefits, coastal areas have served as economic centers of settlement, industry, trade, and tourism. In particular, ecologically rich systems such as deltas, barrier islands, wetlands, and estuaries have been primary sites for human use and development resulting in environmental degradation from a number of sources including conversion to agriculture, industrial, and residential uses (Valiela, 2006). In 2010, out of 313 million people that resided in the U.S., 123 million people (39%) lived in coastal shoreline counties, which make up less than 10% (275, 351 mi^2 of land) of the total amount of land in the U.S (3 million mi^2). This is a 39% increase from the number of people in these areas in 1970. As economically and ecologically significant systems with populations in U.S. coastal counties expected to rise by 10 million (8%) between 2010-2020 (Crossett et al., 2013), these areas are at risk for extensive impacts from chronic and acute coastal hazards.

The terms chronic and acute hazards are used to differentiate between those hazards that have the potential to cause harm from long-term processes (chronic), such as sea level rise from global climate change, and those that occur from relatively short-term events (acute) like coastal flooding. Sea level rise is expected to be one of the most significant climate change related impacts on coastal areas (Church et al., 2013) and is a critical factor to include in coastal hazard assessments. Studies have found that sea level rise is primarily attributed to the expansion of seawater from increases in global temperatures (thermal expansion) and the subsequent melting of glaciers and ice sheets with an expected .5-2.0 meter increase in global sea level rise by 2100 (Church et al., 2013; Grinsted, et al., 2009; Kopp et al., 2014; Rahmstorf, 2007; Vermeer & Rahmstorf, 2009). Semi-empirical models have become important tools to illustrate past and present sea level rise as well as to compare against IPCC sea level rise projections in terms of changes already observed and likely to occur (Grinsted et al., 2009; Rahmstorf, 2007). As a chronic hazard, sea level rise effects are neither immediate nor limited to the loss of land but are also expected to exacerbate other coastal hazards like storm surge (Frazier et al., 2010; Kleinosky et al., 2006; Shepard et al., 2012). Therefore, depending on whether the coastal hazard is chronic or acute has implications for planning and decision-making in terms of how mitigation strategies are prioritized to address short- or long-term impacts.

Before the catastrophic impacts of Hurricane Sandy on the Northeast, most coastal hazards/disasters/risk research focused on the U.S. Southeast and Gulf regions where tropical storms are annual occurrences (Boruff et al., 2005; Frazier et al., 2010; Snow & Snow, 2009). The Northeastern region of the U.S. does experience hurricanes, on occasion, as well as extra-tropical storms, known as nor'easters, annually. Even though Sandy was an extreme event for the Northeast, its impacts highlighted certain vulnerabilities in this region to coastal hazards, specifically sea level rise and its effects on storm surge and erosion. Furthermore, those studies that have been situated in the Northeast (See Clark et al., 1998; Shepard et al., 2012) have been focused on major metropolitan areas. This research contributes to these underdeveloped areas of study by modeling the potential impacts of sea level rise and hurricane storm surges on Cape Cod, which, while not urban, has a population that swells into the millions during the summer. The magnitude of impacts from these coastal hazards varies due to communities' biophysical and social vulnerabilities and hazard mitigation planning and decision-making processes. Therefore, it is necessary to understand the interactions between communities, their vulnerabilities, and their hazard mitigation governance, which inform the following research questions.

1) How are the biophysical conditions of Cape Cod impacted by inundation from sea level rise, hurricane storm surge, and their interactions?

2) How do social characteristics and a tourism-dependent economy interact to produce different degrees of vulnerability to coastal hazards?

3) How does hazard mitigation governance and decision-making processes shape communities' capacities to plan for, respond to, and recover from climate-related coastal hazards?

These research questions present certain challenges, the first of which relates to issues of scale that have emerged from attempts to synthesize hazard vulnerability and climate change research. In particular, Cash & Moser (2000) and Wilbanks & Kates (1999) argue that there is a disconnect between global environmental change assessments at certain scales and management and implementation policies at other scales. Even though vulnerability to coastal hazards may be of national concern in the U.S., policies coming from the top-down usually rely on aggregate data and rankings from national studies such as Cutter & Finch's (2008) national hazard and social vulnerability study. The problem with having assessments mismatch with decision-making is that it tries to provide a "one-size-fits-all" set of solutions to a highly complicated, multi-variable, and multi-stressor context and, as such, may not address the problems populations face at a given location. As Cash & Moser (2000) conclude, studies need to try to match the biophysical area with a particular scale of management and avoid "scale discordance" where the assessment scale does not match the management scale. Therefore, to better link these different scales and inform hazard management, this dissertation provides an empirically based, hazard vulnerability case study that explores how communities' biophysical and social vulnerabilities interact with local hazard mitigation planning and decision-making.

Another challenge relates to issues of community adaptation to coastal hazards. The term adaptation originated in biology and refers to both the current state of being adapted and to the long-term evolutionary process of change to a stimulus. Within the climate change literature, there is limited information on what is considered an adaptation, how it occurs, as well as ways to measure its effectiveness relative to reducing vulnerable conditions (Ford & Berrang-Ford, 2013). In comparison, within hazards/disasters/risk and vulnerability research the idea of adaptive capacity is used and refers to the response strategies of coping and mitigation for coastal hazards. These strategies are shaped and constrained by the broader scales of social, political, and economic processes (Smit & Wandel, 2006). The common issue between these fields of research is determining which actions are feasible within "a context of high uncertainty" (Romieu et al., 2010). To address this challenge, institutional and governance theory and analysis were used to examine the hazard mitigation planning and decision-making processes. Institutional theory considers the processes by which prescriptions (i.e., rules, norms, and shared strategies) are used to organize repetitive and structured interactions (Ostrom, 2005). Examining the adaptive capacity of communities is an important aspect of understanding vulnerability because it refers to how well a community can reduce and manage the negative impacts of coastal hazards, which are shaped by the broader institutional and governance context. Therefore, an important contribution of this study is the analysis of how coastal hazard mitigation planning at the regional and local level uses information on biophysical and social vulnerabilities in their decision-making ~~and influence communities' adaptive capacities~~. I argue that by understanding the underlying institutional and governance structures and local perceptions of risk, as influenced by biophysical and social characteristics, we can better understand how communities experience different degrees of vulnerability as well as the barriers affecting communities' adaptive capacities and resiliency to climate-related coastal hazards.

1.2 Historical Geography of Study Site

Cape Cod (a.k.a. "the Cape", Barnstable County) refers to the easternmost county in Massachusetts (Figure 1.1) that protrudes out into the North Atlantic Ocean. Made up of 15 towns, Barnstable County can be divided into four sub-regions: Upper Cape, Mid Cape, Lower Cape, and Outer Cape. This region has a long geological and archeological history that predates English settlement in the early 17th century. The Wampanoag people flourished throughout eastern Massachusetts and into parts of Rhode Island.[2] Due to the rich natural resources of Cape

[2] While a discussion of the Wampanoag people is outside of the scope of this dissertation it is necessary to acknowledge their historic presence at this study site. Their population suffered greatly from exposure to English diseases like small pox and European settlers displaced them over time. There are two federally recognized tribes located on Cape Cod and Martha's Vineyard:

Cod and the Islands (Martha's Vineyard and Nantucket), these native people had settled this area long before the first landing of the Pilgrims. While Plymouth, MA is considered the earliest permanent English settlement, the Pilgrims on the Mayflower first made land in the New World at, what is today, Provincetown, MA on November 11, 1620. After a few weeks of exploration the Pilgrims crossed Cape Cod Bay and made final port at Plymouth, MA (Barnes, 1958).

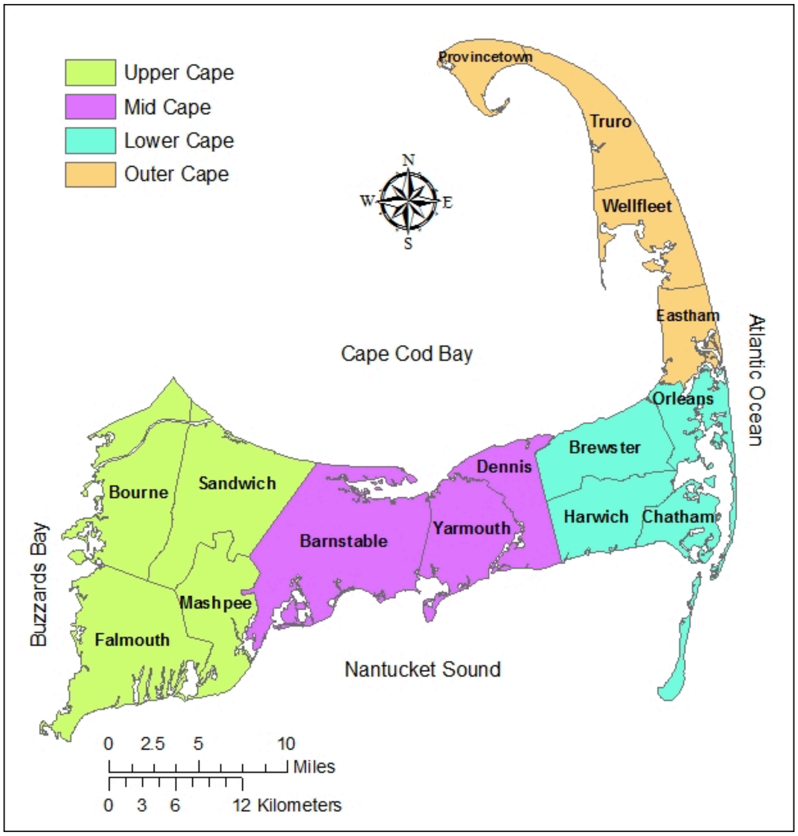

Figure 1. 1. Map of Cape Cod towns by sub-region

The current topography of the Cape and the Islands are the result of the erosion and deposition of material over two million years of glacial and interglacial periods (Mahlstedt & Loparto, 1986). The Cape itself extends twenty-five miles east of the mainland and thirty miles northwest to its northernmost tip, Race Point, in Provincetown. While originally considered a peninsula, the study area effectively became an island in 1914 with the construction of the Cape Cod Canal. The primary reason for the Canal's construction was economic in order to shorten the

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The Mashpee Wampanoag Tribe and The Wampanoag Tribe of Gay Head (Aquinnah) Massachusetts, respectively.

trade routes between Boston and New York City. Even though the idea of a canal was proposed as early as the beginning of the 17^{th} century, it was not until the early 20^{th} century that the technology existed to successfully undertake such a large engineering project. Constructed by the privately owned “Boston, Cape Cod Canal and New York Company,” the Manomet (flows southwest to Buzzards Bay) and Scusset (flows northeast to Cape Cod Bay) rivers in Bourne were connected to create the 480 ft. wide, 32 ft. deep, and 17.4 miles long Cape Cod Canal. The newly created channel effectively separated the Cape from the mainland and, as a result, agencies like the Federal Emergency Management Association (FEMA), the National Oceanic and Atmospheric Administration (NOAA), and the Cape Cod Commission now treat this region as an island particularly in terms of hazard mitigation and disaster preparedness. The only way to access the Cape is by airplane, ferry, or driving over the Bourne or Sagamore Bridge.

Given its topography and geographical location, this study site is most susceptible to sea level rise, storm surge, and erosion. Barnstable County has the longest coastline for a single county in the state with ~559.6 miles of coastline and yet it is only about 10 miles across at its widest point (Mahlstedt & Loparto, 1986). In some areas in the Outer Cape (Figure 1) you can see that the distance between the Atlantic Ocean and Cape Cod Bay is less than two miles apart. As one of the largest barrier islands in the world, the Cape protects most of eastern Massachusetts from large-scale coastal hazards (e.g., nor’easters and hurricanes) that occur making it highly susceptible to erosion and coastal flooding. While sea level rise is a chronic coastal hazard that occurs over a long period of time, there is increasing evidence that it is accelerating due to human activities and will be a serious concern for those low-lying coastal areas (Nicholls et al., 2007) including Cape Cod.

In addition to the Cape’s biophysical conditions, there are certain demographic and economic characteristics that make its coastal communities more sensitive to the adverse impacts of coastal hazards. With a year-round population of 214,914, this number swells to well over 4 million people most of which visit during the summer season (Memorial Day through Labor Day). As of 2014, 27% of the total population was 65 years or older and people aged 45 to 64 represented 32% of the total population (StatsAmerica, 2014). Studies have found that age is an important indicator of vulnerability to hazards since these individuals usually have reduced coping capacities both financially (e.g., fixed income from retirement) and physically (e.g., disabled) (Clark et al., 1998; Cutter et al., 2003). Socioeconomic status (SES) is another important indicator of vulnerability since these individuals also have fewer financial resources that can help them recover. In 2014, while poverty rates in Barnstable County were low compared to other U.S. counties, at 9% this reflects a 21% increase from 2000 (StatsAmerica, 2014). Furthermore, the potential impacts from coastal hazards could be more severe for Cape Cod communities due to the negative effects they could have on the region's primary economic industry, tourism.

The ocean economy can be broken down into 6 sectors (i.e., construction, living resources, minerals, ship/boat building, tourism/recreation, and transportation). In 2010, the ocean economy was comprised of over 2.7 million jobs and contributed more than $258 billion to the total U.S. GDP. Of these sectors, tourism and recreation were the largest with 1.9 million jobs and $89 billion in economic output (Kildow et al., 2014). In terms of this study site, Massachusetts ranks ninth out of thirty coastal states with a coastal labor force of 1,721,214 people employed and ranks fourth in terms of employment in the living resources (e.g., fishing) sector (Kildow et al., 2014). Historically, the primary economic industries on Cape Cod were farming, whaling, and fishing. While some farms remain active throughout the region it is no longer a major part of the overall economy. Rather the majority of the economy depends on its natural resources to promote tourism and healthcare services to provide for the aging population. While commercial whaling was outlawed in U.S. waters (other than for Native American subsistence) during the 1920s, the commercial fishing industry retains a strong presence in some Cape Cod towns particularly Chatham and Provincetown. As one of the major tourist destinations in the Northeast, the Cape's natural resources and recreational opportunities, especially its beaches, recreational fishing, and whale watching, draws millions of visitors each year. With a dependence on tourism, the Cape's economy is particularly sensitive to changes in its natural resources from climate-related coastal hazards.

1.3 Dissertation Roadmap

Informed by hazards and vulnerability and institutional decision-making literatures (Chapter 2), this dissertation uses a mixed-methods approach to conduct three assessments. First, Geographic Information Systems (GIS) is used to simulate a range of different hazard inundation scenarios (i.e., sea level rise and hurricane storm surge) to assess their potential impacts to Cape Cod communities' natural and built infrastructure (Chapter 3). Second, social indicators and principal component analyses are used to identify the most socially and economically vulnerable coastal towns (Chapter 4). Third, thematic content analysis is presented of semi-structured interviews with regional and local planners and decision-makers. These interviews provide first-hand accounts of how communities are preparing for and responding to climate-related coastal hazards as well as the challenges to proactive planning and decision-making (Chapter 5). A synthesis of these assessments is presented (Chapter 6), discussing the interactions between biophysical and social vulnerabilities and hazard mitigation planning and decision-making as it shapes communities' coping and adaptive capacities to coastal hazards. Ultimately, this dissertation seeks to advance a clearer understanding of how the interactions between coastal hazard impacts, community vulnerabilities, and coastal hazard governance influence the efficacy of long-term hazard mitigation planning at the community and regional scales.

CHAPTER 2

LITERATURE REVIEW

Historically, scientific and technological research has been conducted within a dualistic framework (Leiss, 1994; Merchant, 1980). This dualism refers to the human world versus the external world, the separation of humans from nature as though they are not intertwined. The human-nature dualism can be traced back to the Scientific Revolution and Enlightenment eras (Merchant, 1980) as well as throughout early sociological and biological traditions. Early environmental hazards/disasters research operated within this dualism by drawing a distinction between those "natural" hazards that have a clear point of origin (e.g., earthquake) and those that are the result of human activity (e.g., nuclear meltdown). As a result, hazards have been socially constructed in such a way as to be considered both separate and unique from "normal" events and processes that occur with regularity.

It was not until the mid-20th century that there was a shift in how academic traditions, governments, and the public viewed the environment culminating in the first wave of environmentalism in the 1960s and 1970s. While the human-nature dualism still exists, both in popular and in scientific writing, the environmental movement was pivotal in bringing to awareness the interconnected relationships between humans and their environment. O'Keefe et al. (1976) and Hewitt (1983) argue that the major flaw with seeing environmental hazards as "natural" is that it disregards how humans and their environments are interrelated with feedback loops that both amplify and exacerbate each other's influences. Emphasizing the idea of "natural" in hazards only reinforces the separation of humans-from-nature dualism, thereby obfuscating how societies' own actions may magnify hazard impacts. The point is that hazards exist in relationship to people.

In order to understand the full extent of impacts of coastal hazards and how people negotiate them, it is necessary to acknowledge but minimize the human-nature dualism. Furthermore, it is crucial for both researchers and the public to understand that environmental processes do not exist in an ontological vacuum from social processes. Therefore, this dissertation demonstrates how, through biophysical, social, and decision-making assessments, coastal hazards can be viewed as dynamic events and conditions that are inherently natural, social, and political[3]. The following literature review is broken into three sections: 1) historical and theoretical development of vulnerability and risk research, 2) institutions, governance, and decision-making, and 3) methodological advancements in coastal hazard and vulnerability assessments. The chapter closes with an overview of the methods and analytical framework used for the assessments in Chapters 3, 4, and 5.

2.1 Theoretical Developments: Vulnerability & Risk

Vulnerability studies originate in the risk, hazards, and disasters tradition but have become an important part of climate change research. Within these fields there are variations in epistemological emphases (e.g., political ecology, physical science, etc.) that influence how vulnerability is conceptualized and assessed. As a result, there are a variety of definitions to describe vulnerability depending on the particular research approach, which makes it challenging to compare studies. To further complicate matters, these traditions are no longer viewed as separate but increasingly interrelated. This is especially true in cases where certain environmental transitions occurring from climate change (e.g., loss of wetlands to sea level rise) are exacerbating the impacts of an environmental hazard (e.g., storm surge). Therefore, the following discussion reviews key historical and theoretical developments in the hazards, vulnerability, and risk research.

2.1.1 Historical Roots

In the mid-20th century, Gilbert F. White, an American geographer and "the father of floodplain management," became one of the first to pioneer a risk/hazard research approach and model. This approach reflects the dominant view of the time in which environmental hazards/disasters were attributed only to nature and not to human activities. As a result, scholars and policy-makers focused on identifying the different types of hazards, the drivers of those

[3] See Swyngedouw (1999) for a discussion on the socio-natural conditions of environmental issues.

hazards, and approaches to minimize their impacts (White, 1974; White & Haas, 1975). It was not until the seminal article in *Nature*, “Taking the Naturalness Out of Natural Disasters,” (O’Keefe et al., 1976) that there was a shift from a hazard event centric focus to a broader socio-natural vulnerability focus. O’Keefe et al. (1976) argued that the seeming increase in the magnitude of hazards/disasters is attributable to the existing social, political, and economic contexts that influence people’s vulnerabilities and, subsequently, their abilities to cope with the event.

Hewitt’s (1983) seminal work, *Interpretations of Calamity*, was also a significant departure from traditional hazards/disaster research by recognizing that the dominant approach was technocratic, reductionist, and based on socio-cultural constructions. Through O’Keefe et al. (1976) and Hewitt’s (1983) contributions, scholars and policy-makers have refocused their attentions to not only consider the physical hazard/disaster event but also the drivers of human vulnerability that exacerbate impacts. For instance, on Cape Cod coastal development is encouraged in order to promote and support tourism, a mainstay of the region’s economy. As a result, the higher infrastructure and population density increases the potential exposure of the area (biophysical vulnerability) to coastal hazards like hurricanes and nor’easters, which in turn magnifies the potential for loss. Based on these historical developments, advances in vulnerability research can be thematically organized.

2.1.2 Themes in Vulnerability Research

Theoretical developments in vulnerability research can be structured around three themes. First, there is the traditional notion of vulnerability from a risk/hazard perspective wherein the focus is on identifying the conditions of exposure that make a particular location vulnerable to hazards (Parrish et al., 1993; Quarantelli, 1992). The second theme draws from a more political ecology perspective, which views vulnerability as a social condition that includes a population’s coping capacity to hazards (Hewitt, 1997; Wisner et al., 2004). Lastly, the third theme is place-based vulnerability, which is the integration of possible exposures with social characteristics at a given location (Clark et al., 1998; Cutter, 1996; Kasperson et al., 1995; Shepard et al., 2012). Due to the different research traditions and thematic foci, the way vulnerability is conceptualized and assessed is not uniform resulting in different theoretical frameworks and models.

The UN's International Decade of Disaster Research in the 1990s was an important time of progress in vulnerability research. During this period, researchers sought to advance O'Keefe et al. (1976) and Hewitt's (1983) work on hazards/disasters and vulnerability by developing particular theoretical models and associated definitions. Notably, Wisner et al. (2004) did so following the second theme in vulnerability by taking a political ecology perspective. Specifically, they devised the Pressure and Release Model (PAR) to explain how environmental processes and social, political, and economic conditions interact to produce the vulnerable conditions (i.e., social and biophysical) people face, as well as the broader social context of hazards/disasters (Figure 2.1).

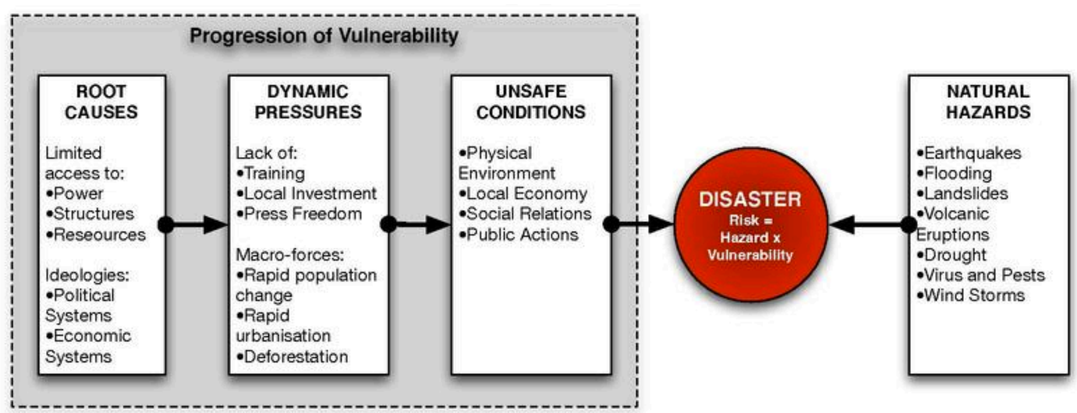

Figure 2. 1. Pressure and Release Model by Wisner et al. (2004)

Within political ecology, vulnerability is defined as "the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover" from the impacts of a hazard (Wisner et al., 2004, p. 11). Implicit in this definition is the idea that based on these characteristics, different groups of people are "differentially at risk" both in terms of the probability an extreme physical event will occur (i.e., risk) and "the degree to which the community absorbs the effects of extreme physical events and helps different classes recover" (i.e., coping capacity) (Susman et al., 1983, p. 264). While vulnerability refers to the limitations communities may possess that make them more susceptible to the effects of hazards/disasters, coping capacity implies certain capabilities that help reduce such effects. To be clear, the way Wisner et al. (2004) uses vulnerability refers only to people and does not include other aspects like biophysical conditions (e.g., natural and built infrastructure).

While the PAR model is not effective as a tool to measure vulnerability it is useful for conceptualizing the processes of vulnerability and their interactions with hazards. For example, Mustafa (2005), a key vulnerability scholar, employed the PAR model to study the interactions of vulnerability in flood zones in Pakistan. By using PAR, he was able to conceptualize the idea of the “hazardscape” to replace the idea of natural (or “unnatural”) hazards that just “happen.” Hazardscape refers to the existing socio-economic and political conditions characterized by degrees of vulnerability and risk that are situated as part of everyday life (Mustafa, 2005). Mustafa’s hazardscape skillfully links the “human” context to hazards where hazard events do not just happen to people. Rather, he argues that their socio-political and economic contexts make them more or less vulnerable to hazard impacts and, thus, hazard events become less “extreme” and more embedded in regular human-nature interactions.

The following theoretical advancement broadens how vulnerability is conceptualized and situates it towards a particular “place vulnerability.” Working within the third theme in vulnerability, Cutter (1996) developed a “hazards-of-place” model that sought to bridge the hazard/disaster exposure approach with the political ecology emphasis on social characteristics through geographically explicit studies. This place-based model describes how social vulnerability interacts with biophysical vulnerability to produce differential burdens on a particular population at a given location and how it changes over space and time (Figure 2.2).

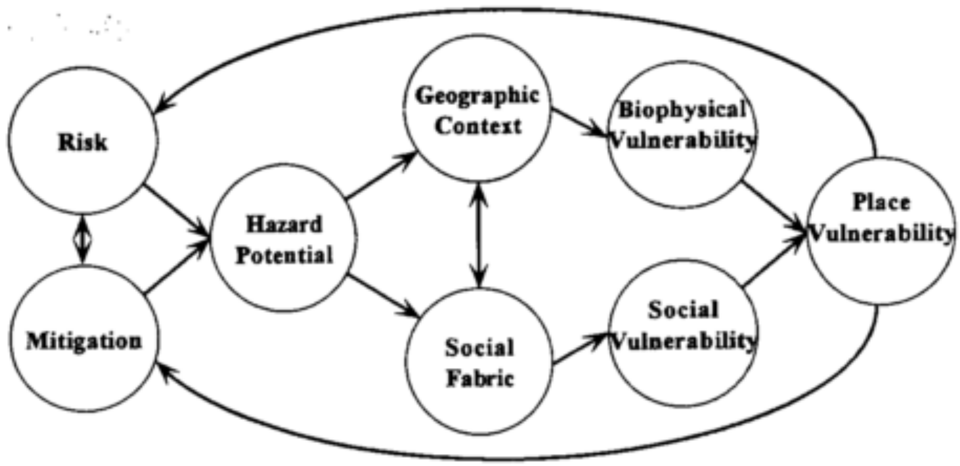

Figure 2. 2. Hazards-of-Place Model by Cutter (1996)

In this model, vulnerability is defined broadly as the potential for loss. While Hill & Cutter (2001) identified three types of vulnerability (i.e., individual, social, and biophysical), the “hazards-of-place” model focuses on social and biophysical vulnerability. Social vulnerability refers to the social characteristics of a particular population. It scales evaluations up to an entire social group by reviewing their demographic and economic characteristics in relation to how more or less susceptible they are to the adverse impacts of a hazard/disaster. These characteristics influence how people are able to respond to and recover from hazards/disasters (i.e., coping capacity). Key variables include class (e.g., differences in wealth), occupation, ethnicity, gender, age, disability/health status, and the nature and extent of social networks (Cutter, 2003). In contrast, biophysical vulnerability is the “potential exposure to a risk” (Cutter, 1996) and refers to both the spatial distribution of hazardous conditions and impacts to ecological, geomorphological, and man-made features (e.g., natural and built infrastructure). Consequently, the intensity and spatial extent of exposure is a fundamental component of risk and vulnerability research.

2.1.3 Risk, Hazards, & Resilience

Risk is referred to as the probability of a hazard occurring, the likelihood of exposure, and the level of expected loss. Wisner et al. (2004) explains the linkages between risk, hazards, and vulnerability as Risk=Hazard x Vulnerability. Risk is a compound function of the hazard and number of people—characterized by their degree of vulnerability—affected in the same spatio-temporal context. In addition to vulnerability, resilience is another theoretical approach used to understand how an ecosystem or population responds to environmental hazards. While Plosky (2007) defines vulnerability as a function of exposure, sensitivity, and adaptive capacity, Turner (2003) draws on resilience theory to explain how social-ecological systems (SES) respond to a given environmental change (e.g., hazard). In this context, resilience refers to the capacity of an SES to absorb disturbances and maintain its function and feedbacks (Adger et al., 2005; Holling, 1973; Walker et al., 2004). Similar to the differences between hazards/disasters research and climate change research (See Romieu et al., 2010), vulnerability and resilience traditions have also evolved from separate domains: social and ecological (Miller et al., 2010). Resilience emphasizes the ecological-biophysical taking a positivist epistemological distinction in which "phenomena can be objectively defined and measured" whereas vulnerability focuses on the social, economic, and political taking a more constructivist approach in which human agency and perceptions are more subjective (Miller et al., 2010). This dissertation is situated within the political ecology of hazards/disasters/risk and vulnerability literatures. Therefore, it focuses on the social, political (i.e., decision-making), and economic dimensions of hazards, as well how these dimensions influence communities' coping capacities. Even though resiliency is not usually used in the political ecology tradition, this dissertation refers to it because that is the term planners and decision-makers on Cape Cod use to describe mitigation and adaptation efforts that build communities' long-term abilities to manage climate-related coastal hazards impacts.

The traditional risk paradigm (National Research Council, 1983) was originally designed to assess the risks from toxic chemicals that had clear points of origin and technological measures to reduce its effects. In contrast, coastal hazards and vulnerability issues lack most of those characteristics and, therefore, require a different approach. As a result, risk research has evolved in ways that seek to address the more complicated contextual and psychological influences that shape hazards/disasters and their effects on populations. Contextual risk perception research tries evaluate how the broader social, political, and cultural context shapes perceptions of risk. For example, Douglas & Wildavsky (1982) were pivotal in positing the cultural theory of risk, which seeks to explain how the underlying cultural structures provide the basis for how a particular population perceives and interprets risk. More recently, Kahan (2012) conducted a study to measure the ways in which individuals' cultural worldviews inform their perceptions of risk.

Psychological risk perception studies are less interested in the contextual influences and more focused on the ways risk is internalized through cognition. Slovic (1987) focused on the role of cognitive processes in how attitudes and perceptions of risk are formed while White (1974) sought to understand how these risk attitudes and perceptions influenced individual and collective behavior to hazards/disasters. These early studies have helped inform more recent research including understanding how related residents' perceptions of risk are to actual coastal hazards in their living environment (Friesinger & Bernatchez, 2010) and how risk perception, shaped by social norms, influences mitigation strategies like deciding whether to buy flood insurance (Petrolia et al., 2014). Risk perception research has also tried to capture how climate change is related to risk. Carlton & Jacobson (2013) conducted a study to evaluate both climate change risk perception as well as factors that influence such perceptions. They found that risk perception is not only influenced by risk characteristics (e.g., likelihood event will occur, impacts, etc.) but also by an individual's cognitive and affective processes. In other words, personal experiences and interpretation of information tends to influence the ways in which people perceive climate-related risks more so than dry analytical facts. This has planning and policy implications in terms of the ways in which decision-makers' risk perceptions influence the ways they try to address hazards through mitigation strategies.

2.2 Institutions: Governance & Decision-Making

Frequently studied as social-ecological systems (Adger et al., 2005), coastal areas can be considered a "commons" where different groups interact together as they pursue a suite of resources. Due to different interests (e.g., recreational, residential, resource extraction, etc.), managing coastal areas is a complex process. A key challenge in managing a "commons" is determining how to get interested groups to avoid acting independently and, instead, engage in collective action, which are coordinated strategies “to obtain higher joint benefits or reduce joint harm” (Ostrom, 1990, p. 39). In relation to coastal hazards, planners and policymakers need to reconcile economic and development interests to construct oceanfront property in flood hazard zones with public safety and wellbeing. Therefore, hazard governance and the character of risk information influence the ways in which hazard mitigation strategies are designed and implemented (Muller & Schulte, 2011).

Governance theory was first introduced within the context of environmental resource conservation but has since been expanded to include larger human-environment landscapes like coastal areas. Broadly, environmental governance involves a variety of intuitions and actors that coordinate through networks and partnerships to produce policy outcomes (Johnston et al., 2000) and “is best understood as the establishment, reaffirmation or change of institutions to resolve conflicts over environmental resources” (Paavola, 2007, p. 93). There are three approaches to environmental governance: 1) top-down (state steer)—“leaving it to the experts”, 2) bottom-up (people steer)—“leaving it to the people,” and 3) market incentives (market steer)—“leaving it to the markets” (Dryzek, 2005). While these types have been debated extensively, there is a growing shift to employ an adaptive governance approach that seeks to consider broader social, political, and institutional contexts and encourages collective action (Dietz et al., 2003; Folke et al., 2005; Munaretto et al., 2014; Pomeroy, 2006).

Adaptive capacity, most frequently used in terms of climate change and its potential hazards, can be defined as the “ability to design and implement effective adaptation strategies, or to react to evolving hazards and stresses so as to reduce the likelihood of the occurrence and/or the magnitude of harmful outcomes resulting from climate-related hazards” (Brooks & Adger, 2005, p. 168). These strategies are “a matter of governance” (Van Nieuwaal et al., 2009) in that “adaptive capacity is only potential until there are governance institutions that make it realizable” (Adger, 2003, p. 33). In other words, multilevel coastal governance can reduce exposure and risk to coastal hazards and improve adaptive capacities through government intervention by encouraging alternative activities and lifestyles (Adger et al., 2005). Part of the challenge in governing coastal areas is that there are multiple actors, uses, and resources interacting within a common space (Wynberg & Hauck, 2014). How the interactions are negotiated depends on the institutional context. Institutions are "the prescriptions that humans use to organize all forms of repetitive and structured interactions" including rules, norms and shared strategies (Ostrom 2005, 3). It is both institutions and networks that shape and constrain the adaptive strategies used by communities to plan for and cope with coastal hazards through their ability to learn, store knowledge, and create flexibility in decision-making and problem solving (Folke et al., 2005). Therefore, effective coastal governance requires flexible strategies, informed by strong coastal science, which are negotiated through trust building and collaboration between national concerns and the local interests most affected by coastal change (Schmidt et al., 2013).

In addition to hazard governance, the character of risk information also influences planning and decision-making processes. While this dissertation acknowledges differences in perceptions of risk among experts and stakeholders (Slovic, 2001), its focus is on how such perceptions are an important influencing factor in governance and decision-making. Mileti & O'Brien (1992) found that it is not only the risk information itself that shapes local government decision-making but also the likelihood and proximity of the risks themselves. In fact, Vasileiadou & Botzen's study (2014) confirmed how the power of proximity and experience of risk can affect adaptive strategies. They found that people who personally experience intense, extreme weather events show higher levels of concern than those without such experiences. They also found that professional experience and secondhand experience by participating in informational events did not significantly affect their level of concern about extreme events. The results of these studies indicate that risk perception and personal experience can potentially influence the degree of priority and support for hazard mitigation planning.

Part of evaluating the efficacy of a particular coastal hazard management regime requires understanding how certain variables contribute to and influence the ability of planners and decision-makers to address hazard impacts. In other words, knowledge of: 1) the biophysical conditions of the coast, 2) the social attributes of the coastal communities, and 3) the rules governing the coastal zone all contribute to and influence how coastal areas and their hazards are managed. One approach is to draw from the Institutional Analysis and Development (IAD) framework developed by Elinor Ostrom and colleagues at the Workshop in Political Theory and Policy Analysis. The IAD framework presents a series of nested conceptual maps researchers can use at all scales of analysis to help understand and explain the diversity of decision-making processes and human patterns of behavior in a given situation (Ostrom, 2005, 2008). As Blomquist & deLeon (2011) argue "IAD's primary value lies in providing a means of organizing inquiry into a subject and a set of variables to examine" (p. 1). In recent years, researchers working with this framework have become increasingly interested in the exogenous variables that impact the actors and the decisions made in the action arena. Ostrom (2005) explains these exogenous variables in terms of three major categories: physical conditions, attributes of the community, and rules (Figure 2.3). While this approach, as illustrated in Figure 2.3, appears to treat the elements of the framework (particularly the exogenous variables) as independent, they are in practice highly interconnected and iterative.

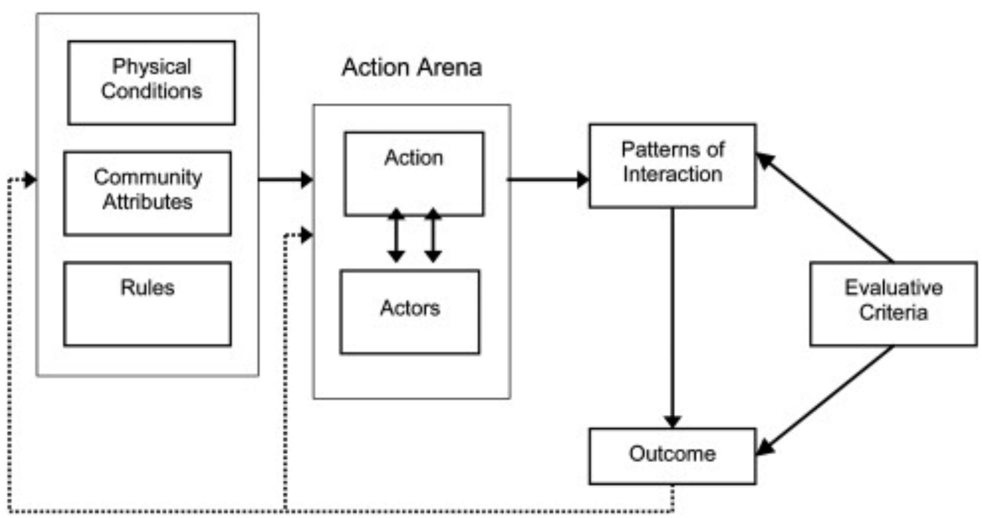

Figure 2. 3. Institutional Analysis and Development (IAD) Framework by Ostrom (2005)

Within this framework, rules are clearly defined and enforceable prescriptions describing required, permitted, or prohibited actions (Ostrom, 2005). For example, in the realm of coastal governance, zoning regulations (e.g., prohibiting new development in flood zones) are a type of rule used to create order and stability regarding human activity in known hazard areas. Less well known, but also influential, are the attributes of a community variable describing the "human" context wherein a particular action arena may be located such as a coastal community in the case of hazard management and mitigation. Attributes of the community, for example, can include such things as the values of behavior generally accepted by the community or the size and composition of the community (Ostrom, 2005). Lastly, it is also important to identify and understand how the world being acted upon (i.e., the biophysical and material context), in a given situation, affects the overall action arena. As Oran Young (2007) argues, management systems are "affected by the character of the goods and services to which they pertain" (p. 1). In the case of coastal areas, it is necessary to understand the biophysical conditions, particularly in terms of exposure to climate-related coastal hazards, that are driving and requiring a variety of mitigation, coping, and adaptive strategies. This dissertation considers these exogenous variables by examining: a) physical conditions in the biophysical vulnerability assessment (Chapter 3), b) community attributes in the social vulnerability assessment (Chapter 4), and c) rules in the governance and decision-making assessment (Chapter 5). Considering the specific purpose of each assessment, utilizing different methods are necessary and are discussed in the following sub-section.

2.3 Measuring Vulnerability: Indicators, Mapping, & Modeling

Since 1967, there has been a significant increase in the number of publications in the domains of resilience, vulnerability, and adaptation across many fields reflecting theoretical and methodological advancements (Janssen et al., 2006). Recent research has focused extensively on identifying and assessing the relationship between vulnerability, hazards, risk, and climate change in a variety of spatial and social contexts including flood zones (Eakin & Appendini, 2008; Collins, 2009; Mustafa, 2005), indigenous communities (Veland et al., 2012) and coastal delta systems (Malm & Esmailian, 2013). In coastal areas, researchers are trying to illustrate how human activities and hazards interact to affect all aspects of coasts whether it is the physical impacts of sea level rise on coastal wetlands and the loss of their benefits (Sherwood & Greening, 2014; Nicholls et al., 2007) or the economic impacts of sea level rise and storm surge on coastal communities (Cooper et al., 2012; Thatcher et al., 2013). How vulnerability and hazard impacts are measured varies depending on the method.

Indices are one quantitative method used by researchers to measure both biophysical and social vulnerability. Biophysical vulnerability refers to both the natural physical and ecological resources as well as the man-made built infrastructures spatially at risk from hazardous conditions and impacts. Pendleton et al.'s (2010) Coastal Vulnerability Index (CVI) combines a coast's susceptibility to change and its adaptive capacity to measure the system's vulnerability to sea level rise. The Coastal City Vulnerability Index (CCFVI) takes the traditional CVI one step further and identifies the cities most vulnerable (i.e., combinations of exposure, susceptibility, and resilience) to coastal flooding (Balica et al., 2012). Recently, more attention has focused on understanding the role natural infrastructure plays in relation to coastal hazards. Arkema et al. (2013) devised a coastal hazard index that includes a coastal habitat component in order to identify and measure how natural coastal infrastructure (e.g., wetlands, dunes, barrier beaches etc.) can protect vulnerable populations and property from coastal hazards (i.e., sea level rise). Despite the biophysical emphasis in each of these indices they do consider the impacts of coastal hazards in relation to human populations.

A growing number of coastal hazard vulnerability assessments are incorporating social vulnerability measurements to identify populations particularly sensitive to hazards including erosion (Boruff et al., 2005) and sea level rise and hurricane storm surge (Kleinosky et al., 2006; Frazier et al., 2010; Shepard et al., 2012). Social vulnerability refers to the demographic and economic characteristics (e.g., age, ethnicity, socioeconomic status, etc.) of a population in relation to how more or less susceptible they are to hazard impacts. Most vulnerability assessments seek to identify, quantify, and explain the interactions between multiple hazards or stressors and social vulnerability by including population specific information (i.e., social indicators) at certain spatial scales. Some of these scales include community (Colburn & Jepson, 2012), county (Cutter et al., 2000; Kleinosky et al., 2007; Ge et al., 2013), city/metropolitan (Clark et al., 1998), and regional/national (Cutter & Finch, 2008; United Nations Development Program, 2004). A major contribution of these studies is that they successfully link social characteristics and information—that is, social vulnerability indicators—to the spatial context of the hazard, the extent of its impacts, and a given population's degree of exposure. In the context of coastal systems, these impacts include economic (Thatcher et al., 2013), built infrastructure and land use (Gunerlap et al., 2013; Shepard et al., 2012), and types of populations differentially impacted (Cutter et al., 2000; Cutter et al., 2003). In her seminal article, "Social Vulnerability to Environmental Hazards," Cutter et al. (2003) constructed a Social Vulnerability Index (SoVI) based on county-level socio-economic and demographic data. They identified 11 factors (i.e., personal wealth, age, density of built environment, African American, Asian, Hispanic, occupation, infrastructure dependence, single-sector economic dependence, and housing stock and tenancy) that explained ~76.4% of the variance of vulnerability to environmental hazards among U.S. counties. The SoVI is a significant methodological contribution to hazards and vulnerability research because it allows for comparison of vulnerabilities and the ways hazards differentially impact populations across spatial dimensions.

Even though the biophysical and social components of hazards vulnerability were discussed separately, the majority of the research studies mentioned merged and modified the indices to account for the complex interactions between these components and provide a more comprehensive analysis. In particular, Thatcher et al. (2013) created the Coastal and Economic Vulnerability Index (CEVI) by merging social indicators (social component) with Pendleton et al. (2010)'s Coastal Vulnerability Index (biophysical component).

In addition to the use of indices, many studies of hazards and vulnerability also employ other methods, especially, Geographic Information Systems (GIS) and modeling, to determine the magnitude and spatial extent (i.e., who/what is impacted) of a particular hazard (See Cutter et al., 2003; Frazier et al., 2010; Kleinosky et al., 2006; O'Brien et al., 2004; Thatcher et al., 2013). In the context of coastal hazards, GIS is used to quantify and visually describe the impacts of storms—particularly from hurricanes —and sea level rise on the biophysical environment to determine the vulnerabilities that exist at a given location (Arkema et al., 2013; Cutter & Finch, 2008; Frazier et al., 2010; Shepard et al., 2012). Many studies also use modeling approaches, in conjunction with GIS, to posit future hazard scenarios and their potential impacts. Notably, Frazier et al. (2010), used SLOSH (Sea, Lake, and Overland Surges from Hurricanes) models, along with GIS and indicators, to identify the primary hurricane storm-surge hazard zones in Sarasota, FL by analyzing how sea level rise will exacerbate storm surge from different categories of hurricanes. They found that, compared to existing conditions, sea level rise increases vulnerability by increasing amount of hurricane storm-surge. Moreover, their results indicate that even if hurricane intensity or frequency remains the same, progressive sea level rise means that there is a greater storm surge risk for low-lying coastal areas (e.g., Category 3 hurricane will mimic exposure of less frequent Category 4). While there are a number of different methodological approaches used to evaluate vulnerability to hazards, the more comprehensive studies are those that used a mixture of complementary methods. Therefore, this dissertation employs three different methods (i.e., both quantitative and qualitative) that are specific to each of the three assessments.

2.4 Assessments: Methods & Analytical Framework

Assessing the impacts from climate-related coastal hazards is a complex process that requires a multi-disciplinary approach to execute effectively. The research outlined in this dissertation adopts and modifies Cutter's (1996) "hazard-of-place" vulnerability framework. This model of vulnerability is particularly suited to the study of coastal hazards on Cape Cod, MA because it has been applied to coastal areas (Cutter et al., 2000; Boruff et al., 2005; Kleinosky et al., 2006) and because of the way it is conceptualized. Specifically, social and biophysical vulnerabilities can be examined simultaneously in relation to a single or multi-hazard situation. Furthermore, they can also be assessed in differing social, economic, and political contexts, based on the characteristics of the hazard (i.e., chronic or acute), and using different methodologies (e.g., GIS, historical, empirical) (Cutter, 1996). I modified Cutter's (1996) model by considering a third area of assessment, governance and decision-making, which draws from institutions and the IAD framework (Ostrom, 2005). Specifically, the exogenous variables (i.e., physical conditions, community attributes, and institutions) are melded with Cutter's biophysical and social vulnerability components to create more comprehensive hazard vulnerability case study of Cape Cod, MA.

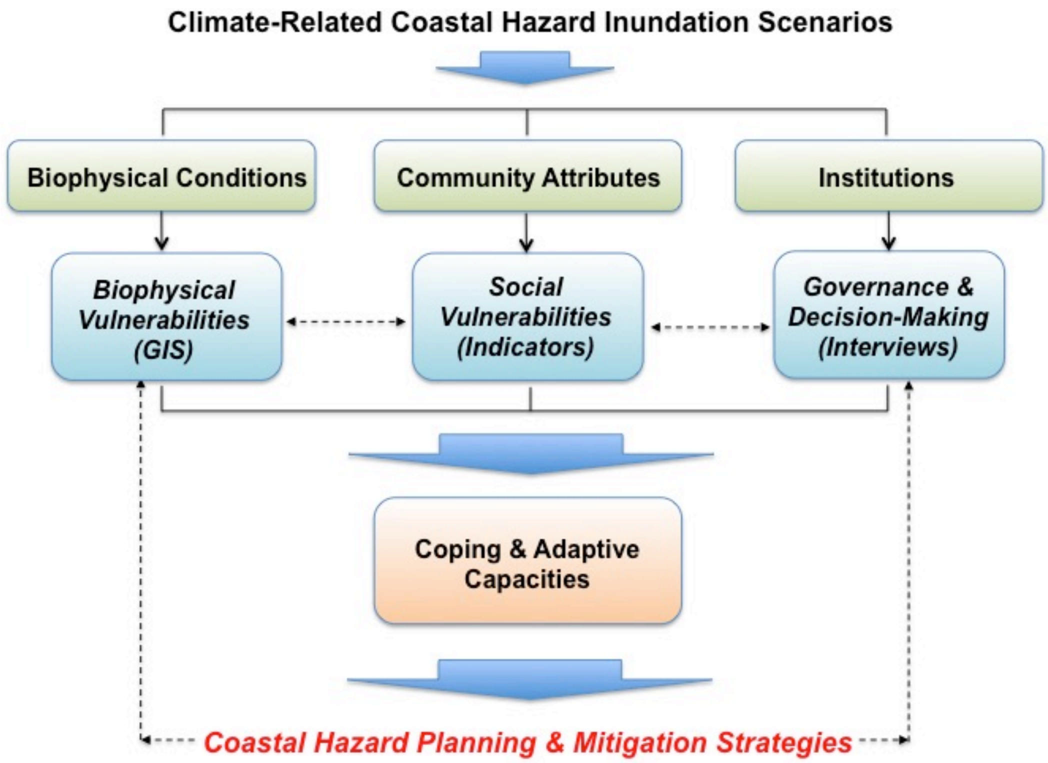

Figure 2. 4. Hazards, Vulnerabilities, & Governance Framework

Using the “hazards-of-place” model and IAD framework as a guide, Figure 2.4 illustrates how climate driven sea level rise and hurricane storm surge scenarios are used to spatially define the areas of exposure at the Cape Cod township level and the potential magnitude of impacts to natural and built infrastructure (i.e., biophysical conditions). The impacts to these conditions are quantified using Geographic Information Systems (GIS) and the Sea Lake Overland Surges from Hurricanes (SLOSH) model display program. Social indicators are used to examine those community attributes and socio-economic characteristics that influence susceptibility to the adverse impacts of coastal hazards. In addition to the biophysical and social, there is a third feature to consider: the institutional context. Specifically, a thematic content analysis of semi-structured interviews with planners and decision-makers is used to assess the governance and decision-making processes (i.e., institutions) and how they shape proactive coastal hazard mitigation planning to improve communities’ capacities to withstand climate-related coastal hazards.

CHAPTER 3

BIOPHYSICAL VULNERABILITY ASSESSMENT

The purpose of this component of the case study is to determine the biophysical vulnerabilities of Cape Cod's natural and built infrastructure to the climate-related coastal hazards of sea level rise (SLR) and hurricane storm surge. Geographic Information Systems (GIS) is used to visualize, question, analyze, interpret, and understand data in order to reveal spatial relationships, patterns, and trends. Considering that hazards and their impacts vary spatially, GIS is an appropriate method to identify, illustrate, and analyze these spatial relationships in greater depth (Montz & Evans, 2001). The chapter is organized into three sections. First, the data and methods used to construct three hazard models are presented. Second, the application of the hazard models to assess impacts to biophysical conditions is outlined. Third, the results of the impact analyses of Cape Cod communities' natural and built infrastructure are discussed.

3.1 Methods: Model Construction of Coastal Hazards

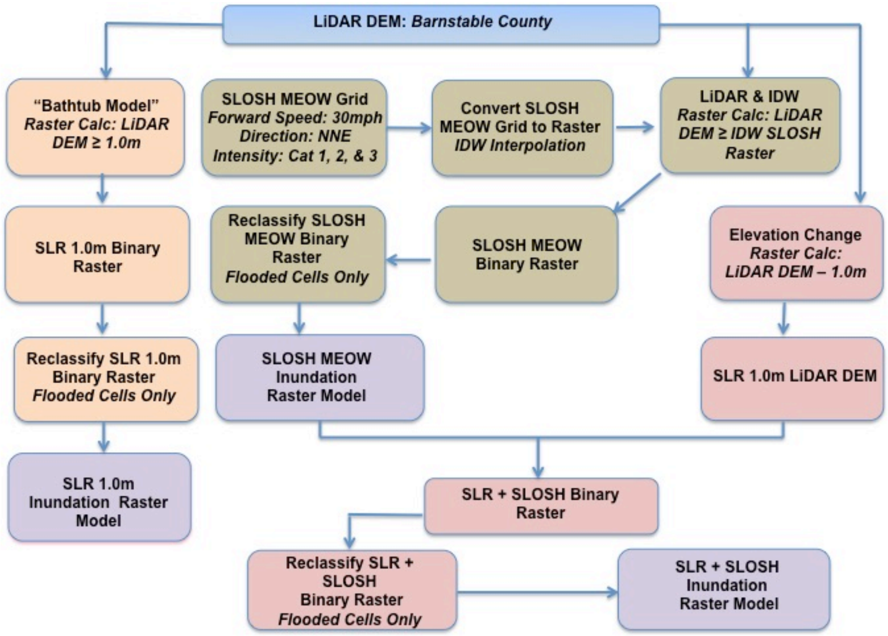

Figure 3. 1. Model development for a) SLR, b) hurricane storm surge, and c) SLR expanded hurricane storm surge

Esri ArcGIS was used to develop three types of climate-related coastal hazard models: 1) SLR, 2) hurricane storm surge, and 3) SLR + hurricane storm surge (Figure 3.1). These hazard models were used to identify the biophysical vulnerabilities of Cape Cod communities assessed as the impacts to the natural and built infrastructure. The natural infrastructure variable selected is land cover (e.g., beaches, wetlands, etc.) and the built infrastructure variables used are land use, roads, and assessors' parcels (Table 3.1). These variables were chosen to illustrate a variety of biophysical conditions vulnerable to potential impacts from SLR and hurricane storm surge. The hazard models were constructed and their impacts analyzed in order to determine the degree of exposure (a component of vulnerability), measured as inundation, Cape Cod communities could face for a given coastal hazard.

Table 3.1
Natural and Built Infrastructure Variables

Variable	Description	Format	Scale	Date	Data Source
Elevation	LiDAR derived digital elevation model, which is a 3-D representation of the earth's surface	Raster	1 to 100,000	2011-2015	MassGIS
Land Cover	Features of the land surface (e.g., wetlands, beaches, etc.)	Raster	1 to 100,000	2006-2011	USGS
Land Use	Human use of land (e.g., agriculture, residential, commercial, etc.)	Raster	1 to 100,000	2006-2011	USGS
Roads	Minor roads, major arteries, state roads, and interstate	Vector	1 to 5000	2005-2014	MassGIS
Assessors' Parcels	Housing (e.g., single family) and tourism (e.g., inns)	Vector	1 to 5000	2013	MassGIS

3.1.1 Sea Level Rise Hazard Scenario

By the end of the 21st century, more than 70% of the world's coastlines are projected to experience sea level changes within twenty percent of the global mean, which for the U.S. East and Gulf coasts is projected to be, at worst, a 0.9 meter increase (IPCC 2014). Based on this estimate and a review of other projections (Church et al., 2013; Grinsted et al., 2009; Parris et al., 2012; Rahmstorf, 2007; Vermeer & Rahmstorf, 2009), a 1.0m SLR scenario was chosen to identify the areas on Cape Cod at high risk for loss from inundation by year 2100.

To model the projected 1.0m SLR, I used a 3m-resolution LiDAR digital elevation model (i.e., LiDAR DEM) of Cape Cod and applied the "bathtub model" approach where the LiDAR DEM was flooded until the desired SLR was reached (Emrich & Cutter, 2011; Titus & Richman, 2001). The "bathtub model" is only as accurate as the underlying elevation data. Many DEM data have a vertical datum of NAVD 1988, which typically measures elevation from the mean sea level. As a result, any SLR scenario would be, at best, a conservative model of inundation since it does not take into account tidal fluctuations. The LiDAR data used in this study, however, was collected during Daily Predicted Low Tides plus or minus 90 minutes and has a vertical accuracy of 9.25cm RMSEz, which improved the accuracy of the "bathtub model" approach and the ultimate 1.0m SLR inundation raster model.

To apply the “bathtub model,” I used the raster calculator function in the spatial analyst tool in ArcGIS to calculate which raster cells (containing elevation data) were flooded and which ones were not based on the 1.0m SLR scenario.[4] The result was a binary raster of flooded and not flooded cells, which was reclassified to create the final 1.0m SLR inundation raster model with flooded cells only (Figure 3.1). While it is unlikely that there will be a uniform rise in sea level due to regional physical conditions (e.g., topography, bathymetry, tidal fluctuations, etc.), creating a uniform 1.0m SLR model is sufficient for the purpose of this study and provides a reasonable approximation of the biophysical conditions potentially affected.

3.1.2 Hurricane Storm Surge Hazard Scenarios

Hurricane storm surge data was collected from NOAA’s National Hurricane Center (NHC) Sea Lake and Overland Surges from Hurricanes (SLOSH) model display program. The SLOSH model coverage divides the Gulf and Eastern U.S. into 32 basins each containing hundreds of grid cells and region-specific information such as topography and bathymetry. Each basin is modeled with hundreds of hurricane simulations using different hurricane categories, forward speeds, landfall directions, landfall locations, and initial tidal levels.[5] SLOSH has two main outputs: the Maximum Envelopes of Water (MEOWs) and the Maximum of MEOWs (MOMs). The MEOW is generated when several hypothetical SLOSH runs—with the same forward speed, initial tidal level, and direction but different landfall locations—are combined to reflect the maximum surge height obtained in each grid cell at any time during those runs. The MOM is generated by aggregating the MEOW output of a particular hurricane category—regardless of forward speed, direction, landfall location, or initial tidal levels—to determine the maximum surge heights for each grid cell as it correlates with each hurricane storm category (National Hurricane Center, 2015). While no single hurricane will produce the regional flooding depicted in the MEOWs (or MOMs), for this study, I decided to use the MEOW output in order to create as

[4] Raster calculator command: LiDAR DEM ≥ 1.0
[5] SLOSH model reports to have an accuracy of +/- 20% (National Hurricane Center 2014).

realistic and tailored hurricane scenarios that reflects historical data, records, and conditions for Cape Cod rather than a maximum of every type as it is with the MOMs.

Table 3.2

SLOSH Model PV2 Basin MEOW Parameters

Category Intensity	1, 2, and 3
Forward Speed	30 mph
Forward Direction	North North East (NNE)
Initial Tidal Level	5 ft. High Tide

To model plausible hurricane storm surge inundation scenarios on Cape Cod, I used the SLOSH MEOW outputs from the PV2 basin (encompasses the entire study site) with the following parameters (Table 3.2). The Saffir-Simpson Hurricane Scale categories of 1, 2, and 3 were selected. These categories are distinguished by the intensity of their sustained winds with damage ranging from minor to devastating. Category 4 and 5 hurricane storm surges were not modeled because, according to the NOAA's Hurricane Research Division historic records, a hurricane category of 4 or 5 intensity has never made landfall in the U.S. Northeast. The forward speed of a hurricane is latitude dependent. As Cape Cod rests at 41.68°N, the average forward speed of hurricanes at this latitude is 30mph (Dorst, 2014). North-Northeast (NNE) was selected as the forward direction for the hurricane storm surge scenarios because, based on historical records and a discussion with a National Weather Service scientist, this is the most common direction hurricanes have traveled and made landfall in this region. Lastly, to maximize potential storm surge an initial high tide of 5 ft. was chosen since it corresponds with the average high tide for most towns on Cape Cod.

The SLOSH MEOW outputs (Cat 1, 2, and 3) are in vector format with each polygon grid containing the water surface elevation (i.e., surge depth) that would occur from the hurricane storm surge. In order to determine the hurricane surge impacts relative to Cape Cod elevation, the three MEOW outputs were converted from their vector, grid format to a raster format. First, the polygon grids were transformed into points based on the centroids of the polygons. Second, the point shapefiles were interpolated, using inverse distance weighted (IDW), to produce raster surfaces representing the storm surge water elevation for each hurricane scenario. IDW interpolation estimates raster cells using sample points, which are weighted so that the closer a cell being evaluated is to a sampled point, the more weight it has in the cell's value calculation (ArcGIS Resource Center, 2013). In terms of creating the three hurricane storm surge inundation rasters, IDW interpolation was used because those raster cells being estimated should have storm surge values similar to the sample points containing the known surge depth values as determined by the SLOSH model display program.

To delineate the hurricane storm surge inundation zones on Cape Cod, the hurricane storm surge interpolated rasters were compared to the Cape Cod LiDAR DEM in order to identify where water surface height (i.e., storm surge heights) exceeded the LiDAR DEM bare-earth elevation values. In other words, similar to the SLR hazard inundation model, I used the raster calculator function in the spatial analyst tool in ArcGIS to calculate which raster cells (containing elevation data) were flooded and which ones were not based on each of the three SLOSH interpolated rasters (i.e., Cat 1, 2, and 3).[6] The result was a binary raster of flooded and not flooded cells, which was reclassified to create the final Category 1, 2, and 3 hurricane storm surge inundation raster models with flooded cells only (Figure 3.1).

3.1.3 SLR + Hurricane Storm Surge Hazard Scenarios

To examine the effect of SLR on the magnitude of each hurricane storm surge inundation scenario, I used the raster calculator function to lower the elevation of the LiDAR DEM by the 1.0m SLR scenario[7] and then re-calculated each of the three hurricane storm surge inundation scenarios (Frazier et al., 2010; Kleinosky et al., 2007; Wu et al., 2002), thereby simulating sea level increase per storm surge category. Once the LiDAR DEM had been adjusted to reflect a 1.0m SLR, I used the raster calculator function in the spatial analyst tool in ArcGIS to calculate which of the raster cells containing elevation data—that had already been adjusted to a 1.0m SLR—were flooded and which ones were not based on each of the three SLOSH interpolated rasters (i.e., Cat 1, 2, and 3).[8] The result was a binary raster of flooded and not flooded cells,

[6] Raster calculator command: LiDAR DEM ≥ SLOSH Interpolated Raster
[7] Raster calculator command: LiDAR DEM-1.0
[8] Raster calculator command: SLR LiDAR DEM ≥ SLOSH Interpolated Raster

which was reclassified to create the final 1.0m SLR and Category 1, 2, and 3 combination inundation raster models with flooded cells only (Figure 3.1).

Table 3.3

Final Set of Seven Climate-Related Coastal Hazard Scenario Models

Sea Level Rise Inundation Model	**Hurricane Storm Surge Inundation Models**	**SLR + Hurricane Storm Surge Inundation Models**
1) 1.0m SLR	2) Category 1	5) 1.0m SLR + Category 1
	3) Category 2	6) 1.0m SLR + Category 2
	4) Category 3	7) 1.0m SLR + Category 3

The seven climate-related coastal hazard scenarios that were developed (Table 3.3) were then applied to natural and built infrastructure data (Table 3.1) to examine their impacts and illustrate Cape Cod communities' biophysical vulnerabilities.

3.2 Application: Analyses of Coastal Hazards Impacts

The seven climate-related coastal hazard scenarios were used to assess three categories of impacts: 1) land use and land cover (LULC), 2) roads, and 3) assessors' tax parcels (Table 3.4). The impacts of the coastal hazard scenarios were analyzed by measuring the loss of or affected features of the natural and built infrastructure due to inundation. All results of impact analysis are reported as amount (i.e., m^2 or m) and percent affected (i.e., inundated)[9] per Cape Cod town.

[9] Percent affected = [(New Total Value-Original Total Value)/Original Total Value] x 100

Table 3.4

Impact Analyses of Types of Natural and Built Infrastructure

LULC (i.e., Natural & Built)	Roads (i.e., Built)	Assessor Tax Parcels (i.e., Built)
Natural Infrastructure: • Marshes • Beaches, Shores, Dunes • Woody Wetlands • Herbaceous	Classes: • U.S. Route 6 • State Routes • Major Arterial Roads • Minor Roads	Housing Infrastructure: • Single Family • Residential Condos • Two Family • Multiple Houses Per Parcel
Built Infrastructure: • Developed: High • Developed: Medium • Developed: Low • Developed: Open • Agriculture		Tourism Infrastructure: • Hotels • Motels • Inns, Resorts, B&Bs • Large Retail • Small Retail • Eating/Drinking • Golf • Marinas

3.2.1 Land Use Land Cover (LULC) Impact Analysis

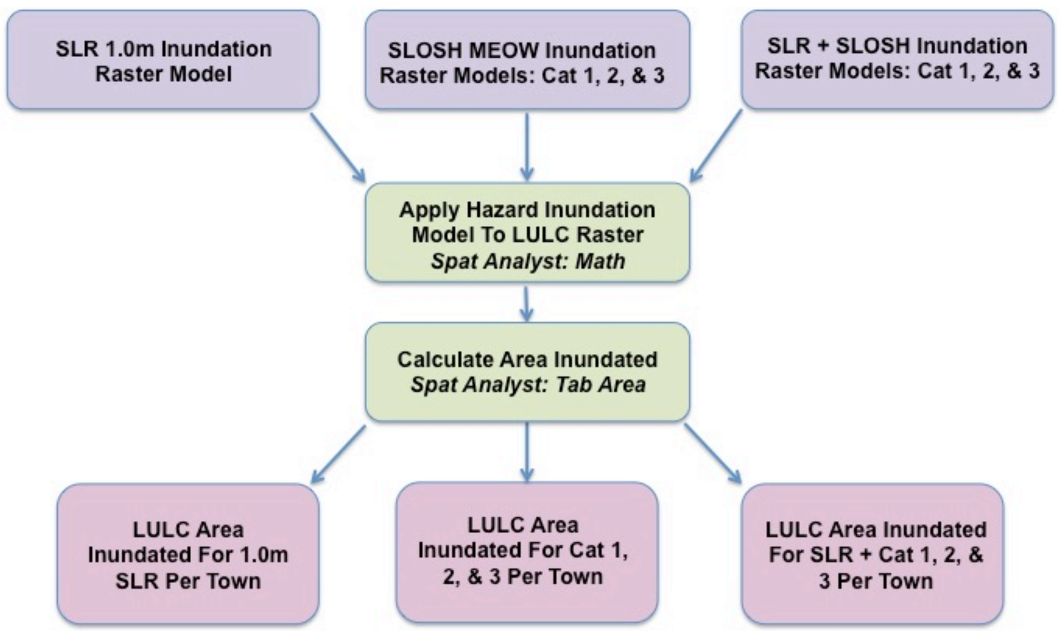

Figure 3. 2. Land cover analysis of inundation from a) SLR, b) hurricane storm surge, and c) SLR expanded hurricane storm surge

The impacts of the coastal hazard scenario models on the LULC on Cape Cod (Figure 3.2) were determined using the ArcGIS spatial analyst tool. Specifically, the mathematical function of the spatial analyst tool was used to calculate which LULC raster cells were flooded and which ones were not. Once the coastal hazard models were applied to the LULC, I used the tabulate area function to calculate, by town, the total land area and land area loss (i.e., from inundation) for both natural and built infrastructure. To calculate percent of natural and built infrastructure land area affected, I took the area inundated for each infrastructure in a particular town and subtracted it from the total area for each infrastructure in that town. This produced a new total infrastructure area value based on inundation. Then I applied the percent change formula (See Footnote 9). I subtracted the original total infrastructure area (pre-inundation) from the new total infrastructure area (post-inundation), divided by the original total infrastructure area, and then multiplied by 100. This process was repeated for each Cape Cod town seven times to assess the impacts of each coastal hazard scenario model.

3.2.2 Roads Impact Analysis

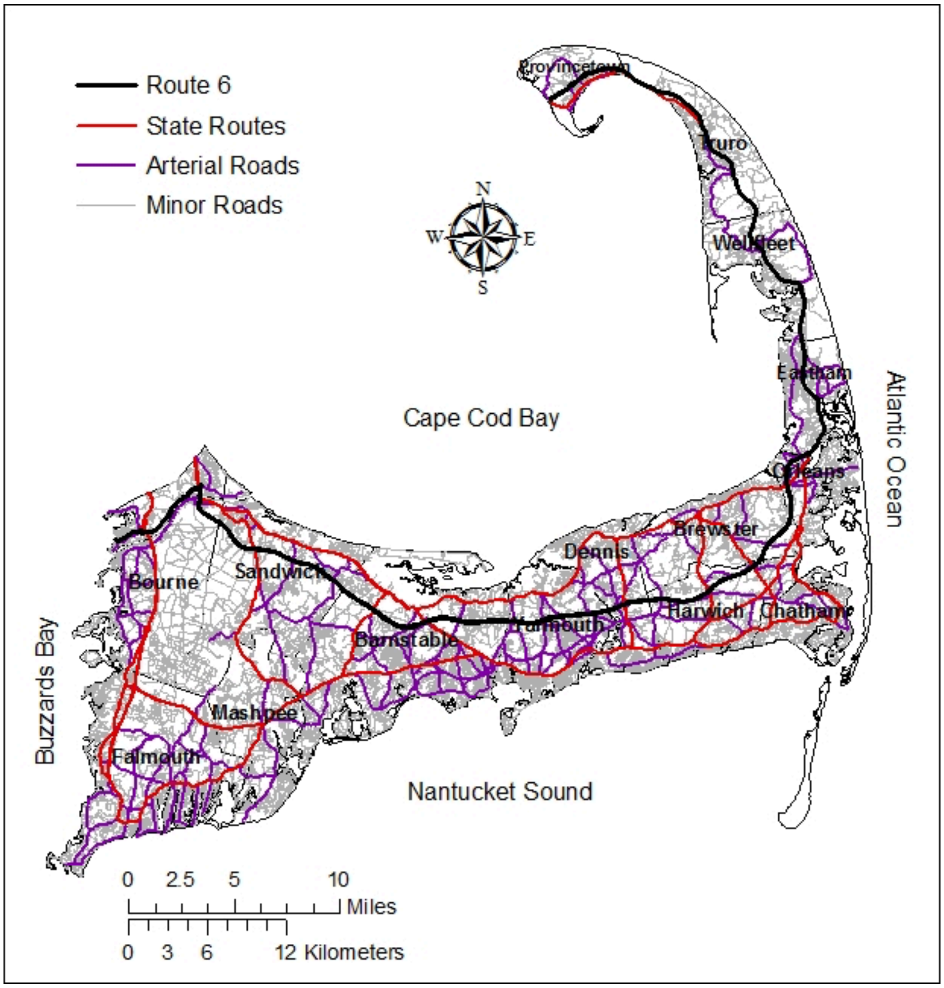

Figure 3. 3. Map illustrating Cape Cod's roadway system

Four main classes of roads on Cape Cod were examined (Figure 3.3). Determining the impacts of the coastal hazard models on these roads (Figure 3.4) required the analysis be conducted in two stages. First, since the roads data are in a vector format each of the seven coastal hazard models were converted from their raster format to vectors. Second, I conducted an overlay analysis of the coastal hazard vector models and the road vector data to identify which roads, by class, (Table 3.4) were flooded. Once the coastal hazard vector models were applied to the roads, I used the ArcGIS summary statistics function to calculate, by town, the total road length and road length inundated for each class of roads. To calculate percent of roads affected I first took the total road length inundated for each class in a particular town and subtracted it from the total road length for each class in that town. This produced a new total road length value based on inundation. Then I applied the percent change formula (See Footnote 9). I subtracted the original total road length (pre-inundation) from the new total road length (post-inundation), divided by the original total road length, and then multiplied by 100. This process was repeated for all 15 towns a total of six times to assess the impacts for each of the hurricane storm surge hazard models. Impacts from SLR were not assessed because it is a chronic hazard whereas hurricanes are acute so identifying primary roadways impacted is more critical for hazard mitigation planning.

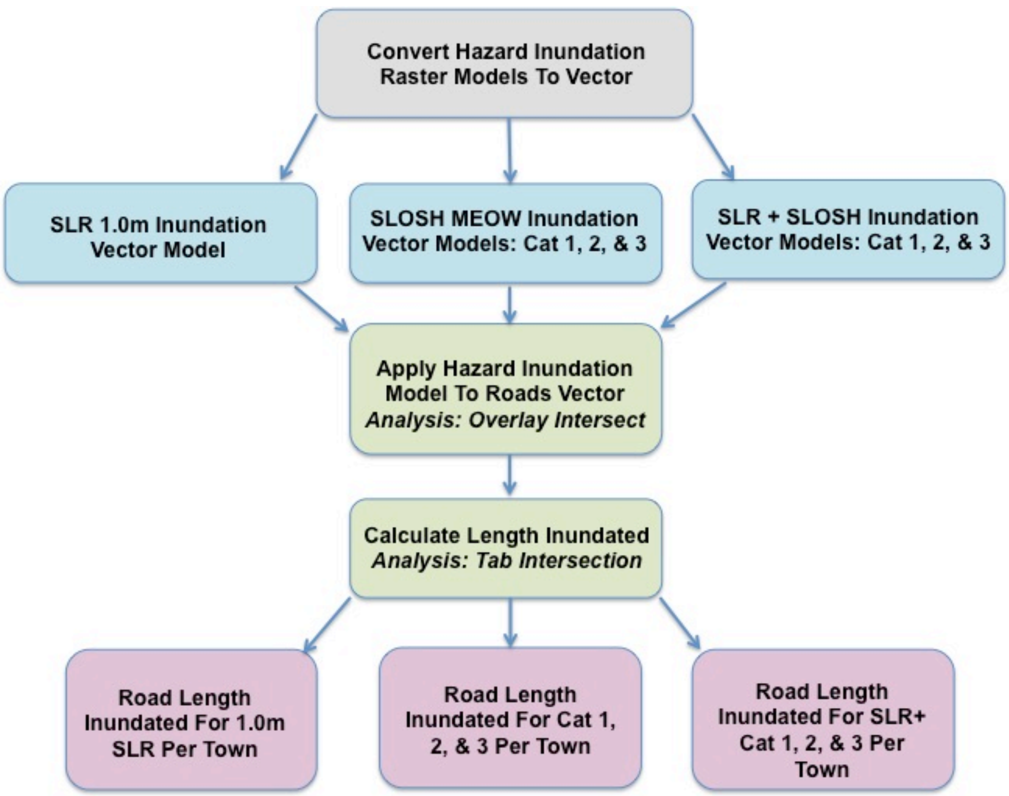

Figure 3. 4. Roads analysis of inundation from a) SLR, b) hurricane storm surge, and c) SLR expanded hurricane storm surge

3.2.3 Assessors' Tax Parcels Impact Analysis

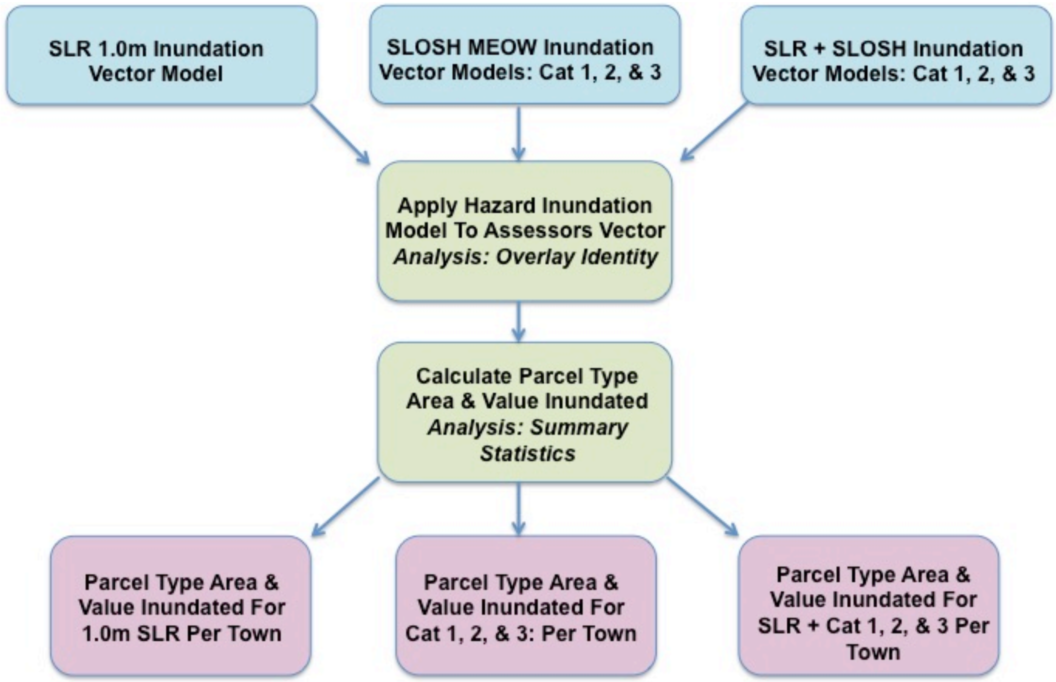

Figure 3. 5. Assessors analysis of inundation from a) SLR, b) hurricane storm surge, and c) SLR expanded hurricane storm surge

The analysis used to determine the impacts of the coastal hazard scenario models on assessors' tax parcels (i.e., housing and tourism) on Cape Cod (Figure 3.5), was similar to that used for the roads. Since the assessors' tax parcels data are in a vector format the vector converted coastal hazard models from the roads analysis were used. An identity overlay analysis of the coastal hazard vector models and the assessors' data was employed to differentiate between inundated and non-inundated tax parcels. Once the coastal hazard vector models were applied to the assessors' data, the ArcGIS summary statistics function was used to calculate, by town, the total land area and land area loss (i.e., from inundation) for both parcel types (i.e., housing and tourism). To calculate percent of housing and tourism land area affected, I took the area inundated for each parcel type in a particular town and subtracted it from the total area for each parcel type in that town. This produced a new total parcel type area value based on inundation. Then I applied the percent change formula (See Footnote 9). I subtracted the original total parcel type area (pre-inundation) from the new total parcel type area (post-inundation), divided by the original total parcel type area, and then multiplied by 100. The ArcGIS summary statistics function was also used to calculate, by town, the total housing and tourism values (pre-inundation) as well as the potential monetary damages (post-inundation) for each parcel type. Both of these processes were repeated for each Cape Cod town seven times to assess the impacts for each of the seven coastal hazard scenarios models.

These analyses produced models of how different scenarios of SLR, hurricane storm surges, and SLR + hurricane storm surge combinations impact the existing biophysical conditions on Cape Cod. Taken together, the effects to natural and built infrastructure via analyses of LULC, roads, and assessors' tax parcels calculated from exposures to these climate-related coastal hazards were used to identify towns with the highest biophysical vulnerabilities.

3.3 Results of Impact Analyses

This section presents the results of impact assessments to the natural and built infrastructure, at regional (i.e., county) and community (i.e., town) scales, from a suite of plausible chronic and acute climate-related coastal hazard scenario models. First, results from the seven hazard scenario models are presented to delineate the inundation zones and patterns. Second, I examined the spatial variations in hazard exposure at the community (i.e., town) scale using the differences in impacts to LULC natural and built infrastructure, based on the percentage of area inundated. Third, I identified the primary roadways impacted based on the percentage (by length) of inundation. Lastly, I assessed communities' housing and tourism vulnerabilities using the impacts to assessors' tax parcel types measured as the percentage of parcel type area inundated as well as the potential economic loss from inundation of housing and tourism facilities.

3.3.1 Hazard Inundation Zones

The seven hazard scenarios demonstrating SLR, hurricane storm surge, and SLR expanded hurricane storm surges are illustrated in Figures 3.6-3.10. While a SLR of 1.0m is an upper bound prediction for 2100 (Church et al., 2013; Grinsted et al., 2009; Parris et al., 2012; Rahmstorf, 2007; Vermeer & Rahmstorf, 2009), the extent of inundation is minimal compared to even the lowest intensity hurricane storm surge scenario (Figures 3.6-3.7). The hurricane storm surge scenarios represent acute climate-related coastal hazards and, by far, have the greatest inundation impacts on Cape Cod (Figures 3.7-3.10). The straightforward hurricane storm surges (Figure 3.7) clearly affect the majority of the Cape coastline to some degree. In particular, some areas experience greater amounts of inundation including the southwestern (e.g., Falmouth), middle southern shores facing the Nantucket Sound (e.g., Yarmouth and Dennis) as well as the northwestern area that “hooks” into Cape Cod Bay (e.g., Provincetown and Truro). The SLR expanded hurricane storm surge scenarios illustrate how chronic (i.e., sea level rise) and acute (i.e., hurricane storm surge) coastal hazards interact to increase the extent of hurricane storm surge inundation zones (Figures 3.8-3.10).

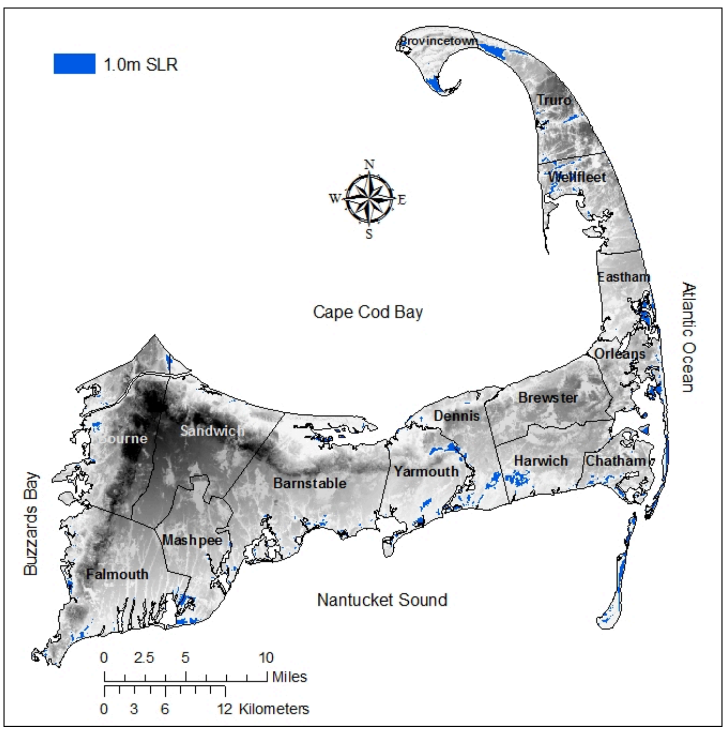

Figure 3. 6. Map illustrating 1.0m SLR inundation

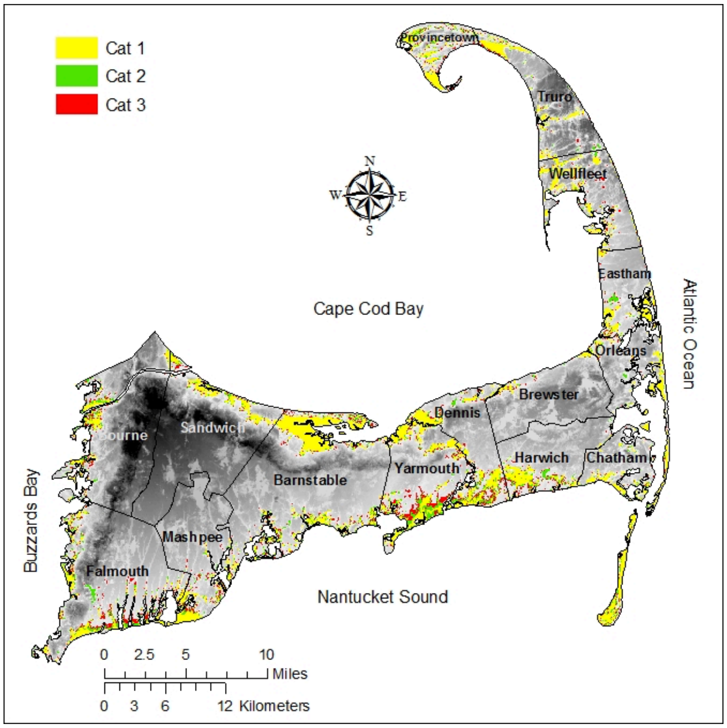

Figure 3. 7. Map illustrating Category 1, 2, and 3 hurricane inundations

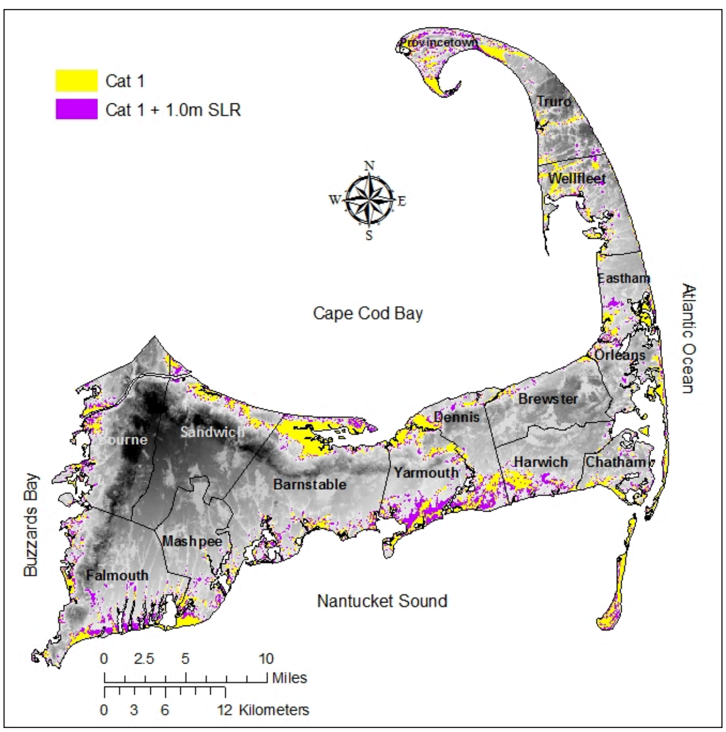

Figure 3. 8. Map illustrating Cat 1 hurricane and SLR expanded Cat 1 hurricane inundations

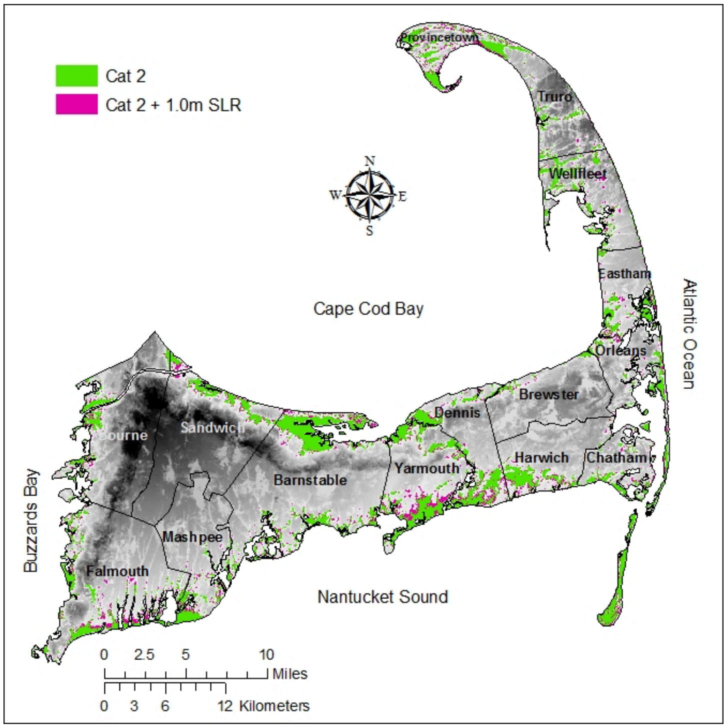

Figure 3. 9. Map illustrating Cat 2 hurricane and SLR expanded Cat 2 hurricane inundations

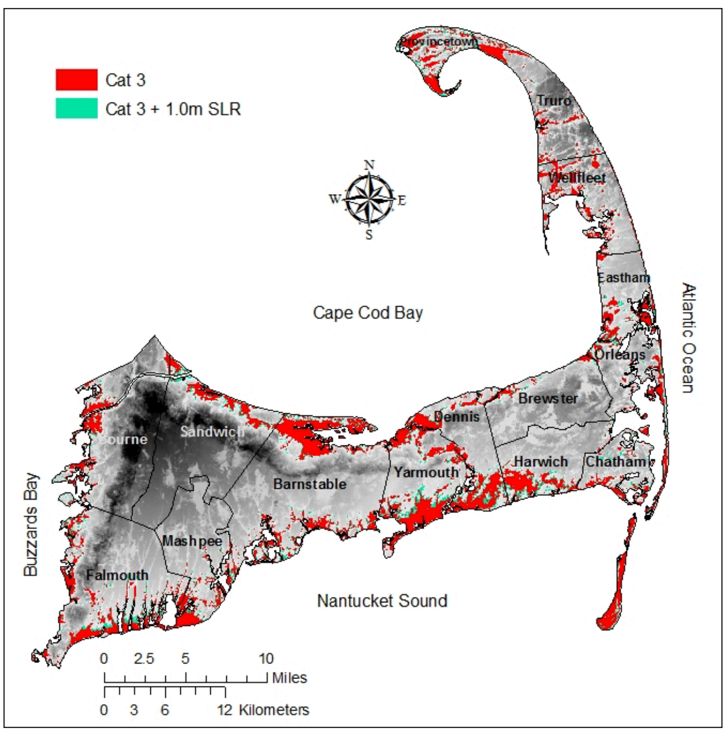

Figure 3. 10. Map illustrating Cat 3 hurricane and SLR expanded Cat 3 hurricane inundations

Barnstable County (i.e., Cape Cod) is comprised of 15 towns that are clustered into four sub-regions: Upper, Mid, Lower, and Outer Cape (Figure 1.1). While Figures 3.6-3.10 illustrate, countywide, the extents of inundation from climate-related coastal hazards, their impacts can vary considerably depending on the spatial scale (i.e., local versus regional) and the types of biophysical conditions (i.e., natural and built infrastructure) affected. Therefore, the differences in impacts to land use and land cover (LULC), roadways, and assessors' tax parcels at the community scale are examined in order to capture spatial variations in hazard exposure.

3.3.2 LULC Impact Analysis: Natural and Built Infrastructure

To account for the spatial variation of climate-related coastal hazards, it is best to analyze impacts at the community scale (e.g., individual towns). The variation in inundation not only occurs between towns but also between the types of land area. In this subsection, the impacts to natural (i.e., land cover) and built (i.e., land use/developed land) infrastructure are examined in order to determine the biophysical vulnerabilities of Cape Cod towns to climate-related coastal hazards.

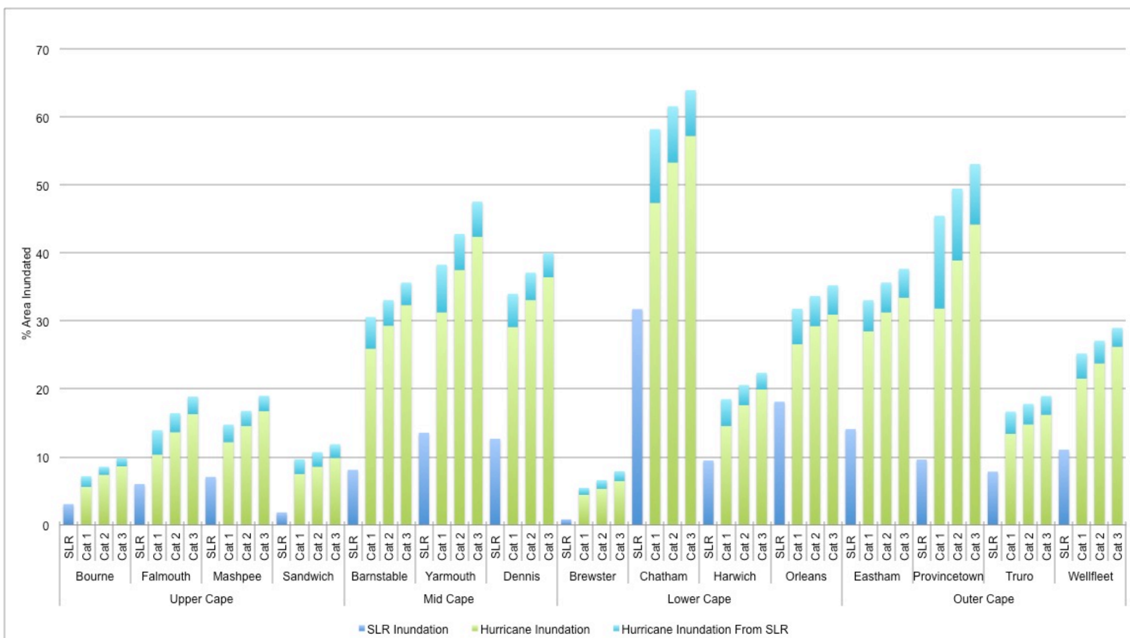

Figure 3. 11. Percent natural infrastructure (i.e., area) affected by a) SLR, b) hurricane inundation, and c) hurricane inundation from SLR

As expected, SLR, overall, causes the least amount of inundation to LULC compared to hurricane storm surges. SLR does, however, have significantly greater affect on the natural infrastructure (Figure 3.11) compared to built (Figure 3.12). Notably, in the Lower Cape, the town of Chatham experiences the largest amount of inundation due to SLR anywhere on Cape with 32% of its natural infrastructure lost (Figure 3.11). In contrast, Truro of the Outer Cape has the greatest inundation of built infrastructure from SLR at 4% (Figure 3.12). The large differences between natural and built infrastructure inundation from SLR indicates the extent to which natural land types dominate the coastline and, therefore, are most susceptible to the incremental rise of sea levels. This is an important finding for long-term hazard mitigation planning because these natural amenities are an important attraction for tourism, the loss of which could have serious economic consequences for Cape Cod towns.

Storm surge from hurricanes causes, by far, the greatest inundation to Cape Cod’s natural and built infrastructure with the addition of SLR moderately expanding hurricane inundation depending on the town. In terms of straightforward hurricanes, Chatham experiences the greatest impacts to its natural infrastructure at 47-57% inundated depending on hurricane intensity (Figure 3.11). Provincetown of the Outer Cape and Yarmouth of the Mid Cape face the second greatest impacts with up to 44% of Provincetown’s natural infrastructure inundated while Yarmouth experiences slightly less flooding at 42 % (Figure 3.11). Such similarities in inundation values indicate that that the natural infrastructure of these towns are located at similar elevations and comparably distributed along the coastline. Furthermore, these natural resources are on the “front-lines” of exposure to coastal hazards taking the brunt of storm surge and protecting the built infrastructure. Therefore, maintaining the health and function of these natural features could be critical both in terms of reducing inundation of built areas by serving as a buffer absorbing storm surges as well as improving the long-term sustainability of these resources for tourism.

Similar to the effects of SLR, overall, the impacts to built infrastructure from straightforward hurricanes are considerably less than those to natural with three towns clearly facing the greatest impacts. Provincetown experiences the greatest impacts with a maximum of 32% of its built infrastructure inundated. Dennis and Yarmouth of the Mid Cape are neighbors that experience the second greatest degree of inundation (9-26%) of its built infrastructure (Figure 3.12). There is a clustering of similar built infrastructure inundation values occurring in other sub-regions including the Upper Cape, between Bourne and Falmouth, and in the Outer Cape between Truro and Wellfleet (Figure 3.12). It is likely that these towns' built up areas were developed similarly across the coast and at comparable elevations resulting in higher degrees of biophysical vulnerability to straightforward hurricane storm surges.

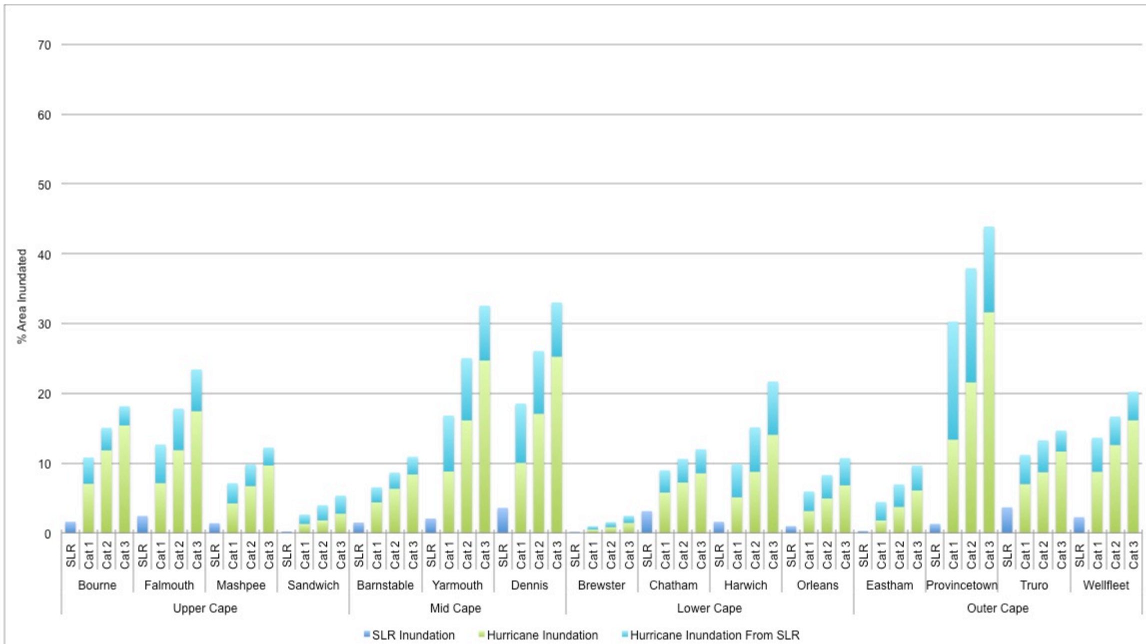

Figure 3. 12. Percent of built infrastructure (i.e., area) affected by a) SLR, b) hurricane inundation, and c) hurricane inundation from SLR

The effect of SLR on the extent of hurricane inundation differs between natural and built infrastructure both in terms of magnitude and relative increase from straightforward hurricanes. Overall, SLR has less effect on extending hurricane inundation of natural infrastructure compared to the built-infrastructure indicating that the majority of natural infrastructure is located in low-lying areas already inundated during straightforward hurricanes. Furthermore, the expansion of hurricane storm surge from the addition of SLR clearly increases the exposure of built areas to inundation, which will be an important consideration for long-term hazard mitigation planning. Provincetown experiences the greatest increase in hurricane flooding of its built infrastructure from the addition of SLR (Figure 3.12). In addition, SLR increases the inundation of Provincetown's built infrastructure during a Category 1, 2, and 3 by 56%, 43%, and 28%, respectively flooding 30-44% of the town's built areas. Similarly, Yarmouth and Dennis experience the second greatest amount of hurricane flooding attributable to SLR for built infrastructure (Figure 3.12) with a 46% increase in inundation for a Category 1, 35% for a Category 2, and 24% for a Category 3, thereby, exposing 18-32% of these towns' built areas to flooding. While impacts to built infrastructure from SLR expanded hurricane storm surges are greater than those to natural infrastructure, there is also a proportional relationship between the amount of SLR expanded hurricane storm surge and straightforward hurricane storm surge. Notably, the amount of hurricane inundation attributable to SLR decreases as hurricane intensity increases. For hazard mitigation planning, this means that SLR has the greatest effect on expanding storm surge for a Category 1 hurricane. This result is important for planners and decision-makers because it illustrates how SLR could magnify the impacts to natural and built infrastructure from a low-intensity hurricane making it similar to the effects of a higher-intensity hurricane.

3.3.3 Roadway Impact Analysis: Route 6, State, Arterial, & Minor

In addition to understanding the differences in impacts to natural and built land areas from climate-related coastal hazards, it is also important to examine the impacts to roadways, another type of built infrastructure. Hurricanes are acute climate-related coastal hazards in that they inundate an area quickly. To be effective, both hazard mitigation and emergency management planning must be able to identify the primary roadways that could be affected by rapid onset flooding. In this subsection, measured as percent of road length inundated, impacts to roadways are organized by class: U.S. Route (a.k.a. Route 6), State Routes (e.g., Routes 28 and 6A), Arterial Roads, and Minor Roads (Figure 3.3).

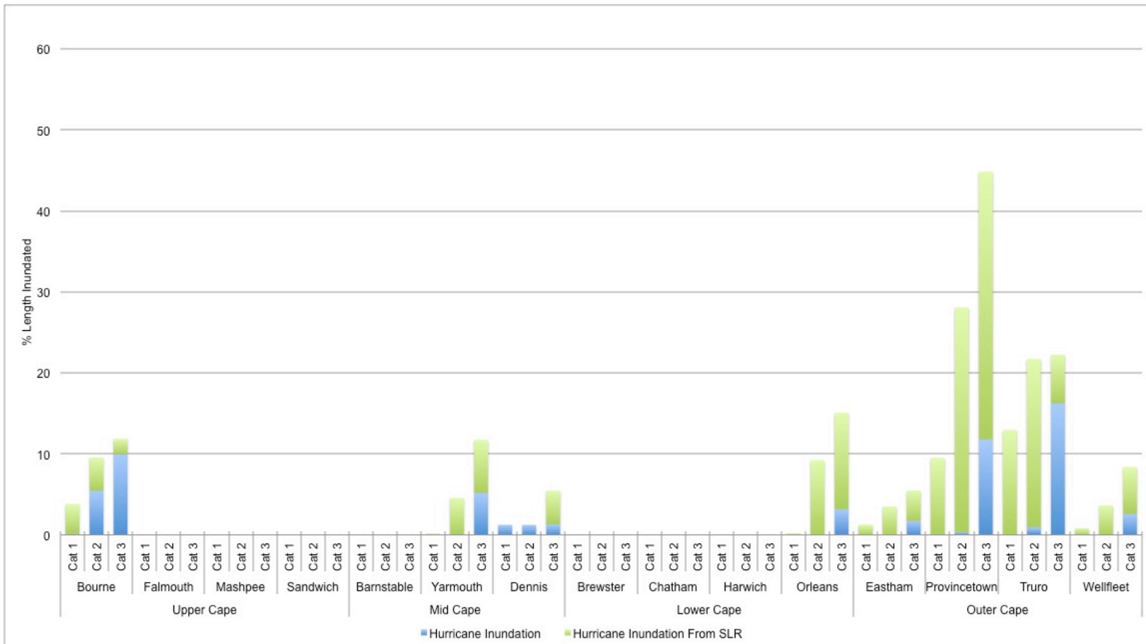

Figure 3. 13. Percent of Route 6 (i.e., length) affected by a) hurricane inundation and b) hurricane inundation from SLR

Route 6 is the primary U.S. highway for Barnstable County, which runs the length of the entire Cape from Bourne to Provincetown. Geographically, it bisects the Cape's landscape and is located at higher elevations inland through the Upper, Mid, and Lower Cape but drops to low-lying areas closer to the coast in the Outer Cape (Figure 3.3). Clearly, the Outer Cape experiences the greatest inundation of Route 6 from both straightforward hurricane storm surges and from SLR expanded hurricane storm surges (Figure 3.13) with each of its towns facing some degree of inundation. This is expected given the road's route through low-lying areas and proximity to both Cape Cod Bay and Atlantic Ocean. In general, SLR noticeably increases hurricane inundation extents of roadways. For example, SLR increased Category 1 inundation in Truro by 100% flooding 13% of Route 6 and in Provincetown by 99% inundating 10% of Route 6. In many towns, Category 1 and 2 straightforward hurricanes do not inundate Route 6 (or it is negligible) whereas SLR expanded Category 1 and 2 hurricane storm surges do (Figure 3.13). This is an important finding for hazard mitigation and evacuation planning because it shows that, in the short-term, Route 6 is less vulnerable to inundation but in the long-term, with the addition of climate change, it will become more susceptible to flooding. Overall, Provincetown is especially vulnerable from SLR expanded Category 2 and 3 hurricanes, with 28% and 45% of Route 6 inundated, respectively. Truro experiences the second greatest amount of Route 6 inundation with 23% of this road flooded from a Category 2 and 22% from a Category 3. While the majority of Route 6 is less vulnerable to hurricane inundation that is not the case for the Outer Cape where these towns are likely to face greater evacuation and recovery challenges due to areas being cutoff from this major highway flooding.

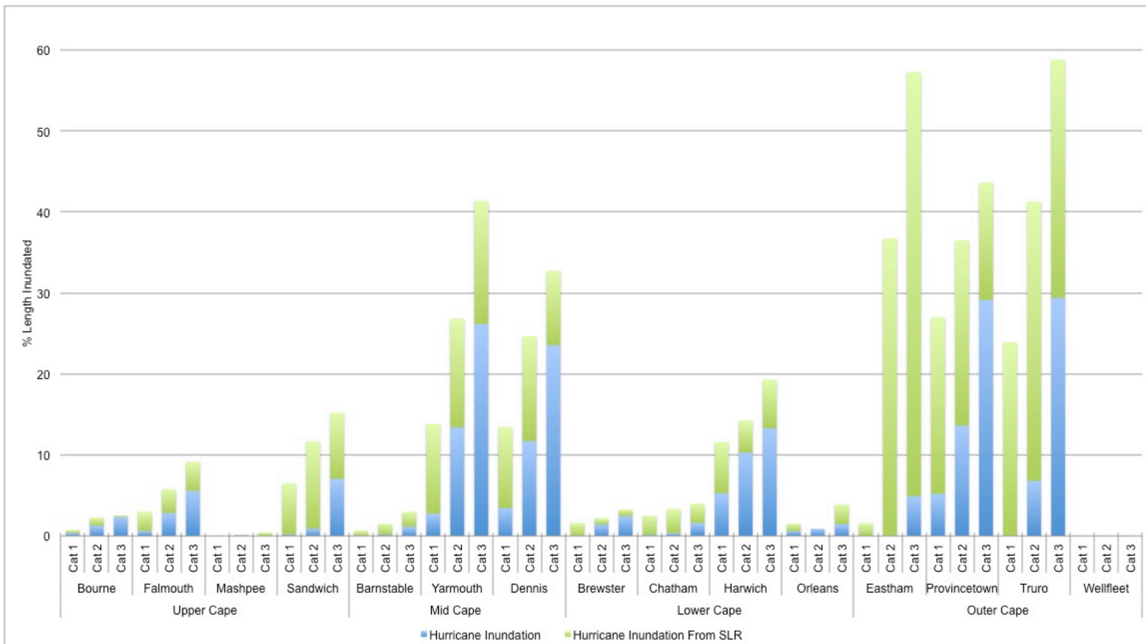

Figure 3. 14. Percent of state routes (i.e., length) affected by a) hurricane inundation and b) hurricane inundation from SLR

Unlike Route 6, many of the state routes are located in low-lying areas close to the coast (Figure 3.3). Consequently, these roads are more susceptible to straightforward hurricane storm surge inundation, which is important for short-term hazard mitigation and emergency management planning particularly since these are heavily traveled roads. This is especially evident in the Mid and Outer Cape (Figure 3.14). Yarmouth and Dennis (Mid Cape) experience similar amounts of hurricane inundation with Yarmouth flooded slightly more from SLR expanded hurricane storm surges. In general, compared to the Outer Cape, Yarmouth experiences the second greatest amount of exposure with 14-41% of state routes inundated from SLR expanded hurricane storm surge depending on hurricane intensity (Figure 3.14). Similar to the Route 6 results, the Outer Cape (i.e., Eastham, Provincetown, and Truro) also faces the greatest inundation to state routes from the effect of SLR on hurricane storm surges. Notably, in Eastham, SLR increased Category 2 hurricane storm surge inundation by 100% flooding 37% of state routes and by 91% for a Category 3 flooding 57% of these routes. Overall, Truro faces the greatest exposure with 24- 59% of state routes inundated from SLR expanded Categories 1- 3. As secondary highways, the inundation of state routes presents a serious threat to the safety of Cape Cod residents both in terms of evacuations and the ability of emergency managers to provide essential services and resources during recovery.

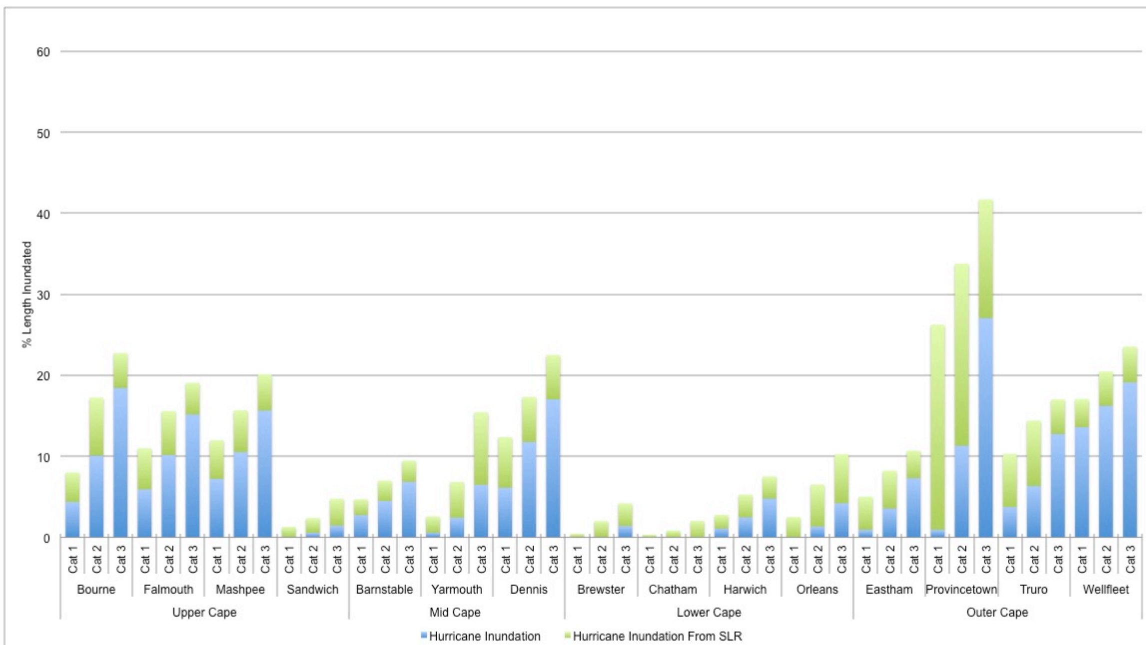

Figure 3. 15. Percent of arterial roads (i.e., length) affected by a) hurricane inundation and b) hurricane inundation from SLR

Similar to the state routes, the arterial roads also run through low-lying areas close to the coast as well as extending inland, thereby connecting areas on the Cape Cod Bay side with those on the Nantucket Sound side (Figure 3.3). Depending on hurricane intensity, storm surges inundate 10-24% of arterial roads in towns of the Upper (e.g., Bourne, Falmouth, Mashpee), Mid (e.g., Dennis), and Lower Cape (e.g., Orleans) (Figure 3.15). Once again, the greatest hurricane inundation of roadways occurs in the Outer Cape. Wellfleet has the greatest flooding from straightforward hurricane storm surges with 14%-19% of arterial roads inundated depending on hurricane intensity (Figure 3.15). Consistent with the other results, SLR noticeably increases hurricane storm surge flooding of arterial roads. Overall, Provincetown experiences the greatest arterial road flooding where SLR increases Category 1, 2, and 3 inundations by 97%, 67%, and 35%, thereby, flooding 26%, 34%, and 42% of these roads, respectively (Figure 3.15). As important connectors within and between towns, the flooding of arterial roads can be disruptive to hazard recovery as more communities could be temporarily disconnected from each other and from Route 6 and the state routes.

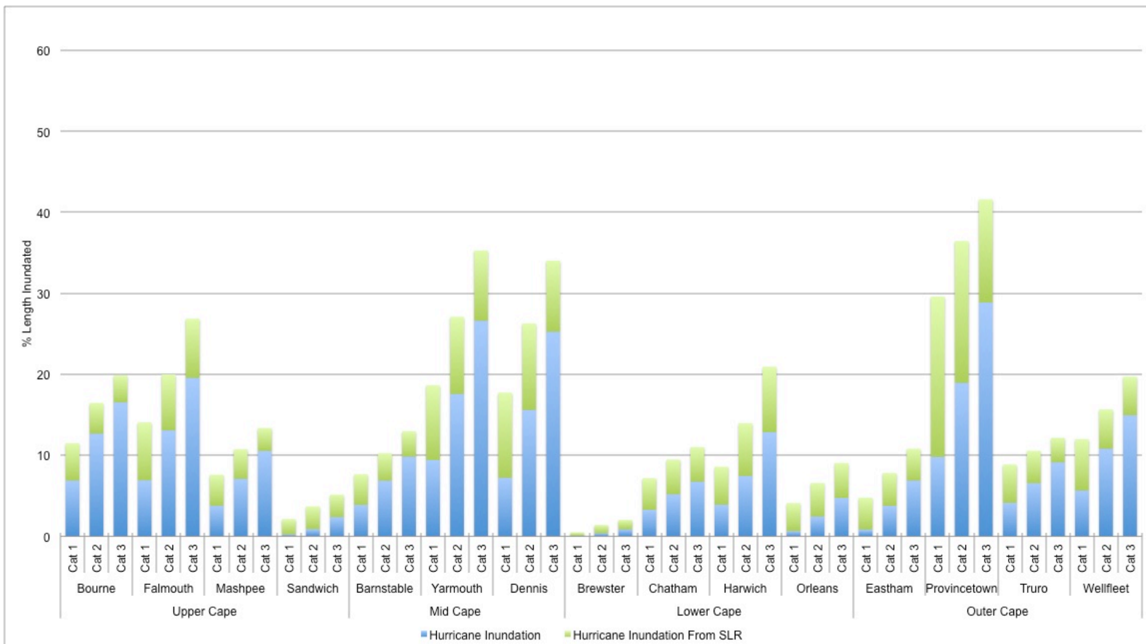

Figure 3. 16. Percent of minor roads (i.e., length) affected by a) hurricane inundation and b) hurricane inundation from SLR

The impacts to minor roads from hurricane inundation cannot be underestimated since these roads account for the majority of the miles of the roadway system on Cape Cod and traverse both inland and low-lying coastal areas (Figure 3.3). Compared to arterial, more minor roads are inundated from hurricane storm surge across the Upper (i.e., Bourne and Falmouth), Mid (i.e., Yarmouth and Dennis), Lower (i.e., Harwich), and Outer Cape (i.e., Provincetown and Wellfleet) with maximum inundations from 10-42% (Figure 3.16). Yarmouth, Dennis, and Provincetown face similar and the greatest degrees of minor road inundation with 8-29% of these roads flooded from straightforward hurricane storm surges (Figure 3.16). Overall, Provincetown experiences the greatest impacts (followed by Yarmouth and Dennis) with 30-40% of its minor roads flooded from SLR expanded hurricane storm surge (Figure 3.16). Clearly, out of all the sub-regions, the Outer Cape is the most biophysically vulnerable with towns experiencing higher degrees of flooding for all roadway classes and, thus, facing particularly challenging conditions that hazard mitigation planners and emergency managers will need to address.

3.3.4 Assessors' Tax Parcel Impact Analysis: Housing and Tourism Infrastructure

In addition to LULC and roadways, built infrastructure is also examined in terms of its economic value. Specifically, assessors' tax parcels were selected that represented two major industries: housing (i.e., residential real estate) and tourism (i.e., supporting businesses and infrastructure). To capture spatial variations and identify the towns with the greatest disruptions to its housing and tourism infrastructure, the impacts from climate-related coastal hazards were measured, as 1) percent parcel type area inundated and 2) parcel type value ($) affected by inundation.

Of all the climate-related coastal hazards, SLR has the least impact on both the housing and tourism infrastructure, which is consistent with the minimal impacts to LULC, built areas, and roadways. This indicates that most built infrastructure is not directly on the coastline, unlike natural infrastructure, where the incremental effects of SLR would be experienced directly. Orleans (Lower Cape) has the greatest amount of housing inundation (6%) attributable to SLR (Figure 3.17). In contrast, the impact to tourism infrastructure is slightly higher with the greatest effect occurring in Wellfleet where 8% of the inundation is solely from SLR (Figure 3.18). In Orleans, however, SLR had negligible impacts (<1%) on tourism infrastructure, which is indicative of the spatial variation in hazard impacts both within and between towns. Considering the long-term term trajectory of chronic coastal hazards, communities have the time to make changes to their housing and tourism facilities through proactive mitigation efforts, thereby, circumventing the potential effects of SLR on these types of built infrastructure before they are realized.

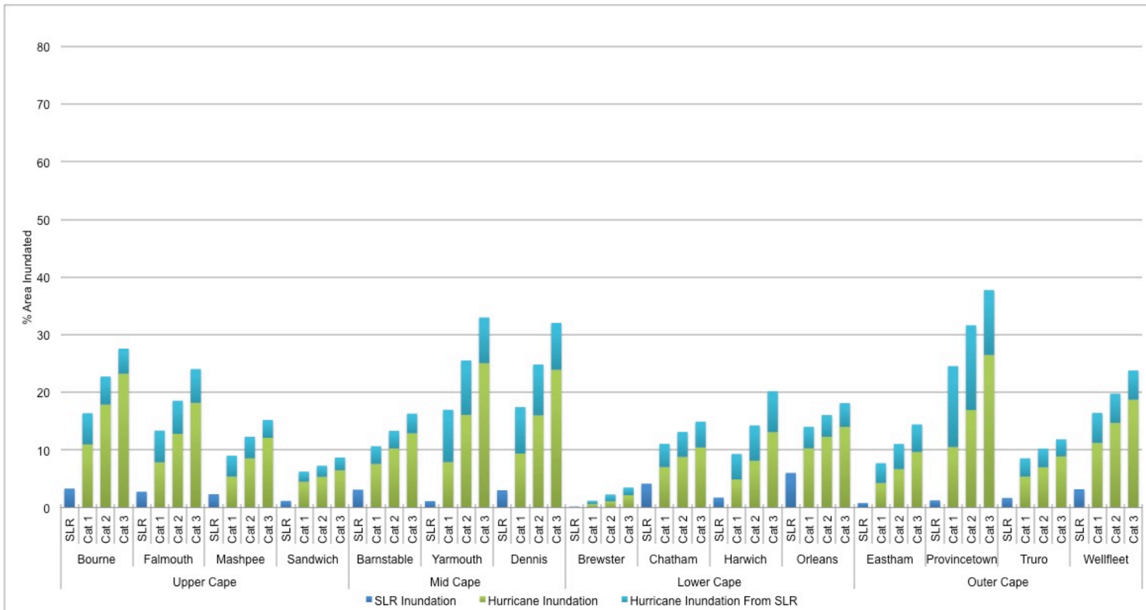

Figure 3. 17. Percent of housing infrastructure (i.e., parcel type area) affected by a) SLR, b) hurricane inundation, and c) hurricane inundation from SLR

Consistent with the LULC and roadways analyses, hurricane storm surge causes the greatest amount of inundation to housing and tourism with SLR considerably expanding the extent of hurricane inundation for tourism facilities. In terms of straightforward hurricane inundation, Provincetown of the Outer Cape experiences the greatest exposure with 11- 27% of its housing flooded depending on hurricane intensity (Figure 3.17). Yarmouth and Dennis of the Mid Cape and Bourne from the Upper Cape experience slightly less impacts to their housing infrastructure than Provincetown but have very similar degrees of inundation to one another (Figure 3.17). Notably, Yarmouth, Dennis, and Bourne experience up to 25%, 23%, and 23%, of their housing infrastructure inundated, respectively. More than likely these towns' residential areas developed similarly along the coast and at comparable elevations resulting in higher degrees of biophysical vulnerability to straightforward hurricane flooding. The impacts to tourism amenities from straightforward hurricanes are considerably greater compared to housing (Figure 3.18), indicating that this type of infrastructure is located in more low-lying areas closer to the coast. This is expected given that these facilities support tourism, which is based on the use of natural infrastructure (e.g., marshes, beaches, etc.) that is directly along the coast. Specifically, Yarmouth and Dennis of the Mid Cape face the greatest impacts with a Category 2 and 3 hurricane flooding 27-46% of their tourism infrastructure (Figure 3.18). Similarly, Provincetown of the Outer Cape faces variation in inundation depending on hurricane intensity with 6%-36% of tourism infrastructure affected, which is likely a function of the pattern of tourism development within these towns.

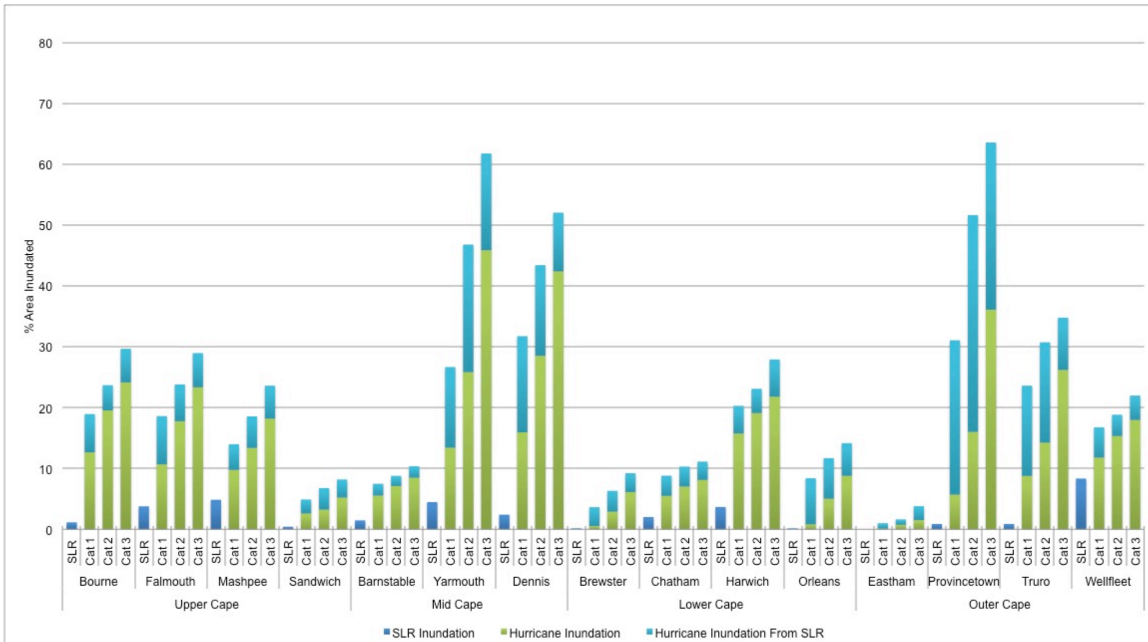

Figure 3. 18. Percent of tourism infrastructure (i.e., parcel type area) affected by a) SLR, b) hurricane inundation, and c) hurricane inundation from SLR

The effect of SLR on the extent of hurricane inundation impacts certain types of infrastructure more than others and follows a similar pattern to the LULC and roadways results. Overall, SLR considerably expands hurricane inundation of tourism infrastructure compared to housing (Figures 3.17-3.18). This has long-term economic implications in terms of tourism facilities being more biophysically vulnerable to climate-related coastal hazards and, therefore, more susceptible to damage. In particular, Provincetown of the Outer Cape experiences the greatest increase in hurricane inundation of tourism infrastructure followed by Yarmouth of the

Mid Cape. SLR increases inundation during a Category 1 by 82%, flooding 31% of Provincetown's tourism facilities. Similarly, Yarmouth experiences a 50% increase in inundation during a Category 1, which floods 27% of its facilities (Figure 3.18). Due to the effects of SLR, Provincetown, Yarmouth, and Dennis experience the greatest overall inundation of their housing, at 17-38% flooded, and their tourism facilities, at 27-64% flooded, depending on hurricane intensity (Figures 3.17-3.18). Lastly, the amount of hurricane inundation attributable to SLR decreases as hurricane intensity increases for both housing and tourism infrastructure (Figures 3.17-3.18), which is consistent with the results of the LULC analysis. Again, these results are important for hazard mitigation planning because the influence of SLR is greatest on a low-intensity hurricane (i.e., Category 1), making impacts similar to higher-intensity hurricanes (i.e., Category 2 and 3).

In addition to examining the degree of housing and tourism infrastructure inundation across Cape Cod towns, it is also necessary to look at the broader economic ramifications of climate-related coastal hazards. In general, housing infrastructure losses result in more economic damage (billions of dollars) compared to tourism amenities (millions of dollars) (Figures 3.19-3.20). This difference is likely because Cape Cod has a large housing market that is driven by high property values, which are fueled by constant competition to live in coastal areas. Falmouth (Upper Cape) experiences the greatest housing value losses at $4-5 billion from hurricane inundation followed by Barnstable (Mid Cape) with $3-4.5 billion in losses (Figure 3.19). Substantial economic losses in these towns are not only due to hurricane inundation, though that is the dominant cause, but also from SLR. For example, Barnstable experiences the greatest housing value loss from SLR at just about $2.75 billion. Interestingly, the farther down Cape (towards Lower and Outer sub-regions) the less monetary losses for housing infrastructure (Figure 3.19) likely because the Lower and Outer Cape are less densely populated with different property values.

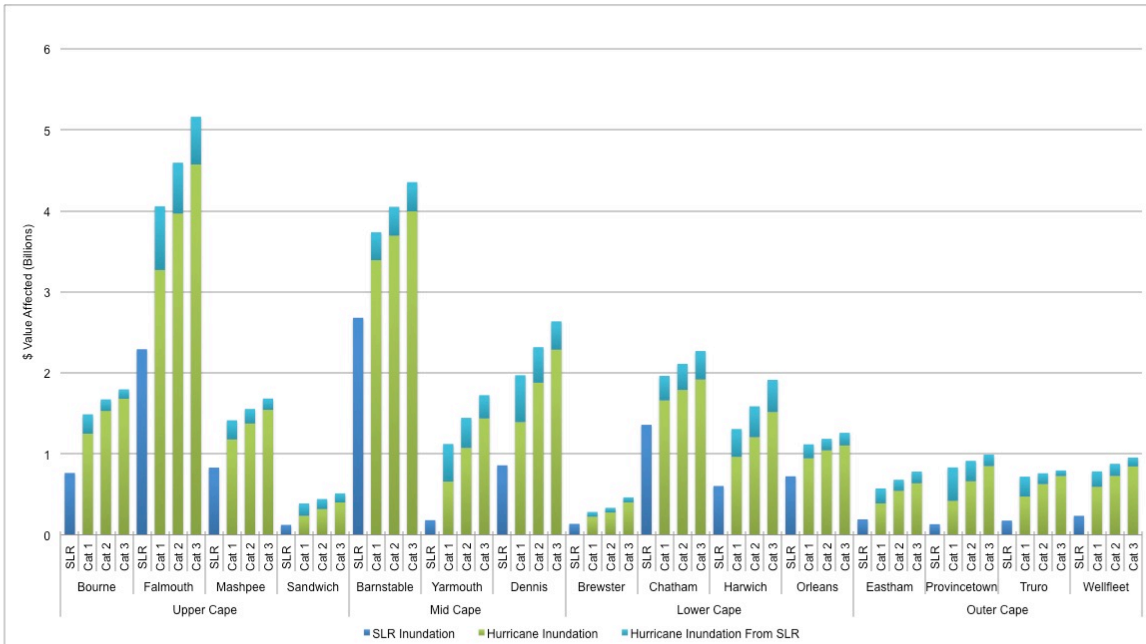

Figure 3. 19. Monetary losses associated with housing infrastructure (i.e., $ value) affected by a) SLR, b) hurricane inundation, and c) hurricane inundation from SLR

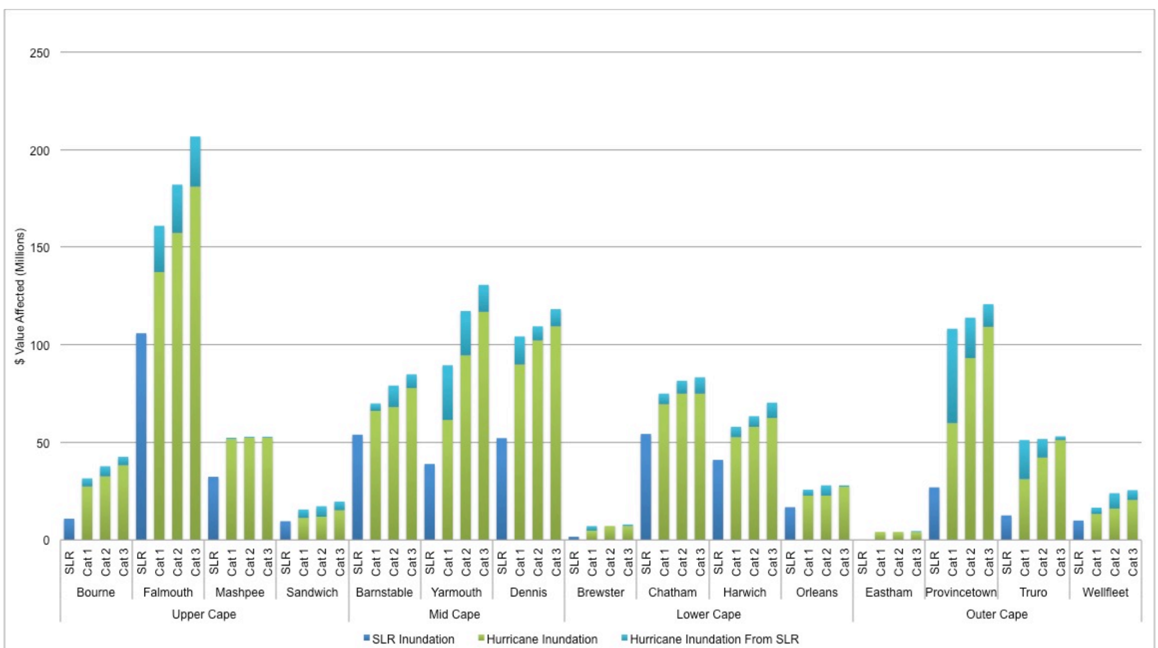

Figure 3. 20. Monetary losses associated with tourism infrastructure (i.e., $ value) affected by a) SLR, b) hurricane inundation, and c) hurricane inundation from SLR

Even though monetary losses of tourism infrastructure are less than housing it is likely that these effects will be felt more directly in those Cape communities with the highest economic dependency on tourism. Notably, the Upper, Mid, and Outer Cape has at least one town that experiences >$100 million in tourism losses from hurricane inundation (Figure 3.20). In this case, Falmouth, Yarmouth, Dennis, and Provincetown clearly suffer the greatest monetary losses indicating that tourism likely plays an important role in their tax base and, subsequently, are particularly vulnerable to disruptions from coastal hazards. Furthermore, SLR causes towns in the Upper, Mid, and Lower Cape to face >$50 million in tourism losses, which is a considerable amount of money that planners and decision-makers need to take into account when prioritizing short-term versus long-term interests.

In terms of the economic ramifications associated with extent of housing and tourism infrastructure inundated (Figures 3.17-3.18), it is important to note that the greatest inundation from climate-related coastal hazards does not necessarily coincide with the highest monetary impacts. For example, while Provincetown may have the greatest inundation of both housing and tourism infrastructure (Figures 3.17-3.18), Falmouth experiences the greatest economic impact with >$4 billion in housing and >$150 million in tourism losses (Figures 3.19-3.20). In other words, while a town may experience extensive inundation of its housing and tourism infrastructure that does not necessarily mean they also lose the greatest amount of money. This is likely a factor of property density and values, which vary across towns. This is an important finding for towns to consider in their hazard mitigation planning because they do not have to have extensive inundation to also face serious economic disruptions. In general, Barnstable County is likely to experience considerable economic impacts from climate-related coastal hazards, which will be directly felt by its small coastal towns.

This chapter uses a combination of GIS and modeling to assess the biophysical vulnerability and impacts to natural and built infrastructure (i.e., LULC, roadways, and assessors' parcels) on Cape Cod from climate-related coastal hazards. The results from these analyses indicate that Cape Cod faces considerable vulnerabilities to coastal hazards. These biophysical vulnerabilities are town-specific with the degree of inundation varying based on the type of infrastructure (i.e., LULC, roadways, assessors' parcels). The larger contribution of this chapter's assessment and impact analyses is its explicit integration of climate change projections, (e.g., sea level rise, hurricane storm surge, and their combinations) into hazard inundation scenario models. These analyses demonstrate the potential interactions between climate change, coastal hazards, and communities' biophysical conditions at the local-scale. While understanding biophysical vulnerabilities is an important component of this research, it is also necessary to assess communities' social vulnerabilities, which influences their capacities to respond to and recover from hazards.

CHAPTER 4

SOCIAL VULNERABILITY ASSESSMENT

Chapter 3 described the biophysical vulnerabilities of Cape Cod to climate-related coastal hazards as well as the spatial variability of impacts across towns and sub-regions. The purpose of this component of the case study is to move beyond the biophysical conditions to examine the social and economic context that influence communities' abilities to respond to and cope with coastal hazards.

4.1 Methods: Socio-Economic Vulnerability Indicators

4.1.1 Data, Indicators, & Relationships to Vulnerability

Data from the U.S. Census Bureau's 2013 American Community Survey and NOAA's Marine Recreational Information Program (MRIP) was compiled for each of the 223 communities in coastal counties of Massachusetts and Rhode Island. In this case, coastal counties are defined as those with a connection to the ocean through a coastline. This criterion was chosen because these communities are more likely to have similar economies and face comparable vulnerabilities given similarities in coastal hazard exposure and the natural amenities that make coastal living attractive. Within coastal counties, the Census Designated Place (CDP) was chosen to represent communities and was substituted with the Minor Civil Division (MCD) where a CDP did not exist. For this study, the CDP is the smallest, meaningful unit to represent coastal communities because even within a town there can be variations in vulnerabilities that I wanted to capture. Cape Cod (i.e., Barnstable County), the focus of this study, is comprised of a total of 42 communities (CDPs). However, this is not a sufficient sample size for a principal component analysis (Gorsuch, 1983; Comrey & Lee, 1992), nor does it provide enough variation in data to allow for the construction of a reliable index (Jacob et al., 2013). Therefore, the number of communities was expanded to include the broader region of coastal Massachusetts and Rhode Island.

One hundred and twenty-nine variables were selected (Appendix A) from these public data sources and used to create indices that illustrate degrees of vulnerability across social, gentrification, and tourism dimensions. The variables, modified from Jepson & Colburn (2013) and Colburn & Jepson (2012), have well known relationships to vulnerability and are discussed in Table 4.1. The social variables can be categorized into socioeconomic status, gender, race/ethnicity, age, home ownership, occupation, family structure, and education. All these reflect the conditions or features that can make it harder for people to cope with disruptions like those experienced due to coastal hazards.

Table 4.1

Indicator Variables Relationship To Vulnerability

Variable	**Relationship To Vulnerability**	**Citation**	**Data Source**
Socioeconomic Status (SES)	Degree of wealth is correlated to ability to absorb and recover from losses. People of lower SES have less access to coping resources (e.g. insurance, political connections, etc.).	Cutter et al. (2003); Wisner et al. (2004); Fothergill & Peek (2004); Clark et al. (1998); Bolin & Stanford (1991)	U.S. Census Bureau
Gender	Women and single-mothers are less able to cope with losses and recover due to usually having lower incomes, caregiving responsibilities, and confinement to certain sectors of employment.	Cutter et al. (2003); Fothergill et al. (1999); Enarson & Morrow (1998); Bianchi & Spain (1996)	U.S. Census Bureau
Race/Ethnicity	Minorities are less able to cope with losses and recover due to usually having lower incomes, language barriers, and confinement (through discrimination) to more hazardous areas. Whites tend to be more privileged.	Cutter et al. (2003); Pulido (2000); Bolin (1993); Bolin & Stanford (1998); Bianchi & Spain (1996); Clark et al. (1998); Fothergill et al. (1999)	U.S. Census Bureau
Age	The elderly and children are less able to cope with losses and recover due to their lack of physical, social, and economic resources (e.g. elderly have reduced/no income, children are not independent and require family support, etc.)	Cutter et al. (2003); Clark et al. (1998); Peacock et al. (1997); Enarson & Morrow (1998)	U.S. Census Bureau
Home Ownership	People who are transient or don't have the financial resources to own a home. Renters are less able to cope with losses and recover due to their lack of financial resources and information regarding hazards if transient.	Heinz Center (2000)	U.S. Census Bureau
Occupation	Those who are in service sector (e.g., tourism) or in natural resource extraction occupations tend to be less able to cope with losses and recover due to the nature of their jobs (e.g. retail relies on disposable incomes; fisheries depend on functioning harbors).	Heinz Center (2000); Hewitt (1997); Stedman et al. (2004)	U.S. Census Bureau
Family Structure	Large families and/or single-parent households are less able to cope with losses and recover due to their limited financial resources and caregiving responsibilities.	Wisner et al. (2004); Heinz Center (2000)	U.S. Census Bureau
Education	Is (usually) directly related to SES in which people with a lower education tend to have lower incomes with less social networks and adaptive capacities.	Heinz Center (2000)	U.S. Census Bureau
Retirees	Are drawn to areas rich in natural amenities and can displace local residents resulting in gentrification.	Nelson (2008); Nelson et al. (2010); Colburn & Jepson (2012)	U.S. Census Bureau
Housing Disruptions & Cost of Living	Shifts in housing tenure (e.g., rent to own), real estate prices (i.e., second homes), cost of living increases etc. excludes low-income groups and causes youth-out migration.	Mcleod (2008); Muller et al. (2004); Hamnett (1991); Colburn & Jepson (2012)	U.S. Census Bureau
Tourism Amenities & Labor Force	Infrastructure (e.g., second homes, rental properties, rec. facilities etc.) that supports tourism dependence resulting in a less diverse labor force and economy that is sensitive to disruptions.	Stedman et al. (2004); Colburn & Jepson (2012); Jepson & Colburn (2013)	U.S. Census Bureau

In addition to the more typical socio-economic indicators of vulnerability, coastal communities can experience shifts in their demographic and economic bases from gentrification creating new areas of vulnerability. Typically, gentrification has referred to a simultaneous socio-economic and physical process occurring in urban areas where working-class populations in the inner-city are being displaced by more affluent, upwardly mobile individuals as well as a physical rejuvenation of those areas (Glass, 1964). This case study focuses on the form of gentrification occurring in exurban and rural environments, which is driven by an in-migration of retirees who tend to rely on accumulated wealth (Nelson, 2008) and, due to more leisure time, are attracted to natural amenities and recreational opportunities (Nelson et al., 2010). Not only are retirees drawn to coastal areas for their amenities but tourists too resulting in tourism-related gentrification, which is marked by changes in social networks, traditional land uses, economic activities, and tax bases (Gosnell & Abrams, 2011; Lamarque, 2009). According to Clark et al. (2007), this form of gentrification can be distinguished from urban contexts due to the strong effects of recreation, tourism, and summer homes. Common indicators of this process include an associated increase in real estate prices from second homes (Mcleod, 2008; Muller et al., 2004), cost of living increases, and shifts in housing tenure from renting to owning (Hamnett, 1991) to the point where lower income groups are excluded and youth out-migration occurs (Clark et al., 2007; Jackson, 2007). The gentrification variables used in this study were modified from previous studies (Colburn & Jepson, 2012; Jepson & Colburn, 2013) and the indices were conceptualized based upon this literature.

As previously mentioned, Cape Cod is a prime tourism destination in New England due to its extensive natural amenities and recreational opportunities. These natural features are at high risk for damage from climate-related coastal hazards like sea level rise and hurricane storm surge (Chapter 3). In addition to the gentrification processes that are occurring there are also specific economic vulnerabilities related to tourism. Stedman et al. (2004) found that communities that do not have a diversified economy are more sensitive to economic fluctuations. I argue that the degree of tourism a community experiences is a significant factor influencing its degree of vulnerability to climate-related coastal hazards. While there have been studies that focus on natural resource extraction, dependency, and well-being (Parkins et al., 2003; Stedman et al., 2004) there does not appear to be any existing studies that have a tourism-dependence vulnerability index. Therefore, to fill this gap, I created a set of indices capturing tourism dependence. The tourism dimension variables can be categorized as labor force economic structure, tourism amenities, and recreational fishing, some of which were modified from Jepson & Colburn (2013) and Colburn & Jepson (2012). All of the variables complied for the CDPs were then analyzed using a series of principal component analyses to determine which grouping of variables best measures each dimension (Figure 4.1).

4.1.2 Principal Component Analyses: The Construction of Indices

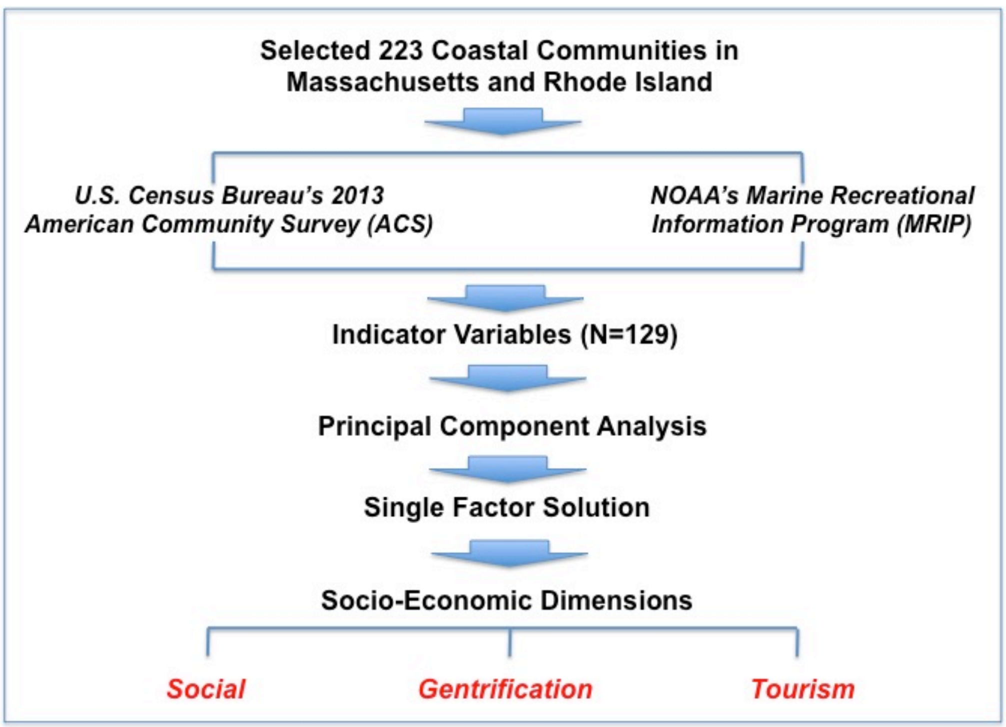

Figure 4. 1. Data collection and analysis of socio-economic indicators

Indices were constructed from the 129 variables collected to identify and analyze the differential vulnerability of coastal communities of Massachusetts (MA) and Rhode Island (RI) to climate-related hazards, across social, gentrification, and tourism dimensions (Figure 4.1). Factor analysis, a data reduction technique, was used to quantify the multivariate characteristics of MA and RI coastal communities. Factor analysis is a latent variable model that can relate a set of thematic variables (e.g., percent seasonal properties) to the latent structure of a conceptual variable (e.g., tourism) (Colburn & Jepson, 2012; Jepson & Colburn, 2013). In this study, the social, gentrification, and tourism dimensions are composites of several indices (e.g., poverty, cost of living, economic structure, and tourism amenities) that are used to represent community wellbeing and vulnerability to change. These indices were developed using principal component analysis (PCA), a common statistical data reduction technique that aggregates large data sets into manageable components based on inter-correlated variables (Yoon 2012).

Building upon the work of Jepson & Colburn (2013), Colburn and Jepson (2012), and Jacob et al. (2010, 2013), index construction began with the variables chosen in these studies and was expanded to include new variables related to gentrification and tourism. Using IBM SPSS statistical software, a principal component analysis (PCA) was conducted to transform these variables into a set of linearly, uncorrelated principal components. A varimax rotation was used to narrow the principal components by determining which variables are loading the highest on each factor (component), which would indicate those variables most likely to result in a single-factor solution. In other words, factor loadings "are the correlations between the factors and the variables that are subsumed by, or appear to be components of, factors" (Bernard, 2011). Factors (i.e., components) were selected based on eigenvalues greater than one. By using factor scores, the variables were standardized (mean of 0) and weighted for their effects in the model according to their factor loadings. PCA was repeated, substituting comparable variables with high factor loadings, until a single-factor solution was achieved where a set of variables, together, represented the index measuring a particular dimension.

An index was retained when it produced a single-factor solution and achieved the following criteria thresholds and significance levels. Two tests were performed to determine whether a principal component analysis is appropriate to use on the variables. First, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy indicates the amount of variance shared among the variables measuring a latent variable compared to the amount shared with the error. Higher values are a stronger indicator of appropriateness so > 0.50 was chosen (Jepson &

Colburn, 2013; Kaiser, 1970). Second, Bartlett's test of sphericity examines the multicolinearity of the variables (i.e., tests hypothesis that the correlation matrix is an identity matrix), therefore, significance had to be < 0.05 to indicate some relationship between variables. Once a PCA was conducted, factor loadings < 0.35 were not considered, resulting in those variables being removed from the analysis (Armor, 1974; Bernard, 2011). To be considered significant, the total variance explained for the indices had to be ≥ 0.50, which is considered acceptable when seeking as few factors as possible to achieve a single-factor solution (Colburn & Jepson, 2012; Jepson & Colburn, 2013). Since multiple indictors are required to characterize each thematic dimension, it is important to establish internal consistency and reliability. Using Armor's Theta reliability test, only coefficients > 0.50 were retained and used in an index (Armor, 1974; Jepson & Colburn 2013).

While 223 communities were used in the PCA to provide a statistically robust analysis, the assessment of social vulnerability, the biophysical impact analyses, and the semi-structured interviews were conducted only for Barnstable County. Therefore, PCA results are presented for each of the 15 Cape Cod towns. Since there are 42 CDPs/MCDs for Cape Cod, some towns have multiple communities included in the PCA. Thresholds for the factor scores were created (i.e., low, moderate, and high) and a categorical number assigned to each index, which were summed by dimension for each CDP/MCD.[10] The CDP/MCD with the greatest sum per dimension was used to represent the larger town. Thresholds were used to ensure that the variation within a town for a particular dimension of vulnerability was captured.

[10] Categorical values assigned to community factor score for purpose of summing indices to get an overall value for each dimension are Low (<0.49= "0"), Moderate (0.50-0.99= "1"), and High (1.0+= "2").

4.2 Results: Vulnerabilities Across Social, Gentrification, and Tourism Dimensions

This section presents the results of the principal component analyses conducted to achieve a single-factor solution for a series of indices that captures three dimensions of vulnerability for coastal communities: 1) Social, 2) Gentrification, and 3) Tourism. First, each of the dimensions is separated into a sub-section that includes a table of the indices[11], variables, factors loadings, and percentage of variance explained as well as the Kaiser-Meyer, Theta Reliability, and Eigenvalue scores. Second, the variables, their contribution (i.e., factor loadings) to the indices, and their relationship to that particular dimension of vulnerability are discussed. Third, the degree of vulnerability according to the index factor scores, which represents the communities' rank within each index, is presented for each of the 15 towns as radar graphs. The towns are further organized along the graphs according to sub-region: Upper Cape (Bourne, Falmouth, Sandwich, and Mashpee), Mid Cape (Barnstable, Yarmouth, and Dennis), Lower Cape (Brewster, Harwich, Orleans, and Chatham), and Outer Cape (Eastham, Wellfleet, Truro, and Provincetown).

Each index and its associated variables relate to one of the many components identified in the literature that are known to correspond with social, gentrification, and tourism vulnerabilities (Table 4.1). Furthermore, most of the variables included and the majority of the indices[12] have been used in previous studies (Colburn & Jepson, 2012; Cutter et al., 2003; Jacob et al., 2013; Jepson & Colburn, 2013) and/or are an appropriate representation of a particular vulnerability dimension. Higher index factor scores relate to higher degrees of vulnerability for that index.

Community vulnerability on Cape Cod was assessed using the corresponding indices within each dimension. The factor scores for each index by community illustrate the

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[11] For the Housing Characteristics and Labor Structure Indices the scores were reversed to maintain directionality with the other indices so that higher index scores indicated higher levels of vulnerability. For example, in the original index, higher scores for percent in labor force meant greater involvement, which indicates that the labor force is stronger and less vulnerable. Therefore, the scores were reversed so that high scores illustrate less vulnerability and the low scores now indicate higher vulnerability.

[12] The Cost of Living Index and Tourism Amenities Index are new (not previous studies) and created specifically for this case study though some of the variables were used in other indices included in Jepson & Colburn (2013) and Colburn & Jepson (2012).

interrelatedness of the indices as well as how the communities' degrees of vulnerability compare. Furthermore, as previously mentioned, some towns have multiple CDPs and so the CDP with the greatest overall vulnerability per dimension was used to represent the town. Figure 4.2 illustrates the location of all the CDPs included in the radar graphs. Allowing variation in the CDP chosen to represent the town across dimensions (i.e., social, gentrification, and tourism) illustrates the heterogeneity of vulnerability within a particular town. In keeping with other studies, a one standard deviation (1.0 SD) above the mean is used as the cutoff where a community with a score at or exceeding this threshold is considered to likely be experiencing high vulnerabilities for that particular index (Cutter et al., 2003; Jepson & Colburn, 2013). An additional threshold of a 0.5 standard deviation (0.5 SD) is also used to include factor scores indicating more "moderate" degrees of vulnerability.

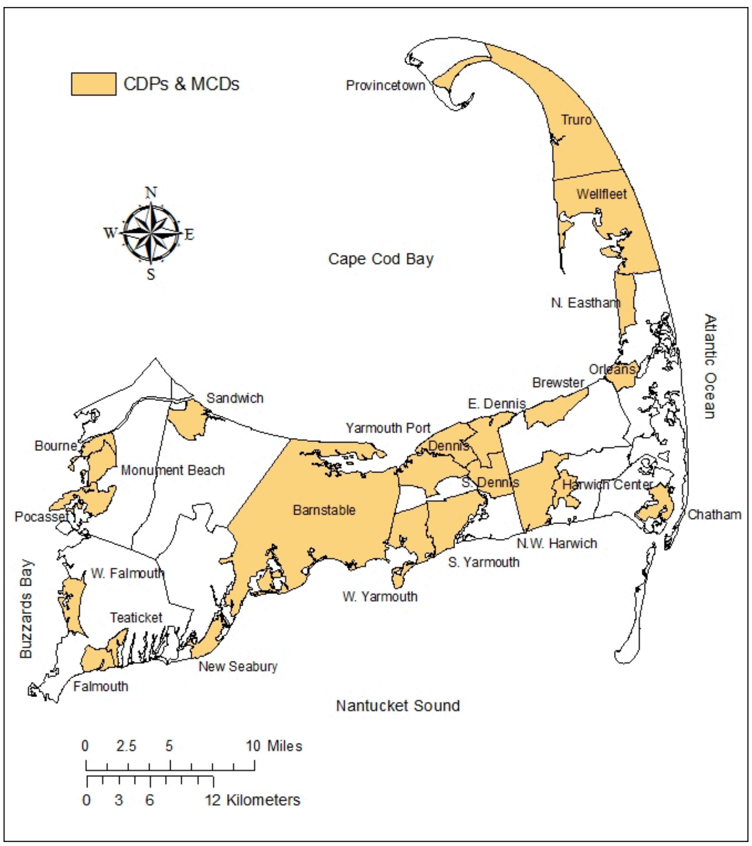

Figure 4. 2. Map illustrating the locations of each CDP or MCD community included in the radar graphs

4.2.1 Social Vulnerability: The Indices

Four indices were created to capture the larger, multi-dimensional concept of social vulnerability (Table 4.2) and include a variety of variables that have been documented in the literature as indicators of social vulnerabilities.

Population composition contains four variables relating specifically to the demographic makeup of each community. In particular, the percent of children age 5 and under, the percent of females that are the head of households, and the percent of the population that speaks English less than well (i.e., English is not first language) are agreed-upon indicators of socially vulnerable groups (Table 4.1). Ethnicity is also a well-known marker with minorities being more vulnerable (i.e., whites are less vulnerable). The factor loadings ranged from -0.852 (low vulnerability) to 0.886 (high vulnerability) with the percent of population that does not speak English well (0.886), the percent of female single headed households (0.730), and the percent of population that is white (-0.852) variables contributing the most to the index. The principal component analysis produced a single factor solution with nearly 60% of the variance explained by these four variables combined with Armor's Theta Reliability coefficient of 0.75, which makes this index a strong measure of population composition.

Table 4.2

Social Vulnerability Indices

Index Variable	Factor Loadings	Percentage Variance Explained
Population Composition Index		
Percent Population Age 5 and Under	**0.580**	**59.503**
Percent Population White	**-0.852**	
Percent of Female Single Headed Households	**0.730**	
Percent Population Does Not Speak English Well	**0.886**	
Kaiser-Meyer 0.692 Theta Reliability 0.77	Eigenvalue 2.380	
Personal Disruption Index		
Percent Unemployed	**0.669**	**57.429**
Percent of Females Separated	**0.780**	
Percent in Poverty	**0.788**	
Percent with 9th Grade or Less Education	**0.788**	
Kaiser-Meyer 0.708 Theta Reliability 0.75	Eigenvalue 2.297	
Poverty Index		
Percent of Families Below Poverty Level	**0.928**	**67.784**
Percent on Food Stamps	**0.886**	
Percent of Children (<18) in Poverty	**0.839**	
Percent of Elderly (65+) in Poverty	**0.744**	
Percent Receiving Public Cash Assistance	**0.697**	
Kaiser-Meyer 0.743 Theta Reliability 0.88	Eigenvalue 3.389	
Housing Characteristics Index[11]		
Median Number of Rooms	**0.896**	**62.143**
Median Mortgage in Dollars	**0.816**	
Percent Rental	**-0.698**	
Median Home Value	**0.728**	
Kaiser-Meyer 0.539 Theta Reliability 0.80	Eigenvalue 2.486	

Personal disruption is comprised of four variables: 1) percent of population unemployed (0.699), 2) percent of females separated (0.780), 3) percent of population exposed to poverty (0.788), and 4) percent of population that achieved at most a 9th grade education (0.788). Each of these variables are associated with changes and/or circumstances that affect the stability and resiliency of people's lives thereby making them more vulnerable and less able to cope (Table 4.1). In particular, a woman becoming the primary caretaker and/or breadwinner due to separation from spouse can increase her vulnerability by reducing her income and therefore her coping capacities. Furthermore, an inability to find work, low educational achievement, and living below the poverty level all indicate a reduction in resources, support, and, when taken together, reflect a community's degree of vulnerability. The factor loadings ranged from 0.699-0.788 with percent of females separated, percent in poverty, and percent with 9^{th} grade or less education having the strongest factor loadings and greatest contribution to the index. A single-factor solution was achieved with about 57% of the variance explained and Armor's Theta Reliability coefficient of 0.75, which together indicates that this index is a moderate measure of personal disruption.

Poverty is key indicator for social vulnerability particularly in terms of reduced financial coping capacities (Table 4.1). The index is comprised of five variables that cover a variety of facets for this concept including the percent of children in poverty (0.839), the percent of elderly in poverty (0.744), and the percent of families in poverty (0.928). Percent of population on food stamps (0.886) and percent of population receiving public cash assistance (0.697) were also included, which capture assistance-related conditions. The variables that contributed the most to the index with the strongest factor loadings are percent of families in poverty, percent of population on food stamps, and percent of children in poverty. The PCA achieved a single-factor solution with about 68% of variance explained, the highest of all the indices for social vulnerability, and an Armor's Theta Reliability coefficient of 0.88, which make this index a strong measure of poverty.

Housing characteristics is the final index in the social vulnerability dimension and reflects the quality and value of housing available in communities. It includes median mortgage as well as median home value both indicating the financial investment made in properties. Median number of rooms relates to the size of dwellings. The percent renters variable adds to the characterization of the types of housing in a community by capturing the nature of home ownership and is a marker socio-economic status (Table 4.1). The factor loadings range from -0.698- 0.896 where the strongest contributing variables are median number of rooms (0.896), median mortgage in dollars (0.816), and percent renters (-0.698). This index was reversed to maintain directionality with other indices by making lower factor scores now high and equal to higher degrees of vulnerability. A single-factor solution was achieved with about 62% of the variance explained combined with an Armor's Theta Reliability coefficient of 0.80, making this index a strong measure of housing characteristics.

4.2.2 Cape Cod Communities' Social Vulnerabilities

In general, most Cape Cod communities have low overall social vulnerability (Figure 4.3). In particular, New Seabury (Mashpee) of the Upper Cape has the lowest vulnerability with all four indices well below the mean (0 SD). Even though none of the communities have all four indices exceed 1.0 SD, which would indicate a high, overall social vulnerability, this does not mean that the Cape does not have socially vulnerable communities. In fact, South Dennis of the Mid Cape has all four indices exceed 0.5 SD indicating that it is facing moderate levels of social vulnerability (Figure 4.3) and that the indices are particularly interrelated for that town.

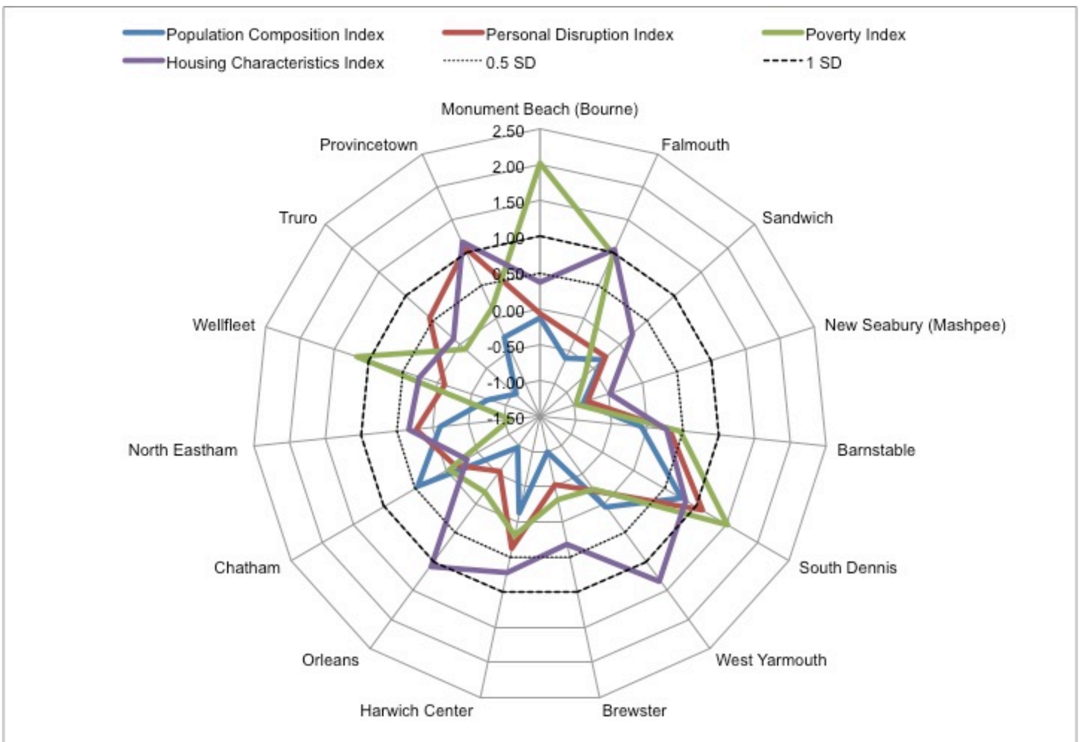

Figure 4. 3. Degrees of social vulnerability across Cape Cod communities

While overall social vulnerability may be lower, certain towns have high degrees of vulnerability for at least half of the indices. For example, Falmouth, South Dennis, and

Provincetown all had two out of the four social vulnerability indices exceed 1.0 SD (Figure 4.3). Specifically, Falmouth of the Upper Cape faces high vulnerability for poverty and housing characteristics at about 1.0 SD for both. South Dennis of the Mid Cape has even higher vulnerability to poverty at about 1.51 SD and faces high vulnerability of personal disruption at about 1.10 SD. Lastly, Provincetown of the Outer Cape faces similar degrees of vulnerability to personal disruption as South Dennis at about 1.05 SD and similar vulnerability of housing characteristics as Falmouth at about 1.15 SD.

Even though four indices comprise the social vulnerability dimension, the poverty and housing characteristics indices have some of the highest community factor scores on Cape. Notably, Monument Beach (Bourne) of the Upper Cape has the highest vulnerability to poverty anywhere on Cape at 2.02 SD. South Dennis of the Mid Cape has the second greatest degree of poverty vulnerability at 1.51 SD. In the Outer Cape, Wellfleet has the greatest vulnerability to poverty at 1.19 SD. In contrast, the Lower Cape clearly has the lowest levels of poverty vulnerability with all of the towns (except for Harwich Center at 0.19 SD falling below the mean). For housing characteristics, four towns at or exceed 1.0 SD with West Yarmouth of the Mid Cape having the greatest vulnerability at about 1.35 SD (Figure 4.3). Since this index reflects the type of housing, it is likely that there is a high degree of renters and/or smaller homes or apartments in these towns. The remaining towns have low vulnerability of housing characteristics, except for Harwich Center, which has moderately high vulnerability at 0.71 SD.

4.2.3 Gentrification Vulnerability: The Indices

Using variables from the literature and previous studies, three indices were created to capture the complex concept of gentrification on Cape Cod: Housing Disruptions, Retiree Migration, and Cost of Living (Table 4.3).

Housing disruptions contains three variables two of which depict fluctuations in the housing market due to changes in median home values from 2000-2013 as well as changes in median mortgages from 2000-2013. The third variable (0.686) captures the degree to which homeowners may be struggling as the cost of their mortgage consumes a larger portion of their income. These variables illustrate fluctuations by demonstrating changes in the costs and affordability of housing, thereby, indicating an overall instability in the housing market due to processes like gentrification (Table 4.1). The factor loadings ranged from 0.686-0.782 with the percent change in median mortgage (0.782) and the percent change median home values (0.749) variables contributing the most to the index. The principal component analysis produced a single factor solution with nearly 55% of the variance explained by these three variables combined with Armor's Theta Reliability coefficient of 0.59, which makes this index a moderate measure of housing disruptions.

Table 4.3

Gentrification Vulnerability Indices

Index Variable	Factor Loadings	Percentage Variance Explained
Housing Disruptions Index		
Percent Change Median Mortgage 2000-2013	**0.782**	
Percent Change Home Value 2000-2013	**0.749**	**54.796**
Percent of Monthly Costs is 35% of Home Owners' Income	**0.686**	
Kaiser-Meyer 0.621 Theta Reliability 0.59	Eigenvalue 1.644	
Retiree Migration Index		
Percent of Households With 1+ People Age 65+	**0.964**	
Percent Population In Labor Force	**-0.815**	
Percent Population on Retirement Income	**0.851**	**80.463**
Percent Population on Social Security	**0.969**	
Kaiser-Meyer 0.786 Theta Reliability 0.92	Eigenvalue 3.219	
Cost Of Living Index		
Median Home Value	**0.748**	
Cost of Living Index	**0.759**	**55.378**
Percent Water Coverage	**0.725**	
Kaiser-Meyer 0.637 Theta Reliability 0.60	Eigenvalue 1.661	

Retiree migration is comprised of four variables with factor loadings ranging from (-0.815-0.969): 1) percent of households with one or more people aged 65 or over, 2) percent of population in labor force, 3) percent of population on retirement income, and 4) percent of population on social security. Each of these variables demonstrates either demographically or economically the strength of retirees' presence in communities and relates specifically to the retiree migration associated with rural gentrification (Table 4.1).[13] The influx of these people from differing areas off Cape Cod is known to cause changes in social networks, property tax bases, etc., which affect the resiliency of communities (Lamarque, 2009). The variables with the highest factor loadings are percent of population on social security (0.969), percent of households with one or more people aged 65 or over (0.964), and percent of population in labor force (-0.815). The PCA achieved a single-factor solution with about 81% of variance explained, the highest of all the indices for gentrification, and an Armor's Theta Reliability coefficient of 0.92, which makes this index a strong measure of retiree migration.

Cost of living is the final index in the gentrification vulnerability dimension and reflects the median values of housing available and general living costs for communities. A third variable pertains to the percent of water cover found within communities and indicates a natural amenity that both draws people (e.g., retirees) to the area as well as increases the costs of housing (i.e., home values rise when located on ponds, rivers, coastlines etc.) (Table 4.1). The factor loadings range from 0.725 to 0.759 where the strongest contributing variables are cost of living index (0.759) and median home value (0.758). A single-factor solution was achieved with about 55% of the variance explained, which combined with an Armor's Theta Reliability coefficient of 0.60, makes this index a moderate measure of cost of living.

4.2.4 Cape Cod Communities' Gentrification Vulnerabilities

In terms of the greatest vulnerability to gentrification, North Eastham of the Outer Cape is the only town where all three of the indices exceed 1.0 SD (Figure B). There are three other towns, however, that have all three indices exceeding 0.5 SD and, therefore, are experiencing moderate degrees of gentrification vulnerability. These include Wellfleet, Chatham, and Pocasset (Bourne) (Figure B). Barnstable is, perhaps, the least vulnerable to gentrification with all three indices falling below 1.0 SD and two of them falling below 0.5 SD.

[13] In addition to their association with gentrification, retirees are also considered a socially vulnerable group due to their increasing age, decreasing mobility, deteriorating health, and fixed income (Table 4.1).

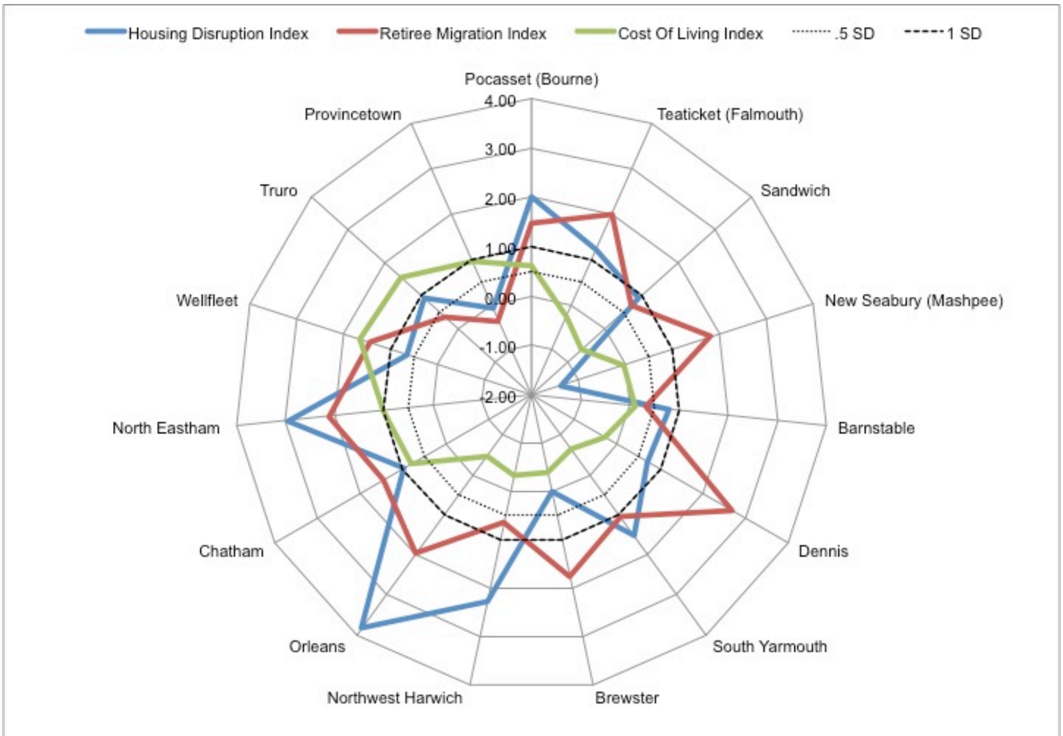

Figure 4. 4. Degrees of gentrification vulnerability across Cape Cod communities

Overall, the housing disruptions and retiree migration indices tend to result in similar factor scores to one another showing a stronger degree of interrelatedness between these indices. For example, Pocasset (Bourne) has retiree migration and housing disruption factor scores of 1.47 and 2.01 SD, respectively and South Yarmouth has 1.06 and 1.52 SD, respectively. Furthermore, the housing disruptions and retiree migration indices also have much higher factor scores compared to the cost of living index (Figure 4.4). For example, North Eastham, Orleans, South Yarmouth, Teaticket (Falmouth), and Pocasset (Bourne), representing each sub-region of the Cape, are all facing high vulnerability (i.e., 1.0 SD or more) to both housing disruptions and retiree migration. Specifically, Orleans of the Lower Cape is experiencing the greatest degree of housing disruptions at 3.84 SD and Dennis of the Mid Cape is facing the most retiree migration at 2.68 SD.

In general, the cost of living index does not seem as interrelated with the other two indices and tends to have, overall, lower factor scores (Figure 4.4). The Outer Cape has the highest degrees of cost of living with Truro, Wellfleet, North Eastham, and Provincetown almost at or exceeding 1.0 SD. Chatham of the Lower Cape (next to North Eastham) and Pocasset (Bourne) of the Upper Cape have moderate vulnerability in cost of living with 0.81 SD and 0.5 SD, respectively. The reason these towns have higher cost of living factor scores is likely because they are prime recreational areas with considerable water coverage (e.g., proximity to beaches) and, subsequently, higher home values. The rest of the Cape has factor scores at or below the mean indicating low vulnerability related to cost of living.

4.2.5 Tourism Vulnerability: The Indices

Based upon known indicators from the literature and previous studies, three indices were created (Table 4.4) to measure the multi-dimensional concept of tourism vulnerability.

Labor force structure contains four variables that convey the types of engagement occurring within the labor force as well as characterize the strength and stability of the labor force and broader economic context. In particular, the percent of females employed, the percent of population in the labor force, and the percent of the population on social security are included to demonstrate the diversity (or lack thereof) of people engaged in the work force. The fourth variable—percent of people employed in the arts, entertainment, recreation, accommodation, and food services—is used as a measure of the degree of tourism engagement and indicates degree of dependency on that type of industry (Table 4.1). The factor loadings ranged from -0.857-0.929 with the percent of population in the labor force (0.929), the percent of females employed (0.919), and the percent of population on social security (-0.857) contributing the most to the index. This index, along with housing characteristics, was reversed to maintain directionality with other indices by making lower factor scores now high and equal to higher degrees of vulnerability. The principal component analysis produced a single factor solution with nearly 65% of the variance explained by these four variables combined with Armor's Theta Reliability coefficient of 0.82, which makes this index a strong measure of labor force structure.

Table 4.4

Tourism Vulnerability Indices

Index Variable	Factor Loadings	Percentage Variance Explained
Labor Force Structure Index[11]		
Percent Females Employed	**0.919**	
Percent of Population In Labor Force	**0.929**	
Percent of Population on Social Security	**-0.857**	**65.063**
Percent Employed Recreation, Accommodation, & Food Services	**-0.402**	
Kaiser-Meyer 0.696 Theta Reliability 0.82	Eigenvalue 2.603	
Tourism Amenities Index		
Rental Vacancy Rate	**0.744**	
Boat Ramps Per 1,000 People	**0.790**	
Percent Vacant Homes	**0.612**	**56.823**
Boat Slips Per 1,000 People	**0.849**	
Kaiser-Meyer 0.549 Theta Reliability 0.75	Eigenvalue 2.273	
Recreational Fishing Engagement Index		
Recreational Private-Rental Fishing Pressure	**0.881**	
Recreational Charter Fishing Pressure	**0.778**	**71.221**
Recreational Shore Fishing Pressure	**0.868**	
Kaiser-Meyer 0.678 Theta Reliability 0.80	Eigenvalue 2.137	

Tourism amenities is comprised of four variables: 1) rental vacancy rate (0.744), 2) boat ramps per 1,000 people (0.790), 3) percent vacant homes (0.612), and 4) boat slips per 1,000 people (0.849). As a major industry for most coastal economies, each of these variables is associated with both supporting and attracting tourists and used to measure the degree of tourism engagement and/or dependence (Table 4.1). The factor loadings ranged from 0.612-0.489 with boat slips per 1,000 people, boat ramps per 1,000 people, and rental vacancy rate having the strongest factor loadings and greatest contribution to the index. A single-factor solution was achieved with about 57% of the variance explained and Armor's Theta Reliability coefficient of 0.75, which together indicates that this index is a moderate measure of tourism amenities.

Recreational fishing engagement is the final index in the tourism vulnerability dimension and reflects the degree of coastal fishing and dependence from a tourism perspective (Colburn & Jepson 2012). It includes three variables that refer to the types of recreational fishing that is being engaged: 1) private-rental boat, 2) charter boat, and 3) shore fishing. The factor loadings range from 0.778- 0.881 where the strongest contributing variables are private-rental boat fishing (0.881) and shore fishing (0.868). The PCA achieved a single-factor solution with about 71% of variance explained, the highest of all the tourism dimension indices, and an Armor's Theta Reliability coefficient of 0.80, which make this index a strong measure of recreational fishing engagement.

4.2.6 Cape Cod Communities' Tourism Vulnerabilities

Similar to the results of the social vulnerability dimension, none of the towns on Cape Cod have high, overall tourism vulnerability where all three indices are at or exceed 1.0 SD (Figure 4.5). There are two towns, however, Wellfleet and Orleans, which exhibit moderate vulnerability with all three index factor scores exceeding a 0.5 SD. A third town, Chatham, is worth mentioning because it is borderline having two of the indices (i.e., labor force structure and tourism amenities) well above 1.0 SD with the recreational fishing engagement index just shy of the 0.5 SD at 0.33 (Figure 4.5). Therefore, this town is likely experiencing moderate degrees of vulnerability.

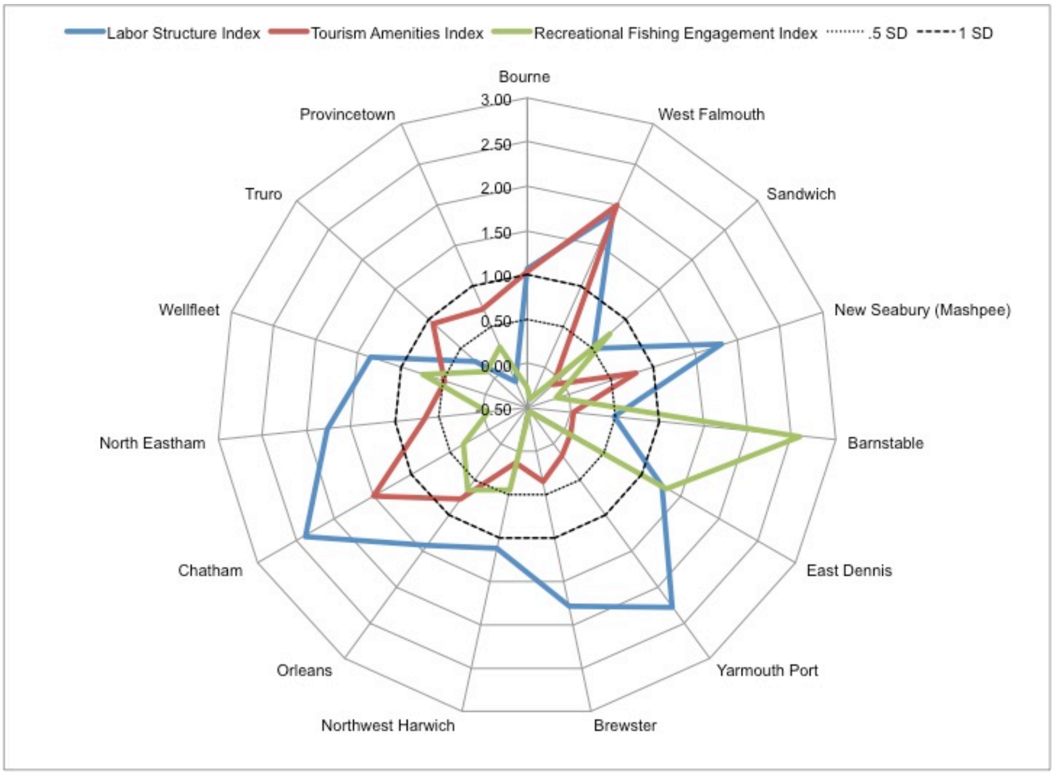

Figure 4. 5. Degrees of tourism vulnerability across Cape Cod communities

Unlike the other dimensions, there seems to be more extreme scores between some of the indices in some of the communities indicating less interrelatedness than expected. Notably, the labor force structure and tourism amenities indices tend to have scores closer together with the recreational fishing engagement index factor scores being different. For example, West Falmouth of the Upper Cape has the highest vulnerabilities in tourism amenities at 2.01 SD and the third highest labor force structure vulnerabilities at 1.89 SD but has some of the lowest recreational fishing engagement vulnerability at -0.40 (Figure 4.5). In contrast, Barnstable of the Mid Cape has a low tourism amenities index factor score (0.03 SD), moderate labor force structure index score (0.5 SD) but the highest recreational fishing engagement at 2.60 SD (Figure 4.5). The high recreational fishing in Barnstable is likely because that town has the largest marina on Cape Cod and, therefore, more private-rental and charter boat opportunities.

While the consistency between index scores is highly variable based on the community, it is clear that most of the towns experience high vulnerability for a particular index. For example, the majority of Cape Cod communities are experiencing high degrees of labor force structure vulnerability with factor scores at or significantly exceeding 1.0 SD. Only Truro and Provincetown of the Outer Cape have scores that fell below 0.5 SD while Sandwich of the Upper Cape and Barnstable of the Mid Cape have moderate vulnerability at about 0.5 SD (Figure 4.5). The Mid and Lower Capes are facing some of the highest labor force structure vulnerability with Yarmouth Port at 2.28 SD and Chatham at 2.39 SD, respectively. For tourism amenities, half of the Lower Cape and all of the Outer Cape are likely experiencing moderate to high degrees of vulnerability with Chatham having the second highest vulnerability on Cape at 1.5 SD and Provincetown having the fourth highest at 0.92 SD (Figure 4.5). West Falmouth of the Upper Cape has the highest tourism amenities vulnerability on Cape at 2.01 SD and Bourne has the third highest at 1.03 SD. The recreational fishing engagement is clearly not as important as some of the other indices with only three towns (Orleans, Wellfleet, and Sandwich) experiencing moderate vulnerability by exceeding 0.5 SD and only two towns, Barnstable and East Dennis of the Mid Cape, experiencing high vulnerability by exceeding 1.0 SD (Figure 4.5).

While it is important to know the biophysical vulnerabilities of communities to climate-related coastal hazards, it is equally important for decision-makers to understand the attributes of communities being affected. In order to provide a more comprehensive assessment of Cape Cod communities' vulnerabilities to coastal hazards, this chapter focused on the socio-economic conditions of its towns. Specifically, three dimensions—Social, Gentrification, and Tourism—were evaluated to identify the communities with the highest vulnerabilities and are, therefore, less able to cope with the impacts of coastal hazards. The broader contribution of this assessment is in the use of indicators to try to capture the conditions/attributes of tourism-dependent coastal communities that are most critical in terms of indicating reduced capacities. Decision-makers can use this information to devise policies that are tailored to addressing these socio-economic vulnerabilities as part of their hazard mitigation planning.

CHAPTER 5

COASTAL HAZARD GOVERNANCE & DECISION-MAKING ASSESSMENT

5.1 Methods

5.1.1 Data Collection

Quantifying social and biophysical vulnerabilities are critical components of a hazard risk assessment but are limited in terms of understanding how these conditions inform and are shaped by the complex decision-making processes of coastal management and hazard mitigation planning. Therefore, this part of the case study necessitated a more in-depth, primary data collection method to identify the ways in which the regional and local institutional planning interactions and processes are affecting communities' degrees of vulnerability to climate-related coastal hazards.

Data was collected from decision-makers at regional (i.e., county) and local (i.e., towns) scales using semi-structured interviews (Table 5.1), which allowed me to elicit open-ended responses from participants based upon my interview guide (Bernard, 2011), which contained a series of thematic topics to be covered (Appendix B). In other words, the interviews were structured to prompt the participants to share their opinions regarding coastal hazard planning on Cape Cod. Participants were also drawn from key collaborative nongovernmental organizations (NGOs), which play a critical role in providing the science decision-makers use to craft plans and policies. The participants were purposively sampled across regional and local scales, which is appropriate during a case study particularly when interested in understanding the viewpoints of a particular group of people like decision-makers (Bernard, 2011). To ensure adequate representation at the local level and capture geographic variability, a majority of the towns were interviewed within each sub-region: Upper (3 out of 4), Mid (2 out of 3), Lower (3 out 4), and Outer Cape (3 out 4).

Table 5.1

Interview Sampling

	Regional (i.e., County & NGOs)	Local (i.e., Towns)
	Cape Cod Commission (CCC)	Falmouth
	Barnstable County Emergency Management	Sandwich
	Cape Cod Chamber of Commerce	Mashpee
	Association To Preserve Cape Cod (APCC)	Barnstable
	Center For Coastal Studies (CCS)	Dennis
	Waquoit Bay National Estuarine Research Reserve (WBNERR)	Brewster
	Woods Hole Oceanographic Institution (WHOI)	Chatham
	Nature Conservancy	Orleans
	Cape Cod National Seashore (CCNS)	Truro
		Provincetown
Number of Participants	12	17

Prior to conducting the interviews, this study was reviewed and approved by the Arizona State University Institutional Review Board (Appendix C), which is required for all research with human subjects. All potential participants were initially contacted by email with a recruitment letter explaining the project and their participation. If they did not respond I followed up at one-week intervals via email and/or phone. If there was no response after the third attempt it was determined that decision-maker was unwilling to participate in the study. A total of 29 people were interviewed during 21 sessions that lasted an average of 60-90 minutes (some were interviewed in groups). All sessions were audio recorded for accuracy purposes and then transcribed to text. The questions focused on four key themes (Table 5.2) that influence decision-makers and their planning processes to address coastal hazards.

Table 5.2

Interview Themes

Themes	Purpose
Coastal Hazards & Risk Perception	Teases out professional opinions about the types of climate-related coastal hazards Cape Cod does and will experience.
Exposure & Vulnerability	Seeks to understand decision-makers' level of awareness of the types of vulnerability (i.e., biophysical, social, and economic) in Cape communities to coastal hazards.
Hazard Preparedness & Mitigation	Focuses on the types and challenges of coastal hazard mitigation and community resiliency efforts underway on Cape.
Collaboration: Program Efforts	Looks at the collaborative efforts and its challenges within hazard mitigation planning.

5.1.2 Thematic Content Analysis

Thematic content analysis was used to analyze the semi-structured interviews. Content analysis allows for the systematic coding and analyzing of qualitative data (Miles et al., 2014). Codes are labels with symbolic meaning assigned to the transcribed information (Miles et al., 2014), which allows for easier reduction, organization, and analysis of the data gathered. Coding was done in two stages. First, codes were assigned to summarize the data reducing them to segments. Second, those summaries were then further grouped into "a smaller number of categories, themes, or constructs" to identify patterns and relationships (Miles et al., 2014, p. 86). This pattern coding is conceptually similar to factor analysis where large datasets can be reduced and organized into meaningful, analyzable categories that represent some concept of research interest (Miles et al., 2014; Singleton & Straits, 1999).

Prior to conducting the semi-structured interviews, a preliminary list of codes was generated deductively based on the literature and then modified inductively during the content analysis. To refine the codebook, inter-rater reliability was used to evaluate the strength of the codes, conceptually as well as the coding process (Lombard et al., 2002). Specifically, a colleague and I independently applied the codes to two interviews that both reflected regional and local concerns. We then systematically reviewed the codes and the way we applied them to uncover and resolve any poorly defined codes or inconsistencies in the coding process. We coded a third interview, taking into consideration the changes made from the previous round of coding, and calculated Cohen's kappa to determine our level of agreement. Cohen's kappa is a more conservative inter-rater reliability measure because it underestimates the rate of agreement by only counting exact matches as agreement (Jacob et al., 2010). A code was retained if it received a kappa of .61 (Wutich et al., 2010) or higher given that .61-.80 is considered as substantial agreement and .81-1.0 is considered near perfect agreement (Landis & Koch, 1977). The finalized codebook contains a total of 12 codes, which were conceptually organized into conditions (e.g., vulnerability), barriers (e.g., to planning and implementation), and solutions (e.g., efforts to improve mitigation and resiliency) (Appendix D). Using MAXQDA, a qualitative data analysis program, the codes were applied to the transcribed interviews to identify (based on frequency) the most important decision-making factors and processes influencing both coastal hazard planning and mitigation strategies.

The results of the thematic content analyses will allow me to elucidate, from planners' and decision-makers' perspectives, the current priorities of coastal hazard mitigation planning across Cape Cod communities, the extent of communities' coping and adaptive strategies, as well as the major challenges in hazard planning and decision-making. Furthermore, the information gathered from the interviews provides strong contextual information to situate the results of the biophysical and social vulnerability assessments (Chapters 3 & 4). Specifically, it helps "ground truth" the more quantitative, secondary data results by providing greater insight into the complex decision-making processes occurring and influencing community vulnerability. The triangulation of results implies that the findings that are corroborated by multiple methods are considered more robust (Yin, 2009).

The following presents the results of the semi-structured interviews and thematic content analyses conducted to identify the current priorities and challenges of coastal hazard mitigation planning on Cape Cod. The results of this analysis are divided into two primary sections: descriptive and interpretive. First, each of the codes from the codebook is described and illustrated with an exemplary quotation from the interviews. Second, the relationships between particularly significant codes, as determined by frequency of occurrence and code overlap, are discussed to give a detailed account of the barriers and successes of coastal hazard mitigation planning and decision-making on Cape Cod.

5.2 Descriptive: The Codebook

Twelve thematic codes were deductively and inductively developed and applied to analyze the semi-structured interviews that were conducted with policymakers and decision-makers on Cape Cod. These codes are organized conceptually into three domains: conditions, barriers, and solutions (Figure 5.1).

The conditions domain includes social vulnerability, biophysical vulnerability, and risk awareness, which reflects the overall coastal hazard conditions on Cape Cod and is the focus of many hazard mitigation and planning efforts. The barriers domain includes four main concepts—planning capacity, political will, short-term thinking, and laws and policies, which are factors that influence effective hazard mitigation planning and implementation. The solutions domain is comprised of the types of solutions being undertaken on Cape Cod to mitigate coastal hazards and improve communities' abilities to withstand impacts.

The robustness of the coding process was determined by conducting an inter-rater reliability test with multiple persons coding the same sample of interviews. The Kappa scores from the inter-reliability test are reported for each of the codes (Figure 5.1) and are considered substantial to near perfect indicating a well-defined suite of codes and effective coding process. The following is a brief description of each of the codes used in this study.

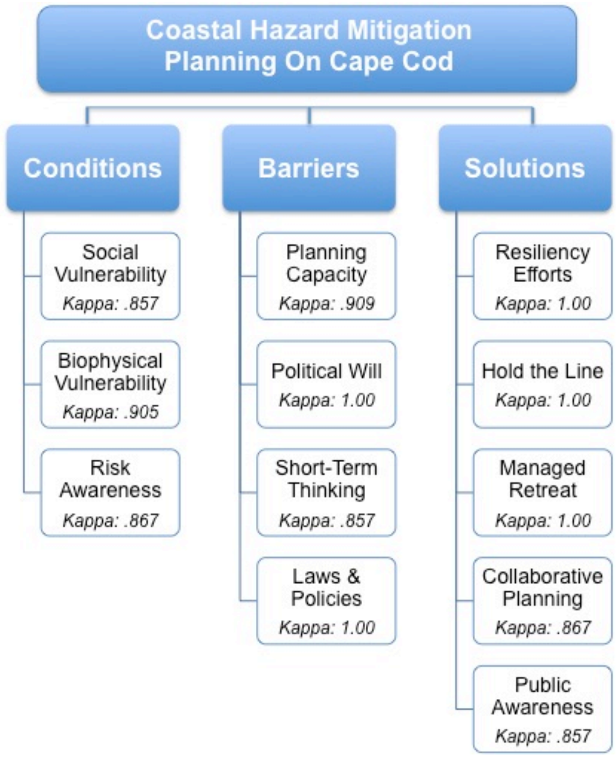

Figure 5. 1. Deductive and inductive thematic hazard mitigation planning concepts from semi-structured interviews on Cape Cod

Social Vulnerability

Maybe you could draw some distinctions in the demographics so that older [populations]...they're on a fixed income now and may not have the means…They may be in a flood zone or an area that could be hazardous…So I think within the demographics and the economic scale, I'm sure there's some vulnerability… (Eastham Participant).

Social vulnerability refers to the demographic and economic characteristics of a population, which makes them less able to cope with and respond to hazards due to reduced resources and capacities. Well known characteristics include low socioeconomic status, gender (i.e., women), age (i.e., young and old), ethnicity (i.e., minorities), disability, education (i.e., low attainment), occupation (e.g., natural resource extractive jobs, service jobs, etc.), tourists, and transients (e.g., renters, homeless).

Biophysical Vulnerability

You have a greater population than you had in the past and you have a lot more development right along the coast. So that creates vulnerability patterns…whether it be erosion-related or storm surge-related…If you're closer, right on the coast, than you're going to be more vulnerable... We're also locked in with two bridges...so I think that that exacerbates a level of vulnerability here—just not having a lot of avenues to be able to evacuate (WBNERR Participant).

Biophysical vulnerability refers to the potential risk of harm or loss from physical exposure to a hazard due to geographic, ecological, or climatic conditions. It also reflects the spatial distribution of hazardous conditions and hazard impacts on the physical environment. This can include impacts to natural infrastructure (e.g., beaches and wetlands) as well as built infrastructure (e.g., residential and commercial structures, roads, etc.).

Risk Awareness

The way that I think about climate change as far as its relationship to coastal hazards—it's basically just going to make it worse. So every sort of…coastal hazard is just gonna be made worse—exacerbated—by climate change (CCC Participant).

Risk awareness relates to the individual or group opinion regarding the likelihood and characteristics, especially magnitude and frequency, of an individual risk while recognizing that different risks (e.g., sea level rise and storm surge) can exacerbate each other. Common examples include how the potential effects of climate change increases both the frequency and intensity of storms, how coastal hazards can exacerbate one another, and how direct experiences of coastal hazards serve as "wake up calls" to the reality of risks.

Planning Capacity

…There has to be funding…to implement projects. And, you know, the time to do the planning associated with the steps and, you know…human resources to implement…I think the capacity too on a local level is an issue because…budgets are always under strain…(CCC Participant).

Planning capacity (inductively identified) is constrained by the ability to manage and mitigate hazard impacts due to internal institutional barriers. Notably, the planning group has reduced resources, staffing, and expertise, which limit the efficacy of their decision-making. For example, they can be underfunded, understaffed, have too much work and too little time. Less typical but equally important conditions include differing priorities within the planning organization as well as operational "silos" where communication and collaboration with others is lacking, which inhibit effective planning.

Political Will

So, the challenges…most directly to dealing with erosion and flooding and storm impacts—the greatest challenge is political. Because there is significant opposition from property owners—to suggest that they might have to live differently (Nature Conservancy Participant).

Political will (inductively identified) refers to the extent of support for hazard mitigation planning and implementation by the public or decision-makers. It often encompasses conflicting political, jurisdictional, economic, and education interests/viewpoints that present challenges to arriving at a consensus for proactive mitigation planning. Political will is also confounded by having to balance conflicting individual and public rights. Examples include citizens voting against a hazard mitigation that impinges on private property rights and reducing the funding available for resiliency projects.

Short-Term Thinking

…When you're sort of just doing enough to sustain what you need to do. So you're fixing your problems as they arise, not forecasting what problems are coming down the pike and being prepared for that…it's [also] a capacity thing…(CCC Participant).

Short-term thinking is defined as the tendency to focus on addressing immediate issues and/or concerns at the expense of considering the long-term implications of decisions. In particular, many attempts to manage the impacts of coastal hazards are temporary (i.e., Band-Aid like), reactive responses. For example, allowing rebuilding in known flood-zones, armoring the coastline, and choosing to site new infrastructure without considering the effects of sea level rise and subsidence.

Laws and Policies

…A lot of towns have a [building] height restriction where you can only go up so high…so there are these restrictions in place on what can be built in particular areas, but those restrictions were written a very long time ago…so it doesn't necessarily consider the current state. But to deal with zoning is kind of like dealing with outdated infrastructure. It's a total hassle and costs a lot of money…(CCC Participant).

Laws and policies (inductively identified) refer to regulatory rules that no longer reflect and/or support the current needs for hazard management and mitigation. They can even place limitations on coastal zone managers and planners abilities to develop and implement more proactive hazard mitigation measures. For example, grandfathering rights allows nonconforming uses making existing properties exempt from current flood plain zoning standards, MA state building code applies uniformly regardless of the potential vulnerability of local conditions and preempts local ordinances that could be more restrictive, and building height restrictions prevent people from elevating structures.

<u>Resiliency Efforts</u>

Coastal Zone Management has made these grants available and there've been various efforts to, you know, improve the state-wide conversation about coastal challenges, and so many of our communities are applying for those funds for planning purposes and for some for building green infrastructure projects. So we're…completing the sediment budget for Provincetown and looking at a green infrastructure project, which will be a beach nourishment project (CCC Participant).

Resiliency efforts relates to the attempts to strengthen communities' coping and adaptive capacities for the long-term through proactive mitigation measures for current and future hazards. This includes policies that make it easier for citizens' to reduce their vulnerabilities. Examples include conducting coastal sediment budget analyses, green infrastructure like dune restoration, and amending town bylaws to address hazards and improve resiliency (e.g., increasing building height maximum to allow structures to be elevated).

<u>Hold the Line</u>

…The thing that makes them most vulnerable is development on the coastline and most of that development is residential. What happens is when you have a residence on the coastline that is experiencing erosion they want to protect their property interests so they want to armor their shoreline. We've seen evidence…of what that's done on the Cape. Eastham is a perfect example where you've seen a lot of the coastline armored on the Bay side and those that aren't are suffering because the armoring is impacting and it's digging out the unarmored areas (APCC Participant).

Hold the line (inductively identified) reflects coastal management techniques to minimize impacts from coastal hazards and protect shorelines. The main goal is to protect public and private property through installation of hard or soft infrastructure. Common examples include revetments, groins, and beach re-nourishment. Green infrastructure is a newer technique that overlaps with resiliency efforts and refers to the enhancing of natural features to help minimize hazard impacts. This can include restoring wetlands, dune systems, and creating reefs for habitat all of which absorb the energy of wave action thereby reducing inundation and erosion.

Managed Retreat

We also have a parking lot up there [Herring Cove Beach] that's really popular…We're moving the parking lot back 120 feet because that's what we predict to be a manageable, dynamic coastal zone. At the moment, we've been patching that parking lot to the tune of several hundred thousand dollars every two years because…it's in the storm surge zone and the asphalt breaks up (CCNS Participant).

Managed retreat is centered on reducing human presence in high-hazard zones and letting natural coastal processes (e.g., flooding, erosion, deposition and re-distribution, etc.) occur. This coastal management technique reflects more long-term thinking and planning to minimize hazard impacts by reducing human and property exposure. Examples include land buy-outs, relocation farther inland, and increasing building setbacks from coastlines.

Collaborative Planning

…Started going out into the communities for local expert knowledge on where the water is located…I met with DPW Directors one-on-one in the different sub-regions of the Cape…and have them go through and identify what I call bright spots and opportunities. So 'bright spots' are…already resilient pieces of transportation infrastructure that are in the town and 'opportunities' are, you know, non-resilient pieces of infrastructure (CCC Participant).

Collaborative planning is defined as the cooperative efforts in hazard mitigation planning between towns, organizations, the state, etc. The goal is to try to address hazards and coastal processes more holistically and uniformly since they cross municipal boundaries. For example, conducting workshops that bring towns together to address issues, funding specific hazard mitigation and resiliency projects undertaken jointly between towns and NGOs, as well as planning efforts between different departments within towns.

Public Awareness

…We started really with education…awareness…a climate change outreach project…was to test out the value of role playing scenarios and whether or not they can influence people's views on an issue…we engaged 150 residents as well as staff members here at the town of Barnstable (Barnstable Participant).

Public awareness relates to increasing the public's knowledge of current and future hazards/risks, their impacts, and mitigation strategies. The intent is to raise awareness and concerns and, therefore, garner more support for hazard mitigation initiatives. This includes using outreach activities (e.g., public events, town meetings, lectures, and workshops, etc.,) to educate and inform the public of local and regional concerns.

5.3 Interpretive: Key Coastal Hazard Mitigation Planning Codes

The twelve thematic codes developed both deductively and inductively through the coding process represent critical aspects of coastal hazard mitigation planning on Cape Cod. Of these codes, however, certain ones stand out by showing a degree of significance and interrelatedness as measured by frequency and code relation analysis, respectively.[14]

5.3.1 Code Frequency Analysis Across Scales & Sub-Regions

Across each of the three domains (e.g., conditions, barriers, and solutions), there is one code that represents a greater percentage of the total number of coded segments (N=670) indicating a higher degree of importance to the coastal hazard mitigation planning process on Cape Cod due to the frequency with which it was mentioned during the interviews (Table 5.3). For the conditions domain, biophysical vulnerability represents 13.4% (i.e., coded 90 times) of the total number of coded segments. In the barriers domain, political will is coded 78 times representing 11.6% of the total number of coded segments. However, it is worth noting that planning capacity was coded 63 times or 9.4% suggesting it also was an important component of the barriers domain. Lastly, in the solutions domain, resiliency efforts is, by far, the most frequently mentioned code (129 times) at 19.3% of the total number of coded segments.

[14] Frequency of codes was calculated two ways using MAXQDA. First, the documents were organized into “regional” and “local” groups and frequencies were calculated providing an overall description of relative code significance across scales. Second, the documents were organized by sub-region (i.e., Upper, Mid, Lower, and Outer Cape) and frequencies calculated to illustrate, geographically, the codes appearing most significant. Code relation analysis was calculated in MAXQDA to demonstrate the codes that are most interrelated as measured by the degree codes overlapped with one another.

Table 5.3

Frequency Analysis of Codes at Regional & Local Scales

		Regional	Local	Total # Codes	% Total
Conditions	Social Vulnerability	18	25	43	6.40%
	Biophysical Vulnerability	41	49	90	13.40%
	Risk Awareness	29	24	53	7.90%
Barriers	Planning Capacity	35	28	63	9.40%
	Political Will	21	57	78	11.60%
	Short-Term Thinking	14	18	32	4.80%
	Laws & Policies	15	29	44	6.60%
Solutions	Resiliency Efforts	64	65	129	19.30%
	Hold The Line	25	21	46	6.90%
	Managed Retreat	10	7	17	2.50%
	Collaborative	28	26	54	8.10%
	Public Awareness	10	11	21	3.10%
Sum		310	360	670	100.00%
N (Documents)		11	11	22	

In terms of differences between the local and regional scales, most codes were mentioned a similar number of times likely indicating a fair amount of consistency within the conditions, barriers, and solutions domains of coastal hazard mitigation planning. For example, the difference in the number of coded segments between local and regional groups was less than ten coded segments for social vulnerability, planning capacity, short-term thinking, resiliency efforts etc. (Table 5.3). Political will, however, was mentioned considerably more times at the local scale (i.e., 57) than at the regional (i.e., 21) (Table 5.3). This is consistent with the political processes in Massachusetts where town governments are powerful, the center of most decision-making, and require voting at town meetings to implement actions. As a result, political will can be a critical barrier to the successful execution of planning efforts.

While the local and regional scales show similarities in the frequency of a given code, an analysis of codes by sub-region illustrates certain spatial differences and patterns between domains. Notably, the Outer Cape has the highest frequencies for most of the codes across the conditions, barriers, and solutions domains (Table 5.4). Biophysical vulnerability was mentioned most frequently in the Outer Cape followed by the Upper Cape (Table 5.4). This reflects existing cases of physical exposure to coastal hazards (e.g., erosion and storm surge) in towns in those sub-regions as well as concerns over more long-term hazards like sea-level rise. Political will and planning capacity are also most frequently mentioned in the Outer Cape followed by the Upper Cape (Table 5.4). More than likely, the towns suffering more physical exposure to coastal hazards are also dealing with political will and planning capacity issues due to a greater involvement in hazard mitigation planning. Particularly in the Outer Cape, some of the towns are very small, with highly active voters and, naturally, have smaller departments and fewer resources than others. This especially relates to the laws and policies code, which was also mentioned frequently in the Outer Cape, and is likely a function of how part of the planning process involves working with existing regulations. In towns where there are a large number of cases of coastal hazard exposure, laws and policies are likely to be consulted, applied, or modified more frequently. Moreover, those that constrain hazard mitigation efforts, like building height restrictions, become more important barriers towns try to overcome. Political will is mentioned consistently across the sub-regions, which reflects the local and regional scale analysis discussed above.

Table 5.4

Frequency Analysis of Codes by Sub-Region

		Upper Cape	**Mid Cape**	**Lower Cape**	**Outer Cape**	**Total # Codes**	**% Total**
Conditions	Social Vulnerability	6	5	7	7	25	6.90%
	Biophysical Vulnerability	14	7	9	19	49	13.60%
	Risk Awareness	6	5	5	8	24	6.70%
Barriers	Planning Capacity	10	2	4	12	28	7.80%
	Political Will	18	12	12	15	57	15.80%
	Short-Term Thinking	6	4	5	3	18	5.00%
	Laws & Policies	5	6	4	14	29	8.10%
Solutions	Resiliency Efforts	15	15	18	17	65	18.10%
	Hold The Line	4	5	6	6	21	5.80%
	Managed Retreat	1	1	4	1	7	1.90%
	Collaborative	3	9	5	9	26	7.20%
	Public Awareness	1	2	2	6	11	3.10%
Sum		89	73	81	117	360	100%
N (Documents)		3	2	3	3	11	

In terms of the solutions domain, most sub-regions were consistent with each other in the frequency of a given code (Table 5.4). Resiliency efforts was, overall, mentioned the most with the highest occurrences in the Lower and Outer Cape, respectively. There are two likely explanations for this. First, the resiliency efforts mentioned during the interviews are those occurring within their town as well as those occurring in other towns that they plan to try and do themselves. Therefore, a town was not only discussing what they are doing but what they plan to do therefore elevating the reported frequency of resiliency efforts. Second, Massachusetts Coastal Zone Management (CZM) has two grant programs specifically geared towards coastal resiliency projects that have allowed a number of towns to undertake projects, making the reported frequency of resiliency efforts more uniform. In particular, towns in the Mid (Barnstable), Lower (Brewster), and Outer Cape (Provincetown) have received these grants, sometimes for multiple projects. Fortunately, these state (MA) grant programs seem to have increased awareness of coastal hazard exposure and encouraged towns to incorporate coastal resiliency into their planning process.

5.3.2 Code Relations Overlap Analysis: Conditions, Barriers, and Solutions

Code relation analysis illustrates the interrelatedness of certain codes indicating a relationship between the different aspects of coastal hazard mitigation planning on Cape Cod. Figure 5.2 illustrates how each domain contains at least one set of codes that overlapped more than others with the larger dots representing the magnitude of overlap. In general, there is more overlap between codes within the same domain than across domains, which is consistent with how the codes were organized into three conceptual domains and speaks to the robustness of the codes to discriminate between domains. Therefore, for organizational purposes, the following discussion is separated into the three conceptual domains.

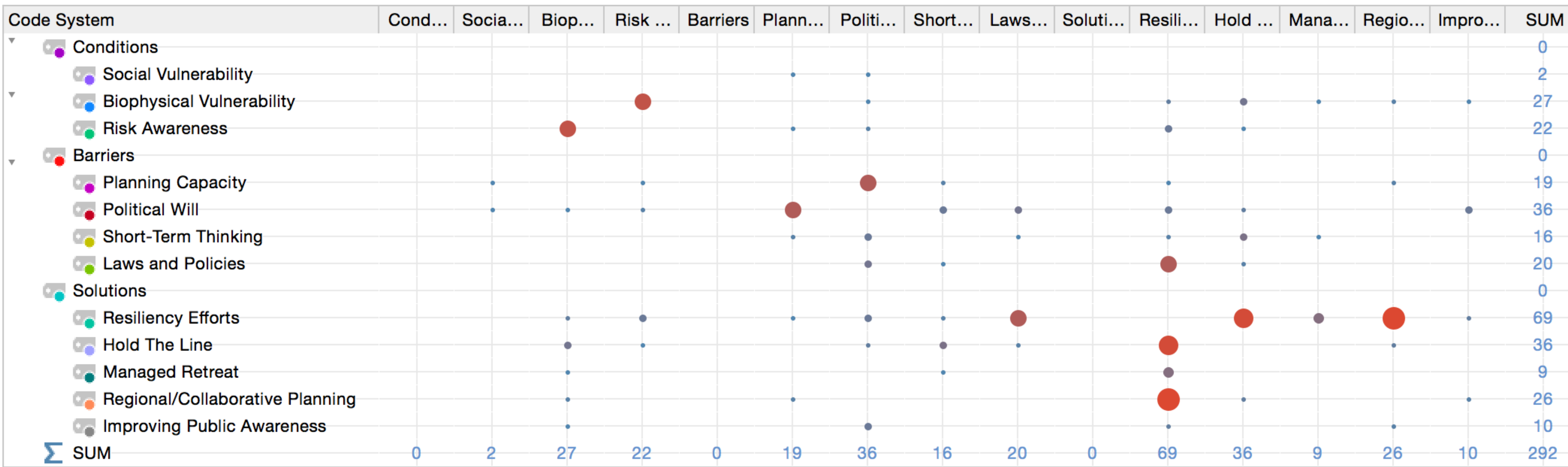

Figure 5. 2. Code relations overlap analysis of semi-structured interviews

5.3.2.1 Conditions

Within the conditions domain, risk awareness and biophysical vulnerability clearly overlap the most (Figure 5.2). This is expected given that both these codes center on the awareness of the frequency and magnitude of coastal hazards as well as physical exposure of natural and built infrastructure. Conversely, social vulnerability refers to the demographic and economic conditions that influence people's ability to cope with and respond to hazards. Based upon the interviews and frequency analysis, it is clear that biophysical vulnerability is a dominant issue across Cape Cod. As one regional participant noted,

> Cape Cod really feels the brunt of Nor'easters, particularly our north coastline, which faces the Bay, has experienced some of the worst erosion…I think up until recent times people thought of the eroding coastline as being the Atlantic facing coastline…But in recent years, it's been the communities along the north side of the Bay facing shoreline that have experienced some really impressive erosion…houses falling into the ocean type of thing (CCC Participant).

Nor'easters, and to a lesser degree hurricanes, cause the majority of coastal flooding and are critical to the natural processes of erosion and accretion, which is how Cape Cod was formed and is maintained (CCNS Participant). As a participant from Barnstable articulated "We do have several barrier beaches and several others that are really affected by just the fact that we're not really a solid land mass here. We're a shifting, evolving, ever-changing town and our coastal environment is constantly changing. And we're pushing and pulling with it." Erosion and flooding are only hazards to humans and their property, which is the risk people undertake when they decide to live in coastal areas. Therefore, the primary reason for the existence of biophysical vulnerability is that land use and development patterns have been concentrated directly along the shoreline putting infrastructure and people in harm's way to flooding from storm surge. Provincetown, the first landing site of the Pilgrims, is located at the tip of the Outer Cape and was historically a fishing community that has since been transformed into an artistic retreat and tourism destination. Due to its historical industry, of course, its commercial center and residential structures were built directly adjacent to the waterfront on the Cape Cod Bay side. As a result, "…whereas, other towns…might have not developed their waterfront so intensely, we have zoning that is very dense, but that reflects the traditional land use patterns" (Provincetown

Participant). To compound this dense, waterfront development pattern the Cape Cod National Seashore (CCNS) owns about 75% of the land in Provincetown. This has created a highly, biophysically vulnerable situation where Provincetown and its residents are locked into the area already developed along the Bay with no opportunity to move inward or develop elsewhere due to the protected land of the CCNS. With biophysical exposure comes an increasing awareness of the risks of coastal hazards: "I think that the Outer Cape is especially at risk because we're like a very narrow spit of sand, and I think that it's likely that one major storm could go through and, you know, essentially turn Provincetown into an island" (Provincetown Participant).

Risk awareness, like biophysical and social vulnerability, falls under the same domain because it reflects a particular context on Cape Cod under which planning and decision-making operates. It represents opinions regarding the frequency and magnitude of coastal hazards as a function of changes in climate. Risk awareness is an important condition that can either help or hinder coastal hazard mitigation planning. Given that climate change is a long-term process, it is important to educate people that there can be considerable variation from year to year but that, over time, the variation is a part of the larger change in our climate and that there are many factors that may be demonstrating climate change (CCS Participant). As a result, it can be challenging to garner enough public concern and political support to incorporate climate change considerations into long-term planning given the myriad of uncertainties. Even though climate change remains a contested and politically fraught topic, some regional decision-makers believe Cape residents are becoming more accepting and aware of climate change and its associated coastal hazard, sea level rise. In fact, the Cape Cod Commission[15] has noticed a real shift in opinion between now and when they last updated their Regional Policy Plan five or so years ago. Not so much that it is universal "…but that there's a lot more acceptance that, yes, something is happening and that we...need to be prepared for those events…you know—major storms, coastal erosion, climate change" (CCC Participant). This growing acceptance was particularly apparent during a polling exercise in the town of Barnstable where it became clear that "…the vast majority

[15] The Cape Cod Commission is the land use planning, economic development, and regulatory agency overseeing all 15 Cape Cod towns.

of people both support…local government municipal action around dealing with and being prepared for climate change and that they really think that local decision makers should be taking climate change into account when making decisions" (Barnstable Participant). Given the low-lying topography of most Cape Cod towns, it is likely the connection to sea level rise, stronger storm surge, and subsequent exacerbation of coastal erosion that is making climate change more accepted. In other words, it is the increasing biophysical exposure of people and property that is also increasing residents' risk awareness. Despite apparent risk awareness on Cape Cod, the region still faces barriers to its coastal hazard mitigation planning.

5.3.2.2 Barriers

While the conditions domain sets the context of what coastal hazard mitigation planning is facing on Cape Cod, there are certain barriers to effectively addressing these conditions. The two major barriers are political will and planning capacity as illustrated by their relationship to one another (Figure 5.2). Massachusetts, along with Connecticut, Rhode Island, New Hampshire, Vermont, and Maine, have a basic unit of local government and local division of state authority known as the "New England town." These towns are fully functioning municipal divisions with similar powers and authority as cities in other states and are governed by a town meeting legislative body. Principally used in the six New England states, the town meeting is a form of direct democratic rule that has been in place since early colonial times in the 17^{th} Century. During such meetings, town members that are registered voters legislate policy and budgets for local government. This gives community members' significant decision-making power over a variety of issues and projects that are put forth. Furthermore, it is necessary to highlight that county government is relatively weak in New England states. In Massachusetts, 8 of the 14 counties have been abolished and the county boundaries are only retained for judicial and census purposes. Given this style of decision-making, it is not surprising that political will was mentioned significantly more times at the local scale (i.e., 58) than at the regional (i.e., 21) (Table 5.3).

Cape Cod is unique because despite the strong "New England town" form of government, the region still has a functioning county government (i.e., Barnstable County) with a powerful planning and regulatory agency known as the Cape Cod Commission. These two jurisdictional scales have created an interesting push-pull dynamic of policymaking particularly in terms of coastal hazard mitigation planning. As a Brewster participant noted how:

> There's a lot of local control…the state has various policies and recommendations that really can only be executed at the local level, because only the local level has the jurisdiction. And there's a bit of that [tension] between towns and…the Cape Cod Commission because it does have regulatory authority…I think that is at times a challenge. The other side of that is…in many ways, local governments are much more agile...

On the one hand, local governments, based on their more direct decision-making process, can be more agile in effecting change than a regional authority. On the other hand, local input via town meetings can actually inhibit planning efforts. It is this last point where political will can be a significant barrier to the coastal hazard mitigation planning process. The first challenge is getting people interested in the need for and value of coastal planning and sustainable land use decisions let alone educating them on the issues to be voted on (Chatham Participants). As a Truro participant mentioned, it is a challenge to just get people to attend public hearings to learn more about the issues and provide their input before the town meeting occurs. The town meeting is supposed to be the time where decisions are made and all it takes is "…one person standing up that says 'I don't understand this' and asks questions…that really has nothing to do with what's before the town meeting…and it kills the whole proposal" (Truro Participant).

Education and interest levels are not the only reasons why political will can be a barrier to planning efforts on Cape Cod. Even more challenging, particularly in the case of coastal issues, are the tensions between private property and public wellbeing. In Massachusetts in general and on Cape Cod in particular, "It's so personal property rights oriented out here that anytime you're going to implement something that restricts somebody from building on their property it's going to be an enormous political process" (Barnstable Participant). Coastal hazard mitigation, by its very definition, is used to minimize the impacts of coastal hazards on people and their property. Therefore, it forces people, properties, and future development along the coastline to become more resilient. Traditional techniques can include prohibitions on where structures are built, restrictions on what type of structures can be built, codes on how they are built, required upgrades to existing structures, etc. In general, Cape Cod citizens dislike being told what to do with their property and so:

> …There's kind of resistance to regulation. You know it's a little bit like the Wild Wild West out here…I think this is generally true all over—although I do think it's magnified in Provincetown—people don't want to be regulated. They feel like they own their property and they should be able to do whatever they want to do with it" (Provincetown Participant).

Economics is embedded in the private property rights position on Cape Cod due to high property values, particularly for beachfront. People buy land and expect to get a return on their investment, however, restrictions, even when well intentioned, can inhibit the economic viability of resale. In addition to the economic aspect, people also buy in coastal areas because of the natural amenities that provide aesthetic and recreational uses. Consequently, they dislike being told that they might have to live differently such as "They may have to move homes away from water. They may have to abandon some areas. They may have to invest in green infrastructure so that the impacts around them are less" (Nature Conservancy Participant). As a result of these tensions, there is a constant balancing act in decision-making between recognizing private property interests and implementing coastal hazard mitigation techniques that are, in the long-term, for everyone's wellbeing.

It is more often than not this conflict of interests and priorities that results in political will that is against hazard mitigation. This, in turn, can impact the planning capacity of the individual towns and regional authorities by influencing the budget and resources allocated to coastal hazard mitigation projects. A Barnstable participant eloquently summarized the situation that many Cape Cod towns are facing:

> We're a local government. We are stretched thin. I mean, I can't tell you how thinly we're stretched, like crazy. So, there's just not a lot of internal capacity to do that just because there's not a lot of money and not a lot of political will to fund planning efforts all the time…I would love to be able to do a huge town wide hazard mitigation planning effort. But, I mean reality is I have to do the day to day zoning and applications and variances…and the constant phone calls and emails…that directly take the money, funding, and staffing in our department.

As with most decision-making, issues are prioritized and the most immediate concerns are addressed first even at the expense of other important issues that operate on a longer timeframe. The critical challenge with coastal hazard mitigation is that so long as people and property are exposed there will always be risk, making planning a never-ending endeavor requiring resources and political support: “Keeping the attention on this is hard, because you’re talking about planning long-term…and you’re talking about sometimes taking resources…to do these plans that are for eventualities that might or might not happen” (WBNERR Participant). This challenge is particularly apparent for sea level rise and its effects on storm surge and erosion given its subtle development and uncertain future impacts. A Cape Cod Commission participant said that they hear the following a lot: “I don’t have time in my day to sit down and forward think…if you’re going to ask me to look at…vulnerability to sea level rise in the next 20 years, well that’s kind of hard for me because…I’m fixing a flooding problem that’s already happening down the road.” Along with the tensions between immediate and long-term planning, which are a major influence on the planning capacity for coastal hazard mitigation, there can also be a tendency for planning to operate in “silos” where the towns and their departments work independently of one another (Provincetown Participant). This is problematic considering that coastal hazards, by their nature, are trans-boundary and hazard mitigation planning is an ongoing process requiring both a long-term commitment and significant resources. Therefore, most of the solutions to addressing the conditions and barriers involve collaborative planning and implementation of coastal resiliency efforts.

5.3.2.3 Solutions

The solutions domain includes aspects of the planning process that focuses on addressing the main conditions on Cape Cod as well as overcoming the barriers that inhibit effective coastal hazard mitigation. Resiliency efforts is the most frequently discussed topic during the interviews (coded 129 times) representing 19.3% of the total number of coded segments (Table 5.3) and demonstrating, overall, how active Cape Cod communities are in improving their coping and adaptive capacities through mitigation planning and resiliency projects. There are two main observations regarding resiliency efforts. First, these activities are the nexus between all the other solutions codes but most especially for hold the line and collaborative planning (Figure 5.2). Second, resiliency efforts is the one code that consistently overlaps (to varying degrees) with each code in the other two domains (Figure 5.2) indicating that it is a keystone concept with important interactions between conditions and barriers.

The emphasis of resiliency, in this context, is to improve existing conditions (e.g., reduce biophysical and social vulnerabilities) and plan for the long-term in anticipation of an increase in climate-related coastal hazards. Therefore, there is a natural connection to biophysical vulnerability, risk awareness, as well as the barrier found in short-term thinking. Resiliency efforts can take a variety of forms and incorporate more than one particular approach. For example, the town of Brewster received a CZM resiliency grant for a coastal hazard mitigation plan for Breakwater Beach, which was beginning to being eroded by storm surge. Rather than facing a similar situation to Paine's Creek, another town beach where they had to retreat and downsize their parking lot significantly, the town decided to take proactive measures. They proposed pulling back the parking lot at Breakwater Beach 140 feet and rebuilding the primary dune that was lost during a winter Nor'easter so it would complement the dune to the east and provide a natural buffer against future storm surge (Brewster Participant). At a town meeting in August there was sufficient political will by the town residents to vote the plan into action, which is now underway. In this resiliency effort, not only is the town being proactive by trying to mitigate future impacts to this extremely popular beach but also are using a complementary mixture of both hold the line (i.e., dune restoration) and managed retreat (i.e., pulling back a parking lot) techniques. Furthermore, they are creating a citizen's advisory group to help develop a comprehensive beach plan that the town will use as a policy guide in future coastal hazard mitigation planning and land use decisions.

Green infrastructure, such as the dune restoration in Brewster, is an increasingly popular hold the line technique where natural features and processes of the coast are enhanced to minimize hazard impacts. Provincetown, using a CZM resiliency grant, has proposed a green infrastructure project to evaluate approaches for actively managing sediment of their shoreline and Provincetown Harbor. Working in conjunction with the Center for Coastal Studies, the first part of the project is to conduct a sediment budget analysis that essentially quantifies the direction, rate, and volume of material moving along the shore. Using the information learned from the analysis, they are looking at ways to offset some of the losses from storm surge erosion and encourage sediment movement to create a better balance in the system (CCS & Provincetown Participants). The Center for Coastal Studies has also conducted sediment budgets for other towns on Cape including Brewster, Dennis, and Chatham. They also plan to work with Barnstable and Sandwich, which just received a resiliency grant, to conduct an analysis of their shoreline. Conducting sediment budgets for all coastal towns provides critical information regarding the movement of sand and how towns are interconnected (not as independent as they think) with one another and how coastal hazard mitigation actions (e.g., revetments) in one town can affect other towns (e.g., more erosion of beaches downstream from armored areas).

Coastal processes and hazards cross municipal boundaries thereby requiring significant resources (i.e., funding, staff, expertise, etc.) for mitigation planning. Collaboration is an important solution that directly addresses planning capacity issues that are endemic in small towns like those on Cape Cod. Given the complex nature of coastal management and mitigation, "…whatever adaptation effort anyone picks—whether it's county, town, or site—has to involve so many different people then why not start from the beginning and collaborate with people" (CCC Participant). Local government is strong in Massachusetts so there can be a certain "It's mine mentality" that resists collaboration (APCC Participant) seeing it as infringing on their authority or as too complicated and time intensive. Fortunately, however, the majority of the resiliency efforts that Cape Cod towns and regional participants mentioned demonstrate a commitment to collaboration and the sharing of resources to better address the complicated issues of coastal hazard mitigation: "…I think everyone realizes you're all on Cape, we're in a unique area, we're obviously tied to the environment very closely, and we need to be proactive. So I think kind of through that there's a…good collaborative spirit and effort" (WHOI Participant). Again, given the pervasiveness of coastal hazards and despite the fierce independence of each town, there is growing recognition that towns cannot function as "silos" if they want to have proactive, integrated, and effective coastal hazard mitigation. Collaboration on Cape Cod is also expanding among different departments and organizations *within* towns in order to "…foster internal collaboration in the town to strengthen their own planning…" (WBNERR Participant). For example, WBNERR piloted a collaborative resiliency project within the Town of Falmouth to develop a Coastal Resiliency Index. Specifically, key people representing different departments (e.g., Public Works, Town Administrator, Conservation Commission, etc.) participated in a series of meetings where they answered a series of questions about coastal issues and collectively assessed their management effectiveness and preparedness. The outcome of the meetings was a ranking that serves as an internal check for the town regarding their coastal resiliency preparedness and planning. The most important takeaway, however, is not the ranking but the information gained during the discussions: "…people are talking through the challenges or talking through their experience or what they know…you get a lot of information about what's going on in their town, what they don't know about what each other are doing, [and] how they need to connect the dots" (WBNERR Participant). Ultimately, there are several benefits from this project including greater collaboration, pooling of resources, networking, as well as a vehicle to identify areas that need to be addressed and/or improved, which is exactly the purpose of a resiliency effort.

Resiliency efforts are not limited to specific projects but also take the form of new policies that are designed to: a) limit the degree of physical exposure (i.e., reduce biophysical vulnerability) of people and property and b) make it easier for citizens' to undertake more proactive strategies by modifying existing laws and policies that are barriers. On Cape Cod, limiting physical exposure to coastal hazards is difficult because land use patterns have resulted in dense beachfront development due to the natural amenities coastal areas provide. As a result, policymakers are trying to manage physical exposure in floodplains both for new and existing development. One of the most rigorous and contentious techniques to limit growth is to put a prohibition on new development in the flood plain. In 1984, Chatham (of the Lower Cape) passed a local zoning bylaw that delineates three types of activities in designated conservancy overlay districts[16] (including a floodplain district): permitted uses, special permit uses, and prohibited

[16] Overlay districts are used to establish alternative land use/development patterns in a designated area of a community. Usually for an area that requires special attention like an environmentally sensitive area or high hazard flood zone. The overlay is superimposed and

uses. Within the prohibited uses, the primary resiliency technique prohibits new residential development in all of the town's FEMA mapped floodplains as well as prohibits any new structures to be built in the town's "high hazard" zones (i.e., V-zones). This has served as an effective coastal hazard mitigation technique that protects people and property by preventing growth and settlement in known hazardous areas. This zoning bylaw was upheld in a landmark 2005 Massachusetts Supreme Court case that "…affirmed the authority of municipalities to regulate or even prevent residential or other high-risk development in flood-prone areas…" (Shaw, 2008). The drawback to this zoning bylaw, however, is that it only applies to new development and yet Chatham, like many other Cape Cod towns, was well developed by 1984.

The major challenge planners and policymakers are facing is how to manage existing development in ways that will minimize the effects of current and future coastal hazards. In Massachusetts, nonconforming or "grandfathered" uses are created during a zoning change and continue to exist even with the transfer of property (Chapter 40A, Section 6). Specifically, the Massachusetts Zoning Act states that "Except as hereinafter provided, a zoning ordinance or bylaw shall not apply to structures or uses lawfully in existence or lawfully begun, or to a building or special permit issued before the first publication of notice of the public hearing on such ordinance or by-law required by section five..." (Chapter 40A, Section 6). While this law and policy provides protection to private property and eases transitions as zoning changes, it has also become a barrier to potential coastal hazard mitigation efforts. The problem with using zoning to govern floodplains is that new ordinances oftentimes will not apply because of grandfathered rights. Consequently, grandfathered property remains at a greater risk and could potentially damage surrounding areas due to its vulnerable structures. Given this barrier, states and towns are trying to use innovative approaches to manage coastal development in a more sustainable and resilient manner. This is being accomplished by focusing on flood-resistant construction where existing structures that are being replaced or substantially improved are forced to follow the current building codes.

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usually supersedes the conventional zoning with regulations that either add to the existing rules or replace them.

An important floodplain mitigation technique is the raising of structures above floodwater heights so that damage is reduced. FEMA is responsible for mapping the flood zones of a community, which are then adopted by the community in order to be able to participate in FEMA's National Flood Insurance Program (NFIP). It is the NFIP that sets the minimum standards for floodplain management, including construction of new and substantially improved structures, which property owners must comply with to qualify for flood insurance. States and municipalities, however, are encouraged by NFIP to adopt higher standards, which further improve a communities' resiliency. In terms of elevating structures, NFIP uses the base flood elevation as the minimum height required to raise the structure and reduce flood damage. Base flood elevation (BFE) refers to the elevation of the flood that has a 1% chance of occurring in a given year. The BFE does not, however, incorporate projected sea level rise or its effects on storm surge. Therefore, the NFIP recommends including freeboard in building construction, which refers to the factor of safety expressed as feet above BFE (e.g., 1 foot of freeboard = 1 foot above BFE), which can significantly reduce flood impacts. In Massachusetts, the state building code incorporates the minimum standards set by the NFIP for general flood-hazard zones but does not require freeboard: "…all buildings or structures, including new or replacement manufactured homes, erected or substantially improved within a flood-hazard zone shall be elevated so that the lowest floor [e.g., basement/cellar] is located at or above the base flood elevation" (780 CMR 120.G.501.2). Furthermore, the State has taken a more proactive approach by including a freeboard requirement in designated "high hazard zones" (aka velocity zones) so that new, replaced, or substantially improved structures have their lowest floor at least two feet above the base flood elevation (780 CMR 120.G.601.2).

Unfortunately for Cape Cod towns, existing state laws and policies may limit the effectiveness of more resilient building design standards (e.g., elevating structures). Typically, municipalities can enact local ordinances that are more restrictive, that is having higher standards, than the State regulations. In the case of buildings, however, Massachusetts law states that the State Building Code governs all aspects of buildings and preempts any local ordinances, thereby, preventing local jurisdictions from regulating in that same arena [Enos v.

City of Brockton, 236 N.E. 2d 919, 921 (Mass. 1968)]. Since Massachusetts State Building Code does not require freeboard for flood-hazard zones, towns cannot pass ordinances requiring it even though “It would seem that freeboard, like provisions regarding density and massing of buildings, would be within the purview of the zoning power. However, in Massachusetts, the Attorney General’s office has opined that local jurisdictions are preempted from regulating freeboard by the State Building Code[17]” (Rinke & Fort, 2012, 93).

To overcome the Massachusetts State Code preemption barrier, towns are starting to devise ways to encourage property owners to freeboard. For example, in the town of Hull, south of Boston, its Board of Selectmen unanimously approved a new freeboard incentive program targeting both new and existing residential structures. The program will give a $500 credit towards building permitting costs if the property owners elect to incorporate two-feet of freeboard into their construction. An additional benefit that extends beyond this program is that the NFIP will reduce flood insurance premiums with the inclusion of a certain amount of freeboard. On Cape Cod, towns are also trying to encourage freeboarding by passing zoning ordinances that amend building height restrictions in all designated flood hazard zones (i.e., A- and V- zones).

Typically, if a property owner elevates their home above BFE it will likely exceed the town’s zoning height restrictions making it noncompliant and requiring a variance from the Zoning Board. To address this law and policy complication, Provincetown, Sandwich, and Dennis have recently passed zoning bylaw amendments via town meetings that changes their building height regulations in flood zones so that the height will be calculated from the BFE and not ground level (Provincetown, Sandwich, and Dennis Participants). A dual benefit to this resiliency effort is that “They would lose building height under the old zoning that they wouldn’t lose under the new zoning…that hopefully will encourage some to elevate their structures” (Dennis Participant). Furthermore, a broader benefit is the increased resiliency of the community at large as more of its structures are better protected not only from existing coastal flood hazards but also from future sea level rise and its effect on storm surges.

[17] Letter from Thomas F. Reilly, Attorney General, to Bonnie T. Pena-Andrade, Falmouth Town Clerk, re: Falmouth Fall Annual Town Meeting of November 13, 2001—Case #1921 (Mar. 15, 2002).

The suite of interconnected codes, representing conditions, barriers, and solutions, used in this analysis depict the complicated decision-making processes faced by Cape Cod coastal towns in dealing with hazard mitigation. Biophysical vulnerability and risk awareness reflect the conditions on Cape Cod that are the focus of coastal hazard mitigation planning. Political will, planning capacity, and laws and policies are oftentimes the greatest barriers to implementing solutions for improving these conditions. It is the resiliency efforts and collaborative planning that can be the most powerful tools to address barriers endemic to local planning efforts and facilitative more proactive coastal hazard mitigation strategies. The larger contribution of this chapter is in its assessment of governance and decision-making processes and how these shape communities' coping and adaptive capacities to mitigate the impacts of existing and future climate-related coastal hazards. Despite conducting three distinct assessments, the biophysical, social, and institutional are all important features that need to be considered collectively. Therefore, it is necessary to look at how these different features interact to shape the coping and adaptive capacities that, in turn, influence coastal hazard mitigation planning.

CHAPTER 6

LINKING OF BIOPHYSICAL & SOCIAL VULNERABILITY WITH GOVERNANCE & DECISION-MAKING

Hazards and vulnerability research has a rich and diverse history that originally focused on the hazards themselves (See White, 1974; White & Haas, 1975), and has evolved to consider the broader social, political, and economic contexts in which hazards occur (See Frazier et al., 2010; O'Keefe et al., 1976). Furthermore, hazards and vulnerability are becoming an increasingly important part of climate change research, particularly within the coastal context, as there is increasing evidence of interactions between climate change (e.g., sea level rise) and its effects on coastal systems (Church et al., 2013). Typically, many studies of sea level rise impacts have been conducted at the global or national spatial scales (Anthoff et al., 2010; Hinkel & Klein, 2009) and yet the impacts of coastal hazards are directly experienced at regional and local levels. Therefore, there is a discrepancy between global environmental change assessments (e.g., climate change) at certain scales and environmental management and policymaking at other scales (Cash & Moser, 2000; Wilbanks & Kates, 1999). My dissertation research narrowed this scalar gap by integrating three local scale assessments (i.e., biophysical vulnerability, social vulnerability, and governance and decision-making) into a single conceptual framework (Figure 2.4).

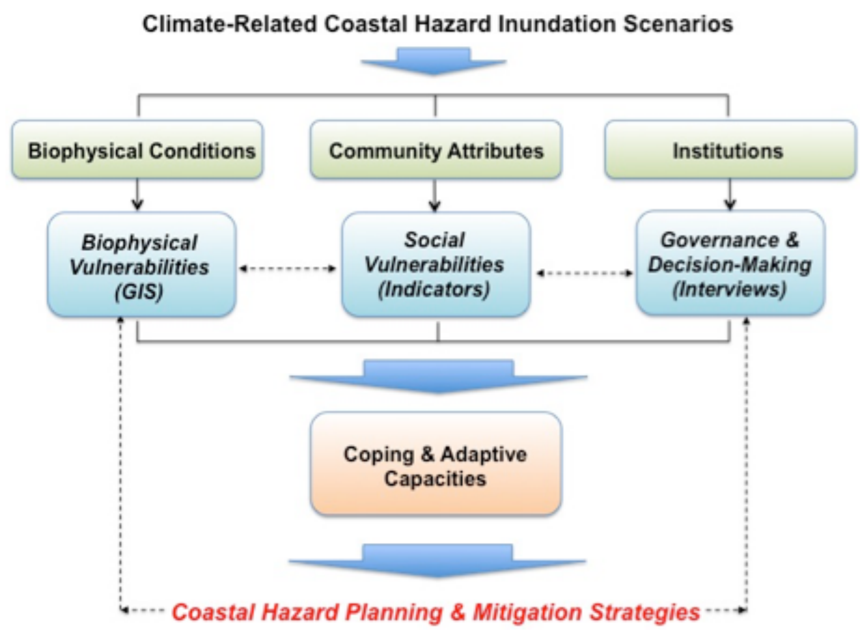

Figure 2. 4. Hazards, Vulnerabilities, and Governance Framework

Biophysical and social vulnerability are important, yet different, aspects of the conditions in which hazards occur. Within Cutter's (1996) "Hazards-Of-Place Model," biophysical and social vulnerabilities meld to create a specific "place vulnerability." Drawing from the governance and institutional literature, my research study assessed a third condition: governance and decision-making of coastal hazards. Examining the institutional governance and planning structures is critical to understanding how decision-making processes function and influence coastal hazard mitigation strategies. The barriers to effective decision-making create an "institutional vulnerability" and contribute to the overall "place vulnerability." Therefore, the power of this framework is that it not only considers biophysical and social vulnerability but also considers the existing governance and decision-making processes, all of which, together, shape communities' coping and adaptive capacities to mitigate the impacts of coastal hazards. To demonstrate the interactions between the three conditions, the discussion is organized as follows: 1) biophysical vulnerabilities and decision-making challenges, 2) natural infrastructure, gentrification vulnerabilities, and green infrastructure, and 3) social vulnerabilities, tourism, and decision-making.

6.1 Biophysical Vulnerabilities & Decision-Making Challenges

Cape Cod (i.e., Barnstable County) is isolated from the rest of the Commonwealth of Massachusetts by the Cape Cod Canal and extends into the Atlantic Ocean making it more physically exposed to coastal hazards than other Massachusetts counties. Based on the biophysical assessment in Chapter 3, however, Cape Cod faces different degrees of impacts from climate-related coastal hazards that vary across spatial scales (e.g., sub-regions and towns) and across natural and built infrastructure.

In general, there are two inundation patterns that affect most of the low-lying coastal towns of Cape Cod. First, a low intensity hurricane (i.e., Category 1) accounts for the majority of inundation relative to the maximum from a major hurricane (i.e., Category 3), which is illustrated by a map of Yarmouth (Figure 6.1). This is significant for hazard mitigation planning because it illustrates how the Cape does not need to experience a major hurricane, and its associated storm surge, to face considerable inundation exposure, which will be amplified by the addition of SLR over the coming years. Second, there are two areas in the Outer Cape where inundation waters from Cape Cod Bay merges with floodwaters from the Atlantic Ocean (Figure 6.2). This is significant because Provincetown and parts of Truro are at risk from being disconnected and isolated from the rest of the county from both a 1.0m SLR and a Category 1 hurricane. Both of these inundation patterns are important findings for short- and long-term hazard mitigation planning given the decision-making context on Cape Cod.

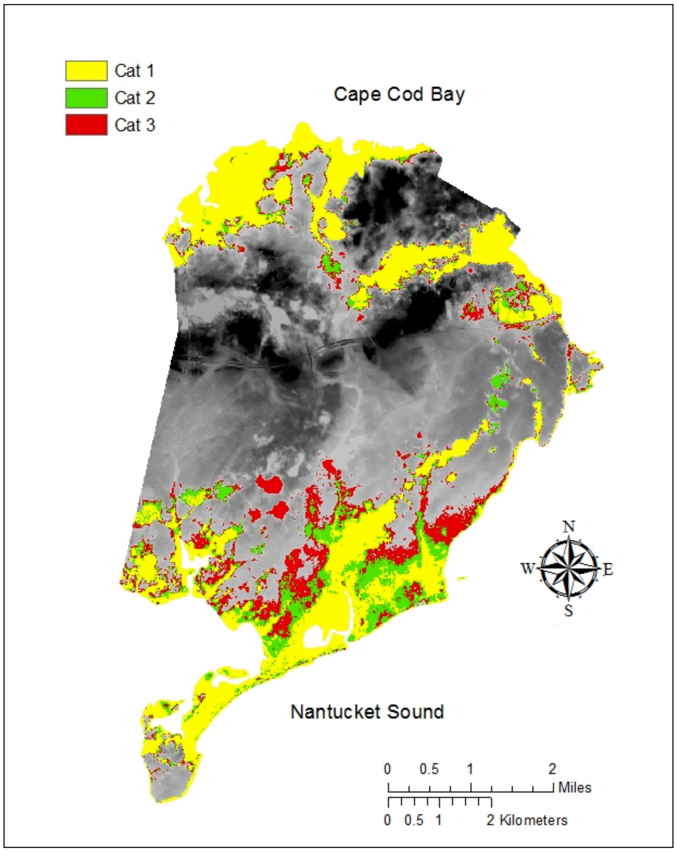

Figure 6. 1. Map illustrating Category 1, 2, and 3 hurricane inundations in Yarmouth

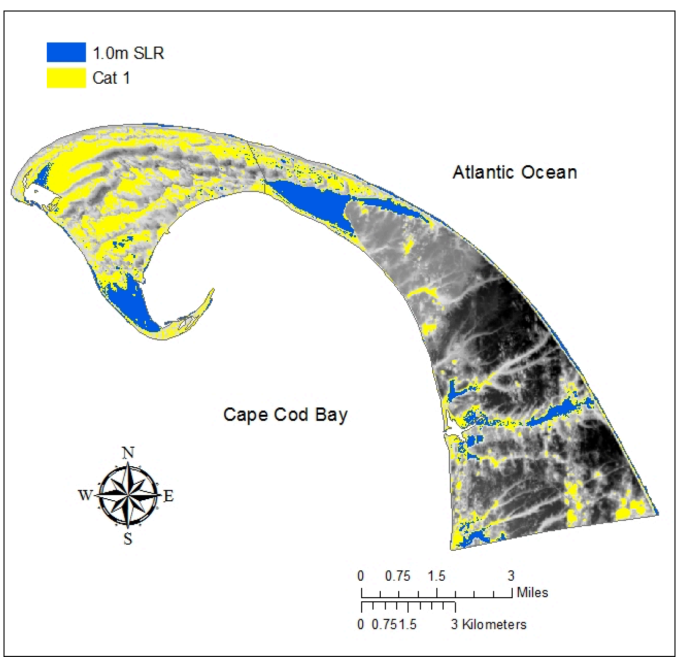

Figure 6. 2. Map illustrating 1.0m SLR and Category 1 hurricane inundations

Overall, most of the interview participants discussed Nor'easters and erosion as the most threatening coastal hazards to Cape Cod communities with only a few towns mentioning hurricanes as a serious concern. For decision-makers and planners, Nor'easters and erosion issues take priority over hurricanes given the frequency with which they occur. Furthermore, on Cape Cod, there are challenges to raising risk awareness regarding the threat from hurricanes that can translate into problems with garnering support for hazard mitigation planning (i.e., political will).

> … While on paper—you could say the region is very vulnerable to hurricanes, experientially we have a lot of people who just don't know what that means or they might see a hurricane…in different places and go, 'Wow—that's so awful.' That could happen here any time, but I think that when you don't have an experiential side, sometimes it's hard to motivate (WBNERR Participant).

Experience is oftentimes the strongest of teachers. The last time Cape Cod was directly impacted by a hurricane was over twenty years ago in 1991 when Hurricane Bob, a Category 2, made landfall in New England. There are many residents and decision-makers who have not experienced a hurricane on the Cape making it very difficult to garner concern, let alone support, for preparing for this type of coastal hazard. As a Dennis Participant noted, there are some cases where "…we have enough people here who are intelligent enough to look at Misquamicut…or live on the southern shore of Connecticut and live on New Jersey Shore—the summer people—they don't have blinders on…" In other words, these people survived the devastation of Hurricane Sandy and bring this experiential knowledge with them. As a result, they are more likely to actively support hazard mitigation efforts for hurricanes.

This particular issue of risk perception fits well within climate change risk perception research where risk awareness and perception are not only influenced by the risk characteristics (e.g., likelihood of event, impacts, etc.) but also people's personal experiences and interpretations as opposed to dry analytical facts (Carlton & Jacobson, 2013). Furthermore, a lack of experiential knowledge can also apply to sea level rise because it is so gradual that people do not notice it (Mashpee Participant) nor do they understand how it magnifies the effects of coastal storms like hurricanes and Nor'easters. The lack of risk awareness for hurricanes, despite the hazard impact analyses results in Chapter 3 indicating that a minimum of a Category 1 will be sufficient to cause considerable damage, presents two potential barriers to coastal hazard mitigation planning on Cape Cod. The first is a planning capacity problem where most Cape Cod towns have limited resources so the more immediate, acute coastal hazard concerns take priority over the more infrequent and/or long-term hazards. The second is the problem of political will, which, due to the lack of experience with hurricanes, makes it particularly difficult to motivate residents voting on hazard mitigation planning projects to be concerned with hurricanes and see them as a viable threat. In lieu of climate predictions of more frequent and intense storms, both of these barriers will need to be addressed in order to improve coastal hazard mitigation planning.

Considering the two major inundation patterns from a Category 1 hurricane, the Cape faces another challenge for decision-makers, particularly emergency managers, regarding its roadway system. Disruptions to this type of built infrastructure from climate-related coastal hazards are particularly problematic due to "…the fact that we're separated by two bridges and we have very limited options in terms of evacuation from major storms…that's a real choke point for the Cape…our reliance on the transportation infrastructure…" (CCC Participant). Furthermore, the acuteness of hurricane and Nor'easter storm surges makes impacts to roadways immediate. According to the roads analyses (Chapter 3), impacts vary both between roadway types and between towns illustrating the role topography and road density plays in influencing the extent and severity of road exposure to inundation. The greatest disruption to the major highways (i.e., Route 6 and State Routes) is clustered in the Mid and Outer Cape (Figures 3.13 & 3.14). This is particularly true in the Outer Cape where the addition of SLR increased Category 1 & 2 hurricane inundation of Route 6 by 100% in Truro and Provincetown and increased inundation of State Routes by 59% in Truro. The Mid and Outer Cape also face the greatest flooding of arterial and minor roads at 20-42% (Figures 3.15 & 3.16), due to the fact that these roads are at higher densities and located in more low-lying areas. With arterial and minor roads making up the majority of roadways, they are equally important in moving traffic across the Cape as the major highways.

Isolation from hurricane inundation and roadway disruptions illustrate how biophysically vulnerable the Outer Cape is to climate-related coastal hazards. As one interviewer succinctly pointed out:

> … I think that one of the biggest physical concerns is the Outer Cape essentially becoming an island…the Orleans Rotary, which is a major hub or node for all the roads on the Outer Cape, is at a pretty low elevation, and so it's vulnerable in the sense that it could be knocked out by a storm or by sea-level rise and that would essentially make the Outer Cape an island. There are also several low-lying areas…One is the Pamet River system…there's various points where it could, you know, isolate Provincetown…or could isolate parts of Truro from the rest of the Cape… (CCC Participant).

While knowing the potential disruptions to roadways is important, an equally important issue is to consider recovery. Notably, there is an added complication of determining who is responsible for road repair. While Route 6 is a U.S. Route that crosses state boundaries, its maintenance and repair, along with internal state routes, are the responsibility of the state of Massachusetts and, in some cases, even the local municipalities. Moreover, repairing arterial and minor roads is even more complicated as they are usually the responsibility of the towns and, at times, the actual residents, which has serious economic implications that will need to be addressed. Clearly, all of the potential impacts discussed present considerable challenges for both hazard mitigation planning and infrastructure recovery at the state, county, and town scales particularly during the peak summer season (Memorial to Labor Day) when more than three million tourists visit the Cape and utilize its amenities.

6.2 Natural and Green Infrastructure & Gentrification Vulnerabilities

Cape Cod's natural infrastructure (i.e., amenities like beaches, wetlands, etc.) is a considerable attraction to tourists, retirees, and second-homeowners alike. As the results of the gentrification vulnerability analysis in Chapter 4 indicate, all Cape Cod towns are experiencing some degree of coastal gentrification. In particular, North Eastham and Wellfleet in the Outer Cape have the highest and second highest overall gentrification vulnerability (Figure 6.3). Chatham and Orleans in the Lower Cape and Yarmouth in the Mid Cape all experience the third highest gentrification vulnerability (Figure 6.3). As more retirees move to these areas, housing disruptions occur where the costs of living increase displaces local residents and limits affordable housing for young families (e.g., teachers, fire fighters, police, etc.). This demographic bias toward a more elderly, services dependent population increases communities' social vulnerabilities by reducing coping capacities.

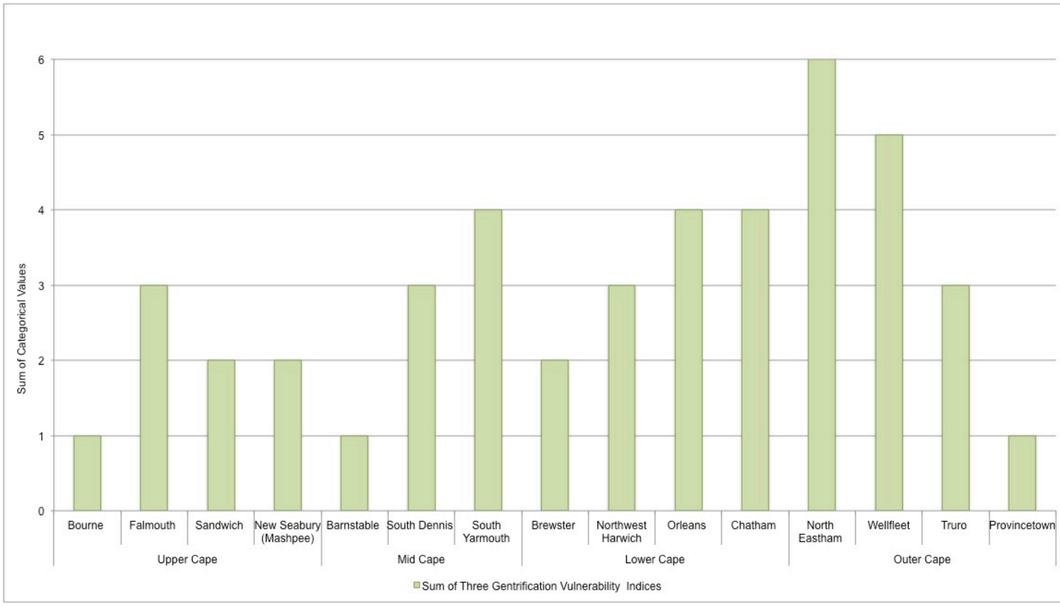

Figure 6. 3. Sum of categorical values assigned (0=<0.49, 1=0.50-0.99, 2=1.0+) to factor scores for each index to determine overall gentrification vulnerability for communities

The potential impacts to natural infrastructure from sea level rise and hurricane storm surge are most prominent in the Lower and Outer Cape. Overall, sea level rise permanently submerges more natural than built infrastructure (Figures 3.11 & 3.12), which is expected given that the types of natural areas examined (e.g., beaches, dunes, marshes, etc.) lie directly along the coast at low elevations and, therefore, are susceptible to the incremental changes in sea level. The greatest potential losses of natural infrastructure from SLR (14-32%) were found with Chatham (Lower Cape) suffering the most followed by its neighbors, Orleans (Lower Cape), Eastham (Outer Cape), and Yarmouth (Mid Cape) (Figure 3.11). Similarly, hurricane storm surges cause significantly more flooding of natural infrastructure with 7 out of 15 towns in the Mid, Lower, and Outer Cape experiencing at least 30% inundation with 46-64% inundation in Chatham (Lower Cape) and Provincetown (Outer Cape) (Figure 3.11). These inundation patterns overlap with the areas of high gentrification vulnerability making these towns both biophysically and socially vulnerable and, therefore, more sensitive to and less able to deal with the impacts of climate-related coastal hazards.

Natural infrastructure not only attracts but also protects development along the coast. Therefore, from a hazard mitigation planning perspective, the impacts to natural infrastructure, in the long term, from chronic SLR are more significant than those from acute storm surges since floodwaters eventually recede. The permanent loss of natural infrastructure, which serve as a protective buffer (Arekma et al., 2013; Barbier et al., 2013), from SLR has the potential to increase exposure of built infrastructure to erosion and storm surges. Furthermore, coastal development itself can reduce the effectiveness of natural infrastructure and increase areas' vulnerability to coastal hazards since it prevents the natural movement and migration of coastal resources (e.g., beach, dune system, salt marsh etc.), which "…increases our lack of resiliency to changes… just makes us more rigid" (CCC Participant). As a result, there has been a substantial effort by the Cape Cod Commission:

> … To try to promote smart growth—growth in areas that already have the development. And then maintain those green spaces in order to absorb the effects of some of these coastal changes because certainly marshes and natural areas are more resilient and more able to bounce back from these different hazards than, hardscape, man-made infrastructure" (CCC Participant).

At the local level, towns have taken this concern for natural infrastructure further through resiliency efforts that focus on green infrastructure projects, which can take a variety of forms (Chapter 5). For example, Provincetown is conducting a sediment budget analysis that will be used to inform a beach nourishment project, Brewster is reconstructing a major dune at Breakwater Beach to protect beach access, and Wellfleet is considering shellfish reef restoration to attenuate the impacts of storm surge on its coastline. Unlike hazard recovery projects, which are reactionary and try to fix what was damaged, the benefit of these resiliency projects is that they are forward looking and try to improve communities' capacities and preparedness by addressing known biophysical vulnerabilities and ensuring the long-term stability of their coastline.

6.3 Social Vulnerabilities, Tourism, and Decision-Making

Due to both its island-like isolation and natural amenities, Cape Cod has developed a reputation for being a tourist destination, retirement community, and playground for the wealthy. While these are all facets that make up Cape Cod, it is the year-round residents who are most affected by climate-related coastal hazards. From a social vulnerability perspective, these people "…who live here year-round don't necessarily live in the mansions…a lot of people who live here, struggle to live here…cost of living is high and salaries are low…" (CCC Participant) resulting in fewer resources for coping and recovery. Furthermore, as a result of gentrification, property values and taxes have increased to the point where they have exceeded the incomes of many local residents, particularly young adults, forcing them to live elsewhere. A Truro participant describes these struggles:

> The year round residents, the old Truro people who have been here for generations and the house has been passed from one to the next. A lot of those folks don't make a lot of money, struggle to make ends meet and pay their mortgages and pay their taxes and pay their insurance. I mean, our property insurance, real estate insurance on the Cape is huge, huge money…. There are people who really struggle with that. So we do have a vulnerable population and we have an older population.

This combination of social and gentrification vulnerabilities is not unique to Truro or the Outer Cape but exists throughout the county. For example, South Dennis of the Mid Cape exhibits the greatest social vulnerability compared to other Cape Cod communities (Figure 6.4), with especially high levels of poverty and personal disruption (Figure 4.3). This community is also moderately vulnerable to gentrification with higher degrees of retiree migration and moderate degrees of housing disruptions (Figure 4.4). In addition to the social and gentrification vulnerabilities, South Dennis also faces a high level of biophysical vulnerability to hurricane inundation of its built infrastructure (Figure 3.12). Consequently, South Dennis is likely to suffer more damage from coastal hazards while also facing greater challenges adapting to and recovering from these disruptions. In general, the more urbanized areas of South Dennis and Falmouth have some of the highest levels of poverty along with the more rural Monument Beach (Bourne) and Wellfleet (Figure 4.3). This contradicts the stereotypical view of some that the Cape is an exclusively wealthy enclave. Moreover, it also illustrates that almost every sub-region of the

Cape has areas with a greater number of people who have fewer financial resources and, subsequently, are far more vulnerable to coastal hazards. The social and gentrification vulnerabilities Cape Cod communities are facing are further compounded by the tourism vulnerabilities that affect the towns' and region's economy.

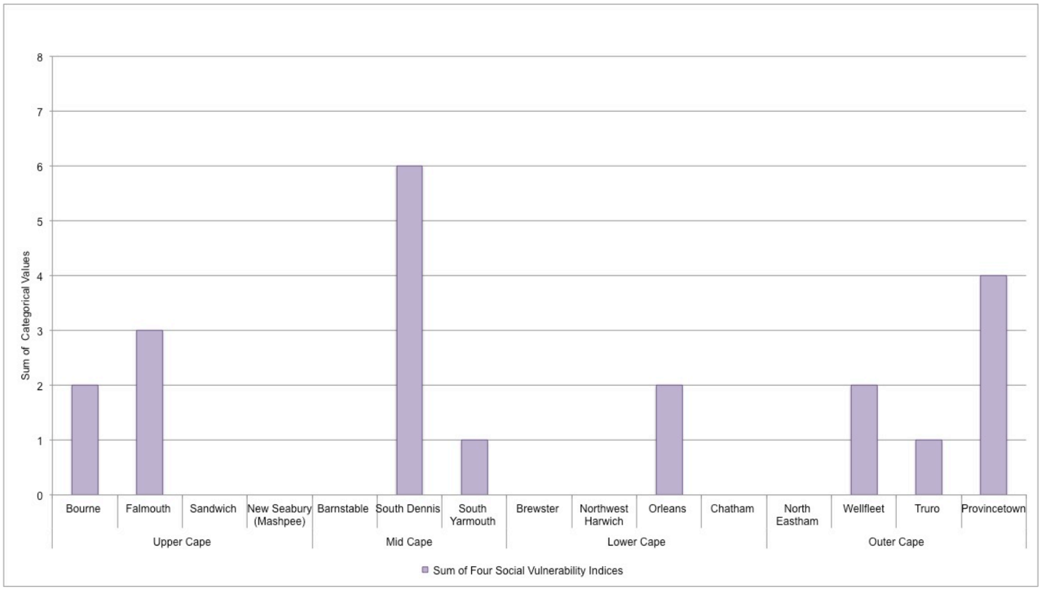

Figure 6. 4. Sum of categorical values assigned (0=<0.49, 1=0.50-0.99, 2=1.0+) to factor scores for each index to determine overall social vulnerability for communities

Tourism has become a major, if not the primary, economic industry on Cape Cod due to the attraction of its natural amenities and recreational opportunities (e.g., beaches, fishing, boating, etc.). Therefore, the impacts from climate-related coastal hazards to natural infrastructure and housing and tourism infrastructure have serious implications for those communities' whose economies are highly dependent on tourism by making it harder for them to recover. Hurricane inundation (both with and without SLR) of housing and tourism infrastructure is a particularly serious issue for hazard mitigation planners and decision-makers given both the immediacy and acuteness of impacts. In general, both year-round and seasonal properties make up the housing market, which contributes heavily to Cape Cod's tax base. More than 40% of seasonal housing, which is directly tied to summer tourism, is concentrated in areas closest to the coast (Figure 6.5) and, like natural infrastructure, is highly vulnerable to inundation. In particular, most Cape Cod towns could experience 15-48% their housing infrastructure inundated from hurricane storm surge (Figure 3.17), which translates into serious monetary damages reaching into the billions of dollars (Figure 3.19). Specifically, Bourne and Falmouth of the Upper Cape, Dennis and Yarmouth of the Mid Cape, Harwich of the Lower Cape, and Wellfleet and Provincetown of the Outer Cape are likely to experience the greatest amount of housing infrastructure inundation (Figure 3.17), including seasonal properties, which impacts both the real estate market and tourism.

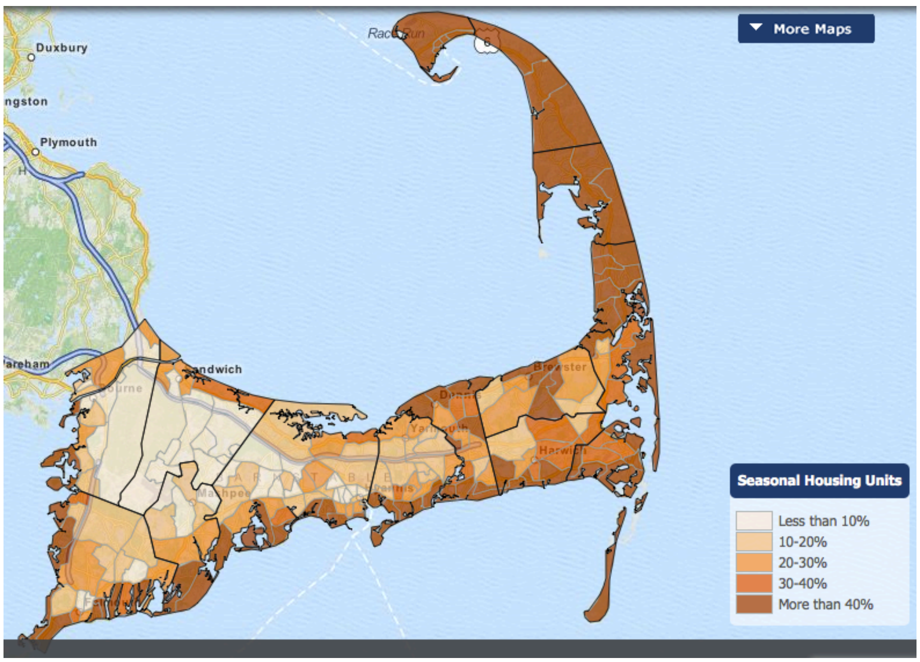

Figure 6. 5. Map illustrating percent of seasonal housing units on Cape Cod

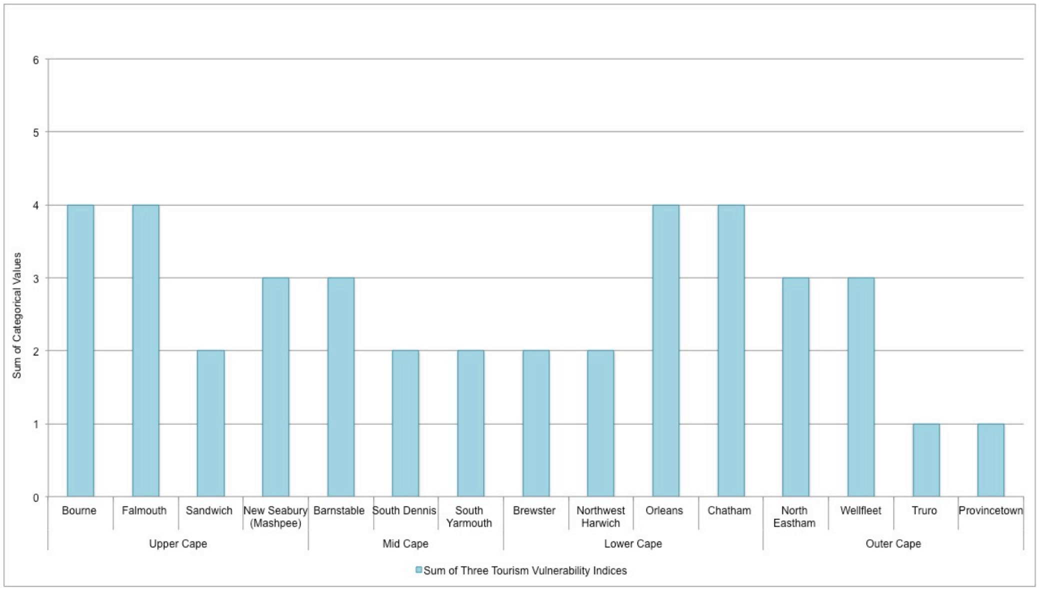

Figure 6. 6. Sum of categorical values assigned (0=<0.49, 1=0.50-0.99, 2=1.0+) to factor scores for each index to determine overall tourism vulnerability for communities

According to the Cape Cod Commission (2013), Barnstable County's core industries account for 66.5% of year-round employment of which most are tourism-related, including accommodation and food services (15, 405 employees), retail trade (15, 425 employees), and rental and real estate leasing (1, 315 employees). This is consistent with the results of the tourism vulnerability index analysis (Chapter 4) wherein the majority of Cape Cod towns show some degree of tourism activity and dependence. In particular, parts of the Upper Cape (i.e., Bourne and Falmouth) and the Lower Cape (i.e., Chatham and Orleans) have the highest overall tourism vulnerability followed by the Outer Cape (i.e., North Eastham and Wellfleet) (Figure 6.6). It is not surprising that Chatham and Orleans face similar degrees of tourism vulnerability as gentrification vulnerability given the presence of the Cape Cod National Seashore located in the Lower and Outer Cape, which attracts an estimated 4 million visitors each year. This relationship between tourism and gentrification vulnerabilities demonstrates how tourism can encourage more gentrification by attracting retirees, visitors, and second-home owners while the gentrification process can shift communities' economic bases towards more service-sector industries (Nelson et al., 2010) and encourage more tourism. The challenge these towns face is that because they appear to have both an unstable labor force and a greater amount of tourism amenities (i.e., infrastructure and support), they likely have a higher economic dependence on tourism and, subsequently, reduced capacities to recover from climate-related coastal hazards.

Hurricane storm surge, particularly with the added effects of sea level rise, has the potential to cause the most destructive impacts to Cape Cod’s tourism economy through both the inundation of its tourism infrastructure as well as the associated monetary damages. In particular, Provincetown on the Outer Cape, followed by Yarmouth and Dennis on the Mid Cape, have the highest tourism infrastructure inundation (Figure 3.18), which equates to approximately $100 million in damages (Figure 3.20). However, just because communities face a greater amount of housing and tourism infrastructure affected by coastal hazards does not mean that the monetary impact is equally high. For example, while Provincetown faces the greatest inundation of its tourism infrastructure with estimated damages between $53-103 million, Falmouth has even greater estimated damages at $130-200 million despite far less of its tourism infrastructure likely being inundated (Figure 3.18 & 3.20). The differences between the extent of tourism and housing infrastructure exposed to inundation and potential monetary damages are a function of not only the density of the infrastructure but also the value of properties, which can vary considerably across towns and sub-regions. This high economic investment in both housing and tourism infrastructure and potential damages from coastal hazards makes hazard mitigation decision-making a complicated process that requires balancing a variety of conflicting interests.

A notable challenge for decision-makers is managing private property and development interests in more sustainable and resilient ways. This is particularly difficult because of a combination of “…the absence of policy…market forces that continue to allow people to put development in vulnerable areas…[and] a lack of political will to restrict people’s right to develop property in a way that would protect them in the long term” (Barnstable Participant). Furthermore, property owners’ own risk perceptions and motivations influence the efficacy of hazard mitigation planning. For example, seasonal residents are focused on getting the highest use out of their Cape Cod property (many do not have mortgages) and enjoying it in the short term:

> … So if a hurricane comes…that's fine they'll just pay to rebuild another…so they're not worried about how much flood insurance is going to cost or the fact that those rates are going up. It's very much just my use and enjoyment at this immediate moment and they're not engaged in our community and thinking about long term planning or policy. They're just here to come and enjoy and leave (Barnstable Participant).

This indifferent mindset clearly presents barriers to long-term hazard mitigation planning because these property owners are less likely to support and take proactive mitigation and adaptive measures, reducing their communities' overall resiliency to coastal hazards. In contrast, other year-round and part-time residents are far more concerned about coastal threats to their considerable financial investment and tend to advocate for hard infrastructure solutions (e.g. armoring, revetments, etc.), which are not sustainable and tend to exacerbate erosion in unarmored areas (APCC and CCC Participants). There is a "resist and fight" mentality among these property owners "because sea level is rising and the storms are coming, you've got to batten down the hatches now" (Chatham Participants) rather than an "adapt" mentality that seeks long-term sustainable solutions. The problem with both of these interests is that they do not consider the interconnectedness of the coastal environment or the trans-boundary nature of these hazards. Therefore, finding ways to address, particularly through education and outreach, those interests that hinder hazard mitigation efforts is critical to gaining the political will required to develop more proactive planning and decision-making approaches for mitigating coastal hazards.

CHAPTER 7

CONCLUSION

Over the last half-century, hazards and disasters research has evolved from focusing almost exclusively on the actual physical events to considering the interaction between the hazard event and its impacts on society. In order to understand the implications of these interactions, it is necessary to recognize how societies' own actions create conditions that can magnify hazard effects by increasing both biophysical and social vulnerability. This is particularly evident in how human-nature interactions have modified the environment (e.g., filling wetlands, rebuilding in flood zones, etc.) making it less resilient to coastal hazards. The crucial point is that hazards and disasters exist in relationship to people and, therefore, such biophysical processes cannot be separated from social processes. Researchers have developed different models of how environmental processes coupled with social, political, and economic conditions interact to produce vulnerable conditions (See Chapman, 1994; Cutter, 2000; Mustafa, 2005; Wisner et al., 2004). This dissertation contributes to the development of the political ecology of hazard, risk, and vulnerability research in three key ways: 1) through the explicit integration of climate change projections into coastal hazard inundation models; 2) by placing coastal hazards impacts within a broader socio-economic context of tourism and natural amenities dependence; and 3) through the coupling of biophysical and social vulnerability assessments with an empirical examination of the coastal hazard mitigation planning and decision-making processes that shape vulnerabilities and coping and adaptive capacities.

7.1 Contributions & Major Findings

The first key contribution of this research is the explicit integration of climate change projections with coastal hazard inundation models to empirically demonstrate, at the local-scale, potential future interactions between climate change, coastal hazards, and community vulnerability (Chapter 3). The biophysical vulnerability assessment in Chapter 3 captured both the spatial distribution of sea level rise, hurricane storm surge, and their interactions as well as the magnitude and extent of inundation to natural and built infrastructure at both the regional and local scales. A critical finding of these analyses is that, under current conditions, a low-intensity hurricane (i.e., Category 1) accounts for the majority of inundation relative to a high-intensity hurricane (i.e., Category 3). Consequently, Cape Cod only needs to experience a Category 1 hurricane to face considerable inundation exposure. This is an important consideration for emergency management and hazard mitigation planning given the expected increase in sea surface temperature (Kirtman et al., 2013) and the potential relationship between intervals of warmer sea surface temperatures and increases in hurricane activity (Donnelly et al., 2015; Emanuel, 2005; Emanuel et al., 2004; Goldenberg et al., 2001). The second major finding is that while sea level rise has the least impact on Cape Cod communities compared to hurricane storm surge, it will likely exacerbate future hurricane (and Nor'easter) storm surges. Notably, in the future, SLR combined with a Category 1 hurricane could resemble (or exceed) the inundation impacts from a Category 2 hurricane experienced today, which is consistent with Frazier et al. (2010). This is noteworthy for long-term hazard mitigation planning because the Cape only has to experience less intense hurricanes as time passes and sea level rises to face similar impacts as current, high intensity hurricanes. From my interviews with town planners there is the perception that Cape Cod has been lulled into a false sense of security believing that hurricanes do not really affect Cape Cod given that it has been over 20 years since one has made landfall in the region. The results of the biophysical assessment illustrate, however, that low-intensity hurricanes could cause substantial damage to natural and built infrastructure both in the short- and long-term. The potential effects of climate change make these hazard risks even more pronounced and severe and, therefore, require more proactive hazard mitigation planning and decision-making.

A second contribution of this research is to improve our understanding of how the magnitude and severity of coastal hazards impacts are also a reflection of broader socio-economic processes in tourism and natural amenity dependent communities (Chapter 4). While the biophysical vulnerability assessment in Chapter 3 identified those Cape Cod communities with the highest expected exposure and potential damages, it was the socio-economic vulnerability assessment in Chapter 4 that identified those features of communities that indicate reduced capacities and resiliency. The social vulnerability indices were constructed to capture the general demographic and economic conditions on Cape Cod with particular emphasis on vulnerable groups of the population and their financial resources (i.e., lack thereof). The results indicate that there are socially vulnerable communities throughout Cape Cod with higher concentrations in the more urbanized areas of the Mid Cape and Upper Cape. This is an important finding as it contradicts the stereotypical view of Cape Cod, and coastal areas in general, as exclusively wealthy and privileged people with unlimited resources to recover from hazard events. Furthermore, the gentrification and tourism indices were developed to provide a more accurate depiction of the socio-economic disruptions and dependencies communities may be experiencing that also lessens their abilities to cope and adapt. As expected, the majority of Cape Cod towns show a moderate to high degree of tourism vulnerability indicating a higher economic dependence on tourism making them more vulnerable to the damages caused by coastal hazards. There is also a relationship between tourism and gentrification vulnerabilities. Specifically, tourism could encourage more gentrification by attracting new residents, which could change communities' economies by reducing the diversity of industries and making it more homogenous and service-oriented (e.g., tourism based) (Nelson et al., 2010). It is a combination of these disruptions, homogenizations (both labor force and economic industry), and dependencies that reduce Cape Cod communities' coping capacities and resiliency to climate-related coastal hazards. Consequently, those areas that are both biophysically and socially vulnerable will find it far more difficult to manage and adapt to coastal hazards. Conversely, those areas with low social vulnerability and high physical exposure are likely to have more resources for mitigation and adaptation.

The third key contribution of this dissertation is the assessment of coastal hazard governance and decision-making processes, within the context of the Cape's biophysical and social vulnerabilities, and the ways they shape communities' coping and adaptive capacities (Chapter 5 & 6). Management of risk and vulnerability is a core strategy of coastal hazard mitigation planning designed to enhance communities' abilities to cope with and recover from the impacts of hazards. Therefore, hazard mitigation planning and decision-making are inherently social, economic, and political processes. The governance assessment in Chapter 5 provides an in-depth account of the conditions, barriers, and solutions in which hazard mitigation planning operates on Cape Cod. Furthermore, understanding the relationships between the conditions, barriers, and solutions identifies the most influential factors affecting proactive hazard mitigation planning and decision-making. Based on the results of the thematic content analysis, risk awareness and biophysical vulnerability are the most important conditions that, subsequently, influence the degree of political will (i.e., barriers) for designing and implementing hazard mitigation projects (i.e., resiliency efforts).

Many participants stated that lack of education and concern about coastal hazard issues and conflicting private property rights interests are root causes of such low political will. While these issues are not unique to the Cape, they are even more relevant given the power and importance of local governance, where the political willingness to act is essential for supporting and implementing proactive hazard mitigation efforts at the local level. Town governance can also influence planning capacity because residents directly vote on coastal issues and budgets through town meetings. Resiliency efforts are the primary strategy used both to address biophysical vulnerabilities (i.e., conditions) as well to overcome laws and policies (i.e., barriers) that constrain proactive hazard mitigation planning and decision-making. The level of risk awareness and political will are key to enforcing or expanding existing laws and policies that influence and shape the planning capacity and resiliency efforts of Cape Cod towns to deal with hazards. These are important findings because they are the areas that decision-makers can try to improve upon and, subsequently, increase communities' resiliency. Lastly, it is clear that a discrepancy exists between the scales at which hazard events occur and those at which hazard mitigation planning and decision-making operates. Consequently, mitigation efforts are likely to continue to be local and piece-meal in the absence of regional, state, and federal scale planning that can provide a more cohesive and integrated strategy for hazard mitigation planning.

7.2 Limitations & Future Directions

The overarching purpose of this case study was to create as comprehensive an account as possible of the biophysical and social vulnerabilities Cape Cod towns could experience as well as to describe the complicated hazard mitigation and decision-making processes influencing these communities' abilities to proactively plan for and recover from coastal hazards. Considering the different methods and analyses, there are certain limitations to this study, which are discussed along with recommendations for future research.

In the biophysical vulnerability assessment (Chapter 3), a series of hazard inundation scenarios were created to model the effects of sea level rise, hurricane storm surge, and their interactions on natural and built infrastructure. One limitation of this assessment is that the sea level rise inundation model is a "worst-case" scenario based on global projections and does not consider regional variations. In particular, a one-meter increase was chosen based on semi-empirical models and the IPCC's upper bound range of the global mean projection for 2100 (RCP8.5) (Church et al., 2013; Grinsted et al., 2009; Kopp et al., 2014; Rahmstorf, 2007; Vermeer & Rahmstorf, 2009). This projection assumes that carbon dioxide emissions continue to rise throughout the 21st century unchecked. A future line of inquiry would be to incorporate regional variation in sea level rise by considering the effects of land subsidence and variations in ocean currents (especially the Gulf Stream), which could provide more locally and regionally specific sea level rise inundation information useful for coastal hazard mitigation planners. Another limitation is that the hurricane storm surge scenarios were developed to create plausible inundation impacts based on historical hurricane events and trajectories for New England. Considering the potential changes in climate, these historical hurricane patterns may become less relevant in the future. Notably, as sea surface temperatures are expected to increase over the 21st century (Kirtman et al., 2013), hazard mitigation planners and decision-makers need to consider the likelihood that hurricanes of different intensities could become more frequent. Similarly, the potential changes to Nor'easter intensity and frequencies from climate change also need to be considered. Since these large-scale, extratropical storms occur annually (even multiple times in a year) causing intense coastal inundation and erosion, a future direction of research would be to see how these coastal hazards can be modeled and integrated into hazard assessments not only for Cape Cod but for the larger regional New England coastline. Specifically, these models would need to include the influences of sea level rise to produce the most useful estimates of storm surge and erosion over the next century. Pursuing these limitations and recommendations would help refine our understanding of the biophysical vulnerabilities of communities to future coastal hazards as well as the uncertainties related to climate change effects.

The indices constructed in Chapter 4 were designed to capture social, gentrification, and tourism vulnerabilities at the community level. While these vulnerability indices help describe the socio-economic conditions of Cape Cod communities there are limitations to this approach. First, not all of the data collected was available at the census designated place (CDP) level and had to be acquired from a larger geographic division. The drawback to increasing the geographic boundary is that the diversity of socio-economic conditions within a particular town is lost due to aggregation. Consequently, the index results may not be as meaningful for those towns as at the CDP level. In this study, however, the municipal civil division (MCD) was necessary to ensure communities were represented that would otherwise have been excluded (e.g., Wellfleet and Truro). The advantage to these indices is that they can be applied to different coastal communities to identify those that may be particularly vulnerable to the impacts of coastal hazards for a given dimension (e.g., social, gentrification, tourism). The next important step in this research would be to spatially link the potential inundation impacts from the hazards scenario models (Chapter 3) with the vulnerability indices. In particular, while the Cape has a reputation for being wealthy, the social vulnerability index results indicate pockets of poverty on Cape Cod where people have reduced financial resources and coping capacities. An important future study for Cape Cod and other coastal communities would be to overlay the spatially explicit inundation patterns from the hazard scenario models for a particular area with the spatial extent of socially vulnerable communities (determined by the indices) and designated environmental justice communities in order to identify those that are both biophysically and socially vulnerable. The larger benefit to such a study would be that local and regional decision-makers could use such information to devise programs that would strengthen assistance to the socially vulnerable both in terms of hazard preparedness and recovery, thereby improving their adaptive capacities. Another direction for future study would focus on the social and economic shifts that occur between tourism and gentrification. Specifically, this relationship needs to be more thoroughly explored in terms of its affect on communities' resiliency to coastal hazards.

In Chapter 5, I used primary data collected from semi-structured interviews to examine the complicated processes of hazard mitigation planning and decision-making on Cape Cod. One important limitation of this study is that I was unable to get the participation of every town on Cape Cod. Therefore, I was not able to include the perspectives from managers in those communities. Another limitation is that the participants were restricted to decision-makers, planners, and researchers. Based on the results of this assessment, it is clear that risk awareness and political will are important barriers to effective hazard mitigation planning and implementation. These results in conjunction with the role of local governance through the power of town meetings indicates that residents play an important role in planning and decision-making processes. Therefore, a future direction of research would be to explore residents' views on risk perceptions of coastal hazards, climate change, hazard mitigation planning, and resiliency efforts through interviews and participation in town meetings. This direction of research would provide a more complete picture of coastal hazard mitigation planning and decision-making by including the perspectives of a key group of stakeholders. A particularly interesting line of inquiry would be to examine the influence of second-homeowners in local governance, especially in terms of hazard mitigation decision-making. This is inspired by the unforeseen situation where second-homeowners tried to claim residency solely to be able to vote (mostly against) at the town meeting on the Breakwater Beach resiliency project in Brewster. This direction of research could be designed to create an interesting comparison between different natural-amenity rich environments with hazards (e.g., forests, mountainous areas, coastal towns etc.) where second-property owners are powerful stakeholders with differing priorities.

7.3 Closing

Historically, hazard and disaster impacts were viewed as independent "acts of God" separate and distinct from societal inputs. That perspective has, however, evolved to where current and future hazard impacts are the result of complex interactions between human and natural activities. The current view of climate-related coastal hazards is that they are a function of human activities in concert with nature, which increases uncertainties and makes it challenging to forecast future risks with any degree of reliability. Two important characteristics of climate-related coastal hazards are: 1) they are not easily defined (i.e., having multiple origins and large-scale geographic and socio-economic impacts) affecting present and future generations and 2) they are not isolated occurrences but cross territorial, political, and economic boundaries (Beck, 1995). As a result, large-scale hazards do not have a historical comparison and are not easily studied, understood, or mitigated.

The State of Massachusetts has been an important facilitator in improving coastal hazard mitigation through its Coastal Zone Management resiliency grant programs, which have resulted in a number of coastal communities being able to take a more proactive approach in their hazard mitigation planning. Not all states, however, provide these resources and, considering the costs associated with planning and the uncertainties of future events, many communities do not have the resources to support long-term planning efforts. Therefore, a critical step to improving planning capacity is to set aside resources specifically for long-term mitigation efforts, which are less likely to be de-prioritized by more immediate planning concerns. Having institutional support for planning is not enough if there is a lack of political will to support and implement the plans. The implementation of actions to minimize hazard impacts and address vulnerabilities is where the rubber meets the road, so to speak. The strength of local governance and involvement of different stakeholders who are not planners, scientists, etc. and have different priorities make implementing hazard mitigation actions particularly challenging. This is compounded by the fact that planning for climate-related coastal hazards requires projecting into the future, despite inherent scientific uncertainties, and a corresponding commitment of resources, which inspires resistance both in town governments and residents.

It is clear from this study's analysis of governance that Cape Cod towns cannot hold tight to their independent thinking but will need to be more collaborative. Otherwise, mitigation efforts will always be local and piece-meal despite the fact these hazards are often large scale and cross-jurisdictional boundaries. Therefore, Federal and State support in terms of providing financial resources, an integrated planning framework, consistent land use and zoning regulations, and compliance monitoring will be necessary to holistically address both short- and long-term coastal hazards.

The research conducted for this dissertation employs a Hazards, Vulnerabilities, & Governance Framework (Figure 2.4), which includes the addition of an institutional and governance component that examines coastal hazard mitigation planning and decision-making processes. The results from my assessments using this approach, while specific to Cape Cod, demonstrate that this framework can be used successfully to provide a clearer understanding of how the interactions between coastal hazard impacts, community vulnerabilities, and coastal hazard governance influence the efficacy of long-term hazard mitigation planning at the community and regional scales. In so doing, this dissertation demonstrates the potential, broader applicability of this framework for assessing other types of hazards (e.g., floods, fires, contaminant spill, etc.) operating at a wide range of spatial and governance scales.

There is no “one-size-fits” all approach to mitigating coastal hazards or navigating its complex planning and decision-making processes. Rather, it is necessary to examine communities’ vulnerabilities, planning, and decision-making processes at local scales so that resiliency and mitigation efforts are as socially and politically flexible as possible and specific to the unique set of issues and circumstances which individual communities experience. Therefore, the transferability of this approach is that it provides a comprehensive, systematic, and structured framework that is also flexible. It can be tailored to assessing the biophysical and social vulnerabilities from a wide range of hazard impacts while also considering the institutional and governance practices that shape communities’ capacities for proactive and effective hazard mitigation.

REFERENCES

Adger, W., Hughes, T., Folke, C., Carpenter, S.R., & Rockstrom, J. (2005). Social-ecological resilience to coastal disasters. *Science* 309, 1036-1039.

Adger, W.N. (2003). Social aspects of adaptive capacity. *In: Climate change, adaptive capacity and development*. Smith, J.B., Klein, R.T., & Huqh, S. (Eds.). London, UK: Imperial College Press.

Anthoff, D., Nicholls, R.J., & Tol, R.S.J. (2010). The economic impact of substantial sea-level rise. *Mitig. Adapt. Strateg. Glob. Change* 15, 321-335.

ArcGIS Resources Center (2013). *How IDW works*. Retrieved from http://resources.arcgis.com/en/help/main/10.1/index.html#/How_IDW_works/009z00000075000000/.

Arkema, K., Guannel, G., Verutes, G., Wood, S. A., Guerry, A., Ruckelshaus, M., Kareiva, P., Lacayo, M., & Silver, J.M. (2013). Coastal habitats shield people and property from sea-level rise and storms. *Nature Climate Change* 3 (10), 913-918.

Armor, D.J. (1974). Theta reliability and factor scaling. *Sociological Methodology*, 5, 17-50.

Balica, S., Wright, N., & Meulen, F. (2012). A flood vulnerability index for coastal cities and its use in assessing climate change impacts. *Natural Hazards* 64(1), 73-105.

Barbier, E.B., Georgiou, L.Y., Enchelmeyer, B., & Reed, D.J. (2013). The value of wetlands in protecting Southeast Louisiana from hurricane storm surges. *PLos ONE* 8(3), 1-6.

Barnes, F. (1958). *Cape Cod In History*. National Park Service Region Five.

Beck, U. (1995). *Ecological politics in an age of risk*. Cambridge UK: Polity Press.

Bernard, R.H. (2011). *Research methods in anthropology: Qualitative and quantitative approaches* (5th Ed.) UK: AltaMira Press.

Bettini, G. (2013). Climate barbarians at the gate? A critique of apocalyptic narratives on 'climate refugees.' *Geoforum* 45, 63-72.

Bianchi, S.M., & Spain, D. (1996). Women, work, and family in America. *Population Bulletin* 51(3), 2-47.

Blomquist, W., & deLeon, P. (2011). The design and promise of the institutional and development framework. *Policy Studies Journal* 39(1), 1-6.

Bolin, R. (1993). *Household and community recovery after earthquakes*. Boulder, CO: Institute of Behavioral Science, University of Colorado.

Bolin, R., & Stanford, L. (1991). Shelter, housing and recovery: A comparison of US disasters. *Disasters* 15(1), 24-34.

Boruff, B., Emrich, C., & Cutter, S. (2005). Erosion hazard vulnerability of US coastal counties. *Journal of Coastal Research* 21(5), 932–943.

Brooks, N., & Adger, W.N. (2005) Assessing and enhancing adaptive capacity. In: *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*.

Cambridge UK: Cambridge University Press.

Carlton, S.J., & Jacobson, S.K. (2013). Climate change and coastal environmental risk perceptions in Florida. *Journal of Environmental Management* 130, 32-39.

Cash, D.W., & Moser, S.C. (2000). Linking global and local scales: Designing dynamic assessment and management processes. *Global Environmental Change* 10, 109-120.

Chapman, D. (1994). *Natural hazards*. London: Oxford University Press.

Church, J.A., Clark, P.U., Cazenave, A., Gregory, J.M., Jevrejeva, S., Levermann, A., Merrifield, M.A., Milne, G.A., Nerem, R.S., Nunn, P.D., Payne, A.J., Pfeffer, W.T., Stammer, D., & Unnikrishnan, A.S. (2013). Sea level change. In*: Climate Change 2013: The Physical Science Basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., & Midgley, P.M. (Eds.). Cambridge, UK and New York, NY: Cambridge University Press.

Clark E., Johnson, K., Lundholm, E., & Malmberg, G. (2007). Island gentrification and space wars. In *A World of Islands: An Island Studies Reader.* G. Baldacchino (Ed.). Agenda Academic & Institute of Island Studies: Malta and Canada.

Clark, G., Moser, S., & Ratick, S. (1998). Assessing the vulnerability of coastal communities to extreme storms: The case of Revere, MA. *Mitigation and Adaptation Strategies for Global Change* 3, 59–82.

Colburn, L. L., & Jepson, M. (2012). Social indicators of gentrification pressure in fishing communities: A context for social impact assessment. *Coastal Management* 40, 289-300.

Collins, T.W. (2009). The production of unequal risk in hazardscapes: An explanatory framed to disaster at the US-Mexico border. *Geoforum* 40, 589-601.

Comrey, A.L., & Lee, H. (1992). *A first course in factor analysis*. Hillsdale, NJ: Erlbaum.

Cooper, H.M., Chen, Q., Fletcher, C.H., & Barbee, M.M. (2012). Assessing vulnerability due to sea-level rise in Maui, Hawai‘i using LiDAR remote sensing and GIS. *Climatic Change* 116(3-4), 547–563.

Cowell, P.J., Stive, M.J.F, Niedoroda, A.W., De Vriend, H.J., Swift, D.J.P., Kaminsky, G.M, & Capobianco, M. (2003). The coastal tract (Part I): A conceptual approach to aggregated modeling of lower-order coastal change. *Journal of Coastal Research* 19, 828-848.

Crossett K., Ache, B., Pacheco, P., & Haber, K. (2013). *National coastal population report: Population trends from 1970 to 2020*. Silver Springs, MD: National Oceanic and Atmospheric Administration.

Cutter, S.L. (1996). Vulnerability to environmental hazards. *Progress in Human Geography* 20(4), 529–539.

Cutter, S.L., & Finch, C. (2008). Temporal and spatial changes in social vulnerability to natural hazards. *PNAS* 105(7), 2301–6.

Cutter, S., Mitchell, J., & Scott, M. (2000). Revealing the Vulnerability of People and Places : A Case Study of Georgetown County, South Carolina. *Annals of the Association of American Geographers* 90(4), 713–737.

Cutter, S.L., Boruff, B., & Shirely, W. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly* 84(2), 242-261.

Davis, B.C. (2004). Regional planning in the US coastal zone: A comparative analysis of 15 special area plans. *Ocean & Coastal Management* 47, 79-94.

Dietz, T., Ostrom, E., & Stern, P.C. (2003). The struggle to govern the commons. *Science* 302 (5652), 1907-1912.

Donnelly J.P., Hawkes A.D., Lane P., Macdonald D., Shuman B.N., Toomey M.R., van Hengstum P.J., & J.D. Woodruff (2015). Climate forcing of unprecedented intense-hurricane activity in the last 2000 years. *Earth's Future* 3(2), 49-65.

Dorst, N. (2014). What is the average forward speed of a hurricane? Hurricane Research Division, NOAA. Retrieved from http://www.aoml.noaa.gov/hrd/tcfaq/G16.html.

Douglas, M., & Wildavsky, A. B. (1982). *Risk and culture: An essay on the selection of technical and environmental dangers*. Berkeley: University of California Press.

Dryzek, J. (2005). *The politics of the earth: environmental discourses* (2nd Ed.). New York, NY: Oxford University Press.

Eakin, H., & Appendini, K. (2008). Livelihood change, farming, and managing flood risk in the Lerma Valley, Mexico. *Agric Hum Values* 25, 555-566.

Emanuel, K. (2005). Increasing destructiveness of tropical cyclones over the past 30 years. *Nature* 436(7051), 686–688.

Emanuel, K., DesAutels, C., Holloway, C., & Korty, R. (2004). Environmental control of tropical cyclone intensity. *Journal of Atmospheric Science* 61(7), 843–858.

Emrich, C.T., & Cutter, S. (2011). Social vulnerabilityto climate-sensitive hazards in the Southern United States. *Weather, Climate, and Society* 3, 193-208.

Enarson, E., & Morrow, B. (1998). *The gendered terrain of disaster*. New York, NY: Praeger.

Folke C., Colding, J., & Berkes, F. (2002). Building resilience for adaptive capacity in social-ecological systems. In: *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change.* Berkes F., Colding, J., & Folke, C. (Eds). Cambridge, UK: Cambridge University Press.

Folke C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. *Annual Review Environmental Resources* 30, 441-473.

Ford, J., & Berrang-Ford, L. (2013). How to Track Adaptation to Climate Change: A Typology of Approaches for National-Level Application. *Ecology & Society* 18(3).

Fothergill, A., & Peek, L.A. (2004). Poverty and disasters in the United States: A review of recent sociological findings. *Natural Hazards* 32, 89-110.

Fothergill, A., Maestas, E.G.M., & Darlington, J. D. (1999). Race, ethnicity and disasters in the United States: A review of the literature. *Disasters* 23(2), 156-173.

Frazier, T. G., Wood, N., Yarnal, B., & Bauer, D. H. (2010). Influence of potential sea level rise on societal vulnerability to hurricane storm-surge hazards, Sarasota County, Florida. *Applied Geography* 30(4), 490–505.

Friesinger, S., & Bernatchez, P. (2010). Perceptions of Gulf of St. Lawrence coastal communities confronting environmental change: Hazards and adaptation, Quebec, Canada. *Ocean & Coastal Management* 53, 669-678.

Ge, Y., Dou, W., Gu, Z., Qian, X., Wang, J., Xu, W., Shi, P., Ming, X., Zhou, X., & Chen, Y. (2013). Assessment of social vulnerability to natural hazards in the Yangtze River Delta, China. *Stochastic Environmental Research and Risk Assessment* 27(8), 1899–1908.

Glass, R. (1964). Introduction. In: *Aspects of Change, Centre for Urban Studies* (Ed.). London UK: MacGibbon & Kee. xii-xlii.

Goldenberg, S. B., Landsea, C. W., Mestas-Nuñez, A. M., & Gray, W. M. (2001). The recent increase in Atlantic hurricane activity: Causes and implications. *Science* 293(5529), 474–479.

Gorsuch, R. L. (1983). *Factor analysis* (2nd Ed.). Hillsdale, NJ: Erlbaum.

Gosnell, H., & Abrams, J. (2011). Amenity migration: Diverse conceptualizations of drivers, socioeconomic dimensions, and emerging challenges. *GeoJournal* 76, 303-322.

Grinsted, A., Moore, J., & Jevrejeva, S. (2009). Reconstructing sea level from paleo and projected temperatures 200 to 2100AD. *Climate Dynamics* 34, 461-472.

Gunerlap B., Guneralp, I., Castillo, C.R., & Filippi, A.M. (2013). Land change in the Mission-Arkansas coastal region, Texas: Implications for coastal vulnerability and protected areas. *Sustainability* 5(10), 4247-4267.

Hamnett, C. (1991). The blind men and the elephant: The explanation of gentrification. *Transactions of the Institute of British Geographers* 16, 173-189.

Heinz Center for Science, Economics, and the Environment (2000). *The hidden costs of coastal hazards: Implications for risk assessment and mitigation*. Covell, CA: Island Press.

Hewitt, K. (1983). *Interpretations of Calamity*. Winchester, VA: Allen and Unwin, Inc.

Hewitt, K. (1997). *Regions of risk: A geographical introduction to disasters*. New York, NY: Routledge.

Hill, A., & Cutter, S.L. (2001). Methods for determining disaster proneness. *In: American Hazardscapes: The Regionalization of Hazards and Disasters*, S.L. Cutter (Ed.). Washington, D.C.: Joseph Henry Press.

Hinkel, J. & Klein, R.J.T. (2009). Integrating knowledge to assess coastal vulnerability to sea-level rise: The development of the DIVA tool. *Global Environmental Change* 19, 384-395.

Holling, C.S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4, 1-23.

Jackson, R. (2006). Bruny on the brink: Governance, gentrification, and tourism on an Australian Island. *Island Studies Journal* 1(2), 201-222.

Jacob, S., Weeks, P., Blount, B., & Jepson, M. (2013). Development and evaluation of social indicators of vulnerability and resiliency for fishing communities in the Gulf of Mexico. Marine Policy 37, 86-95.

Jacob, S., Weeks, P., Blount, B.G., & Jepson, M. (2010). Exploring fishing dependence in gulf coast communities. *Marine Policy* 34(6), 1307-1314.

Janssen, M.A., Schoon, M.L., Ke, W., & Börner, K. (2006). Scholarly networks on resilience, vulnerability and adaptation within the human dimensions of global environmental change. *Global Environmental Change* 16(3), 240–252.

Jepson, M., & Colburn, L.L. (2013). *Development of social indicators of fishing community vulnerability and resilience in the U.S. Southeast and Northeast regions*. NOAA Technical Memorandum NMFS-F.SPO-129.

Johnston, R.J., Gegory, D., Pratt, G., & Watts, M. (2000). *The Dictionary of Human Geography (4th Ed.)*. Oxford, UK: Wiley-Blackwell.

Kahan, D. (2012). Cultural cognition as a conception of the cultural theory of risk. *In: Handbook of Risk Theory: Epistemology, Decision Theory, Ethics, and Social Implications of Risk*. Roeser, S., Hillerbrand, R., Sandin, P., & Peterson, M. (Eds.). Springer Reference Publishing.

Kaiser, H.F. (1970). A second generation Little Jiffy. *Psychometrika*, 35, 401-415.

Kasperson, J.X., Kasperson, R.E., & Turner, B.L. (1995). *Regions at risk: Comparison of threatened environments*. United Nations University Press.

Kildow, J.T., Colgan, C.S., Scorse, J.D., Johaston, P., & Nichols, M. (2013). *State of the U.S. ocean and coastal economies*. Center for the Blue Economy at the Monterey Institute of International Studies. Retrieved from www.oceaneconomics.org.

Kirtman, B., Power, S.B., Adedoyin, J.A., Boer, G.J., Bojariu, R., Camilloni, I., Doblas-Reyes, F.J., Fiore, A.M., Kimoto, M., Meehl, G.A., Prather, M., Sarr, A., Schär, C., Sutton, R., van Oldenborgh, G.J., Vecchi G., & Wang, H.J. (2013). Near-term climate change: Projections and predictability. In: *Climate Change 2013: The Physical Science Basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex V., & Midgley, P.M. (Eds.)., Cambridge, UK and New York, NY: Cambridge University Press.

Kleinosky, L. R., Yarnal, B., & Fisher, A. (2006). Vulnerability of Hampton Roads, Virginia to storm-surge flooding and sea-level rise. *Natural Hazards* 40(1), 43–70.

Kopp, R.E., Horton, R.M., Little, C.M., Mitrovica, J.X., Oppenheimer, M., Rasmussen, D.J., Strauss, B.H., & Tebaldi, C. (2014). Probabilistic 21st cent 22nd century sea-level projections at a global network of tide-gauge sites. *Earth's Future* 2(8), 383-406.

Lamarque, J.C. (2009). *The Making of a Waterfront Suburb: An Ethnography of Coastal Gentrification in New Jersey* (Doctoral Dissertation). Anthropology, Rutgers, The State University of New Jersey, New Brunswick, NJ.

Landis, J.R., & Koch, G.G. (1977). The measurement of observer agreement for categorical data. *Biometrics* 33, 159-174.

Leiss, W. (1994). The domination of nature. Montreal, Quebec: McGill Queens University Press.

Lichter, M., & Felsenstein, D. (2012). Assessing the costs of sea-level rise and extreme flooding at the local level: A GIS-based approach. *Ocean & Coastal Management* 59, 47-62.

Lombard, M., Snyder-Duch, J., & Bracken, C.C. (2002). Content analysis in mass communication: Assessment and reporting of intercoder reliability. *Human Communication Research* 28, 587-604.

Mahlstedt, T., & Loparto, L. (1986). Chapter 1: Topographic overview. *In: Historic & Archeological resources of Cape Cod & the Islands: A framework for preservation decisions.* Massachusetts Historical Commission.

Malm, A., & Esmailian, S. (2013). Ways in and out of vulnerability to climate change: Abandoning the Mubarak project in the Northern Nile Delta, Egypt. *Antipode* 45 (2), 474-492.

Mcleod, J.B. (2008). *Second-home owner attachment to a destination: A driver of tourism promotion.* Las Vegas: University of Nevada, Las Vegas.

Merchant, C. (1980). *The death of nature, women, ecology, and the Scientific Revolution*. San Francisco, CA: Harper and Row.

Miles, M.B., Huberman, A.M., & Saldana, J. (2014). *Qualitative data analysis: A methods sourcebook* (3rd Ed.) Los Angeles, CA: Sage Publishing.

Mileti, D.S., & O'Brien, P.W. (1992). Warnings during disaster: Normalizing communicated risk. *Social Problems* 39, 40-57.

Miller, F., Osbahr, H., Boyd, E., Thomall, F., Bharwani, S., Ziervogel, G., Walker, B., Birkmann, J., van der Leeuw, S., Rockstrom, J., Hinkel, J., Downing, T., Folke, C., & Nelson, D. (2010). Resilience and vulnerability: Complementary or conflicting concepts? *Ecology & Society* 15 (2).

Montz, B.E., & Evans, T.A. (2001). GIS and social vulnerability analysis. *Coping With Flash Flood (Part I)*. Netherlands: Springer Publishing.

Muller, B., & Schulte, S. (2011). Governing wildfire risks: What shapes county hazard mitigation programs? *Journal of Planning Education & Research* 31, 60-73.

Muller, D.K., Hall, C.M., & Keen, D. (2004). Second home tourism: Impact, planning and management. In: *Tourism, mobility and second homes: Between elite landscape and common ground*. C.M. Hall & D.K. Muller (Eds.). Clevedon, England: Channel View.

Munaretto, S., Siciliano, G., & Turvani, M. E. (2014). Integrating adaptive governance and participatory multicriteria methods: a framework for climate adaptation governance. *Ecology and Society* 19(2).

Mustafa, D. (2005). The production of an urban hazardscape in Pakistan: Modernity, vulnerability, and the range of choice. *Annals of Assoc. American Geographers* 95(3), 566-586.

National Hurricane Center (2016). *Sea, lake, and overland surges from hurricanes (SLOSH)*. Retrieved from http://www.nhc.noaa.gov/surge/slosh.php.

National Research Council (1983). *Risk assessment in the federal government: Managing the process.* Washington, D.C.: National Academy Press.

Nelson, P.B. (2008). Life-course influences on nonearnings income migration in the United States. *Environment and Planning A* 40, 2149-2168.

Nelson, P.B., Oberg, A., & Nelson, L. (2010). Rural gentrification and linked migration in the

United States. *Journal of Rural Studies* 26, 343-352.

Nicholls, R.J., Wong, P.P., Burkett, V.R., Codignotto, J.O., Hay, J.E., McLean, R.F., Ragoonaden, S., & Woodroffe, C.D. (2007). Coastal systems and low-lying areas. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., & Hanson, C.E. (Eds). Cambridge, UK: Cambridge University Press.

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L., & West, J. (2004). Mapping vulnerability to multiple stressors: climate change and globalization in India. *Global Environmental Change* 14(4), 303–313.

O'Keefe, P., Westgate, K., & Wisner, B. (1976). Taking the naturalness out of natural disasters. *Nature* 260.

Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. New York, NY: Cambridge University Press.

Ostrom, E. (2005). *Understanding institutional diversity*. Princeton, NJ: Princeton University Press.

Paavola, J. (2007). Institutions and environmental governance: A reconceptualization. *Ecological Economics* 63, 93-103.

Parkins, J.R., Stedman, R.C., &. Beckley, T.M. (2003). Forest sector dependence and community well-being: A structural equation model for New Brunswick and British Columbia. *Rural Sociology.* 68(4), 554-572.

Parris, A., Bromirski, P., Burkett, V., Cayan, D., Culver, M., Hall, J., Horton, R., Knuuti, K., Moss, R., Obeysekera, J., Sallenger, A., & Weiss, J. (2012). Global sea level rise scenarios for the US National Climate Assessment. *NOAA Technical Memo OAR CPO-1*, 1-37.

Parrish, D.A., Townsend, L., Saunders, J., Marney, G., & Langston, C. (1993). US EPA comparative risk project: Evaluating ecological risk. In: *Environmental modeling with GIS*. Goodchild, M.F., Parks, B.O., & Steyaert, L.T. (Eds.). New York, NY: Oxford University Press.

Peacock W., B.H. Morrow, & H. Gladwin (1997). *Hurricane Andrew and the reshaping of Miami: Ethnicity, gender, and the socio-political ecology of disasters*. Gainseville FL: University Press of Florida.

Pendleton, E.A., Thieler, E.R., & Williams, S. J. (2010). Importance of coastal change variables in determining vulnerability to sea-and lake-level change. *Journal of Coastal Research* 26(1), 176-183.

Petrolia, D.R., Landry, C.E., & Coble, K.H. (2013). Risk preferences, risk perception, and flood insurance. *Land Economics* 89(2), 227-245.

Polsky C., Neff, R., & Yarnal, B. (2007). Building global change vulnerability assessments: The vulnerability scoping diagram. *Global Environmental Change* 17, 472-485.

Pomeroy, R.S., & Ahmed, M. (2006). Fisheries and coastal resources co-management in Asia: selected results from a regional research project. *WorldFish Center Studies and Reviews*

30. Penang, Malaysia.

Pulido, L. (2000). Rethinking environmental racism: White privilege and urban development in southern California. *Annals of the Association of American Geographers* 90(1), 12-40.

Quarantelli, E.L. (1992). *Urban vulnerability and technological hazards in developing societies.* Newark, DE: University of Delaware, Disaster Research Center.

Rahmstorf, S. (2007). A semi-empirical approach to projecting future sea-level rise. *Science* 315, 368-370.

Rinke, N., & Fort, S. (2012). Legal options for municipal climate adaptation in South Boston: An example for Connecticut coastal jurisdictions. *Sea Grant Law & Policy Journal* 5(1), 89-97.

Romieu, E., Welle, T., Schneiderbauer, S., Pelling, M., & Vinchon, C. (2010). Vulnerability assessment within climate change and natural hazard contexts: revealing gaps and synergies through coastal applications. *Sustainability Science* 5(2), 159–170.

Schmidt L., Prista, P., Saraiva, T., O'Riordan, T., & Gomes, C. (2013). Adapting governance for coastal change in Portugal. *Land Use Policy* 31, 314-325.

Shaw, W. (2008). Case study-A Cape Cod community prevents new residences in floodplains. Storm Smart Coasts, Massachusetts Office of Coastal Zone Management. Retrieved from http://www.mass.gov/eea/docs/czm/stormsmart/ssc/ssc3-chatham.pdf.

Shepard, C.C., Agostini, V.N., & Gilmer, B. (2012). Assessing future risk: Quantifying the effects of sea level rise on storm surge risk for the southern shores of Long Island, Mew York. *Natural Hazards* 60(2), 727-745.

Sherwood, E.T., & Greening, H.S. (2014). Potential impacts and management implications of climate change on Tampa Bay estuary critical coastal habitats. *Environmental Management* 53, 401–415.

Singleton Jr., R.A., & Straits, B.C. (1999). *Approaches to social research* (3rd Ed.). New York, NY: Oxford University Press.

Slovic, P. (1987). Perception of risk. *Science* 236, 280-285.

Slovic, P. (2001). *The perception of risk*. London, UK: Earthscan.

Small, C., & Nicholls, R.J. (2003). A global analysis of human settlement in coastal zones. *Journal of Coastal Research* 19, p. 584-599.

Snow, M.M., & Snow, R.K. (2009). Modeling, monitoring, and mitigating sea level rise. *Management of Environmental Quality* 20(4), 422-433.

Solecki, W.D., & Oliveri, C. (2004). Downscaling climate change scenarios in an urban land use change model. *Journal of Environmental Management* 72(1-2), 105–15.

StatsAmerica (2014). USA counties in profile. Retrieved from http://www.statsamerica.org/USCP/default.aspx?geo_id=25001.

Stedman, R.C., Parkins, J.R., & Beckley, T.M. (2004). Resource dependence and community well-being in Rural Canada. *Rural Sociology.* 69(2): 213-234.

Susman, P., O'Keefe, P., & Wisner, B. (1983). Global disasters, a radical interpretation. In: *Interpretations of Calamity*, K. Hewitt (Ed). Winchester, VA: Allen and Unwin, Inc.

Swyngedouw, E. (1999). Modernity and hybridity: Nature, regeneracionismo, and the production of the Spanish waterscape, 1890-1930. *Annals of the Assoc. of American Geographers* 89(3), 443-465.

Thatcher, C.A., Brock, J.C., & Pendleton, E.A. (2013). Economic vulnerability to sea-level rise along the Northern U.S. Gulf Coast. *Journal of Coastal Research* 63, 234–243.

Titus, J.G., & Richman, C. (2001). Maps of lands vulnerable to sea level rise: Modeled elevations along the US Atlantic and Gulf coasts. *Climate Research* 18, 205-228.

Tobin, G., & Montz, B.E. (1997). *Natural hazards*. New York, NY: Guildford Press.

Turner, B. L., Kasperson, R.E., Matson, P.A, McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., Polsky, C., Pulsipher, A., & Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *PNAS* 100(14), 8074–9.

United Nations Development Program (2004). *Reducing Disaster Risk: A Challenge for Development*. Retrieved from www.undp.org/bcpr/disred/rdr.htm.

Valiela, I. (2006). *Global Coastal Change*. Oxford, UK: Blackwell Publishing.

Van Nieuwaal, K., Driessen, P., Spit, T., & Termeer, K. (2009). A state of the art of governance literature on adaptation to climate change: Towards a research agenda. *IOP Conference Series: Earth and Environmental Science* 6.

Vasileiadou, E., & Botzen, W.J.W. (2014). Communicating adaptation with emotions: The role of intense experiences in raising concern about extreme weather. *Ecology & Society* 19 (2).

Veland, S., Howitt, R., Dominey-Howes, D., Thomalla, F., & Houston, D. (2012). Procedural vulnerability: Understanding environmental change in a remote indigenous community. *Global Environmental Change* 23, 314-326.

Vermeer, M., & Rahmstorf, S. (2009). Global sea level linked to global temperature. *PNAS* 106 (51), 21527-21532.

Walker, B., Holling, C.S., Carpenter, S. & Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology & Society* 9(2).

White, G.F. (1974). Natural hazards research: Concepts, methods, and policy implications. *In: Natural Hazards: Local, National, Global*, G.F. White (Ed.). London, UK: Oxford University Press.

White, G.F., & Haas, J.E. (1975). *Assessment of research on natural hazards*. Boston, MA: MIT Press.

Wilbanks, T., & Kates, R.W. (1999). Global change in local places: How scale matters. *Climatic Change* 43, 601-628.

Wisner, B., Blaikie, P., Cannon, T., & Davis, I. (2004). *At risk: Natural hazards, people's vulnerability, and disasters* (2nd Ed.). London, UK: Routledge.

Wu, S.Y., Yarnal, B., & Fisher, A. (2002). Vulnerability of coastal communities to sea-level rise: A case study of Cape May County, New Jersey, USA. *Climate Research* 22, 255-270.

Wutich, A., Lant, T., White, D.D., Larson, K.L., & Gartin, M. (2010). Comparing focus group and individual responses on sensitive topics: A study of water decision makers in a desert city. *Field Methods* 22(1), 88-110.

Wynberg R., & Hauck, M. (2014). People, power, and the coast: A conceptual framework for understanding and implementing benefit sharing. *Ecology & Society* 19 (1).

Yin, R.K. (2009). *Case study research: Design and methods* (Vol. 5). Thousand Oaks, CA: Sage Publications, Inc.

Yoon, D.K. (2012). Assessment of social vulnerability to natural disasters: a comparative study. *Natural Hazards*, 63(2), 823–843.

Young, O.R. (2007). Rights, rules, and common pool resources. *Natural Resources Journal* (47), 1-13.

APPENDIX A

INDICATOR VARIABLES CODEBOOK

Variable Code Name	Description	Data Source
GEO_ID	Geographic Identifier	
GEO_ID2	Geographic Identifier	
GEO_NAME	Community	
TOT_POP	Total Estimated Population	2013 Census ACS Demographic Summary File
POP_DENSITY	Population Density	2013 Census ACS Demographic Summary File/Area in Square Miles
PCT_MALE	Percent Male	2013 Census ACS Demographic Summary File
PCT_FEMALE	Percent Female	2013 Census ACS Demographic Summary File
PCT_POP5	Percent Pop Age Under 5	2013 Census ACS Demographic Summary File
PCT_POP85	Percent Pop Age 85+	2013 Census ACS Demographic Summary File
MED_AGE	Median Age (Years)	2013 Census ACS Demographic Summary File
PCT_POP65	Percent Pop Age 65+	2013 Census ACS Demographic Summary File
PCT_MALE 65	Percent Pop Male Age 65+	2013 Census ACS Demographic Summary File
PCT_FEMALE65	Percent Pop Female Age 65+	2013 Census ACS Demographic Summary File
PCT_WHITE	Percent Pop White Alone	2013 Census ACS Demographic Summary File
PCT_BLACK	Percent Pop Black Alone	2013 Census ACS Demographic Summary File
PCT_NATIVE	Percent Pop Native American Alone	2013 Census ACS Demographic Summary File
PCT_ASIAN	Percent Pop Asian Alone	2013 Census ACS Demographic Summary File
PCT_ISLANDER	Percent Pop Pacific Islander Alone	2013 Census ACS Demographic Summary File
PCT_HISPANIC	Percent Pop Hispanic Alone	2013 Census ACS Demographic Summary File
PCT_WH_NONHISP	Percent Pop Non-Hispanic White Alone	2013 Census ACS Demographic Summary File
TOT_HH	Total Estimated Households	2013 Census ACS Social Summary File
PCT_FEMALE_HH	Percent Female Headed Household	2013 Census ACS Social Summary File
PCT_FEMALE_HH_UNDR18	Percent Female Headed Household With 1+ Under 18	2013 Census ACS Social Summary File
PCT_HH_ALONE_65OVR	Percent Household 65+ Alone	2013 Census ACS Social Summary File
PCT_HH_UNDR18	Percent Households With 1+ Under 18	2013 Census ACS Social Summary File

PCT_HH_OVR65	Percent Households With 1+ Age 65+	2013 Census ACS Social Summary File
AVG_HH_SIZE	Average Household Size	2013 Census ACS Social Summary File
PCT_MSEP	Percent Males Separated	2013 Census ACS Social Summary File
PCT_MDIV	Percent Males Divorced	2013 Census ACS Social Summary File
PCT_FSEP	Percent Females Separated	2013 Census ACS Social Summary File
PCT_FDIV	Percent Females Divorced	2013 Census ACS Social Summary File
PCT_GRAND_UNDR18	Percent Grandparents Raising 1+ Grandkids Under 18	2013 Census ACS Social Summary File
PCT_PRIM	Percent Enrolled Primary School	2013 Census ACS Social Summary File
PCT_SEC	Percent Enrolled Secondary School	2013 Census ACS Social Summary File
PCT_POP_9GRD	Percent Pop Less Than 9th Grade	2013 Census ACS Social Summary File
PCT_POP_NODIP	Percent Pop No High School Diploma	2013 Census ACS Social Summary File
PCT_POP_HSGRAD	Percent Pop High School Grad	2013 Census ACS Social Summary File
PCT_POP_BACH	Percent Pop Bachelor's	2013 Census ACS Social Summary File
PCT_DISAB	Percent Pop Disabled	2013 Census ACS Social Summary File
PCT_LIV_SAMEHS	Percent Lived In Same House 1 Year Ago	2013 Census ACS Social Summary File
PCT_LIV_DIFCO	Percent Lived In Different County 1 Year Ago	2013 Census ACS Social Summary File
PCT_LIV_DIFST	Percent Lived In Different State 1 Year Ago	2013 Census ACS Social Summary File
PCT_LIV_ABRD	Percent Lived Abroad 1 Year Ago	2013 Census ACS Social Summary File
PCT_FORGN	Percent Pop Foreign Born	2013 Census ACS Social Summary File
PCT_NOCTZN	Percent Pop Not A U.S. Citizen	2013 Census ACS Social Summary File
PCT_SPK_ENG_NTWELL	Percent Pop Speaks English "Less Than Well"	2013 Census ACS Social Summary File
TOT_HU	Total Housing Units	2013 Census ACS Housing Summary File
HU_DENSITY	Housing Units Density	2013 Census ACS Housing Summary File/Area in Square Miles
PCT_VCNT	Percent Vacant	2013 Census ACS Housing Summary File
HMOWN_VCNT_RATE	Estimated Homeowner Vacancy Rate	2013 Census ACS Housing Summary File
RNT_VCNT_RATE	Estimated Rental Vacancy Rate	2013 Census ACS Housing Summary File
PCT_MOBILE_HM	Percent Mobile Homes	2013 Census ACS Housing Summary File
PCT_BOAT_HM	Percent Boats, RVs	2013 Census ACS Housing Summary File
PCT_BLT_2010	Percent Houses Built 2010+	2013 Census ACS Housing Summary File

PCT_BLT_2000_09	Percent Houses Built 2000-2009	2013 Census ACS Housing Summary File
MED_HU_RMS	Median Number Of Rooms	2013 Census ACS Housing Summary File
PCT_OWN	Percent Owner	2013 Census ACS Housing Summary File
PCT_RNT	Percent Renter	2013 Census ACS Housing Summary File
PCT_MOV_2010	Percent Moved In 2010+	2013 Census ACS Housing Summary File
PCT_MOV_2000_09	Percent Moved In 2000-2009	2013 Census ACS Housing Summary File
PCT_HEAT	Percent Households With Heat Fuel	2013 Census ACS Housing Summary File
PCT_NO_VHCLE	Percent Households Without Vehicle	2013 Census ACS Housing Summary File
PCT_NO_PLBNG	Percent Households Without Plumbing	2013 Census ACS Housing Summary File
PCT_NO_PHNE	Percent Households Without Phone	2013 Census ACS Housing Summary File
MED_HM_VAL	Median Home Value	2013 Census ACS Housing Summary File
MED_MORTG	Median Monthly Mortgage	2013 Census ACS Housing Summary File
MED_GROSS_RNT	Median Gross Rent	2013 Census ACS Housing Summary File
PCT_OWN_CST35	Percent Households With Monthly Owner Costs 35%+ Of Income	2013 Census ACS Housing Summary File
PCT_RNT_CST35	Percent Households With Monthly Renter Costs 35%+ Of Income	2013 Census ACS Housing Summary File
PCT_LBR	Percent Pop Labor Force	2013 Census ACS Economic Summary File
PCT_EMPL	Percent Employed	2013 Census ACS Economic Summary File
PCT_UNEMPL	Percent Unemployed	2013 Census ACS Economic Summary File
PCT_LBR_FEMALE	Percent Female In Labor Force	2013 Census ACS Economic Summary File
PCT_LBR_FEMALE_EMPL	Percent Females Employed	2013 Census ACS Economic Summary File
MEAN_WRK_COMM	Mean Work Commute	2013 Census ACS Economic Summary File
PCT_MANAGE	Percent Management Occupation	2013 Census ACS Economic Summary File
PCT_SRV	Percent Service Occupation	2013 Census ACS Economic Summary File
PCT_SALE	Percent Sales And Office Occupation	2013 Census ACS Economic Summary File
PCT_NR	Percent Natural Resources, Construction, and Maintenance Occupation	2013 Census ACS Economic Summary File
PCT_AG_FISH_MINE	Percent Agriculture, Forestry, Fishing, Hunting, and Mining Industry	2013 Census ACS Economic Summary File
PCT_CONST	Percent Construction Industry	2013 Census ACS Economic Summary File

PCT_RETAIL	Percent Retail Industry	2013 Census ACS Economic Summary File
PCT_INSUR_RLESTATE	Percent Finance, Insurance, Real Estate, and Rental Leasing Industry	2013 Census ACS Economic Summary File
PCT_REC	Percent Arts, Entertainment, Recreation, Accommodation, and Food Services	2013 Census ACS Economic Summary File
PCT_SLF_EMPL	Percent Self Employed	2013 Census ACS Economic Summary File
PCT_HH_UNDR10K	Percent Households With Income Under $10,000	2013 Census ACS Economic Summary File
PCT_HH200K	Percent Households With Income $200,000+	2013 Census ACS Economic Summary File
MED_HH_INC	Median Household Income	2013 Census ACS Economic Summary File
MEAN_HH_INC	Mean Household Income	2013 Census ACS Economic Summary File
PCT_SS	Percent Pop With Social Security	2013 Census ACS Economic Summary File
PCT_RETIRE_INC	Percent Pop With Retirement Income	2013 Census ACS Economic Summary File
MEAN_RETIRE_INC	Mean Retirement Income (Dollars)	2013 Census ACS Economic Summary File
PCT_SSI	Percent Pop With Supplemental Security Income	2013 Census ACS Economic Summary File
PCT_PUB_CASH	Percent Pop With Cash Public Assistance	2013 Census ACS Economic Summary File
PCT_FOOD_STMP	Percent Pop With Food Stamp/SNAP Within Last 12 Months	2013 Census ACS Economic Summary File
CAPITA_INC	Per Capita Income (Dollars)	2013 Census ACS Economic Summary File
PCT_HLTH_NOINSUR	Percent Pop No Health Insurance	2013 Census ACS Economic Summary File
PCT_FM_POV	Percent Families In Poverty	2013 Census ACS Economic Summary File
PCT_POP_POV	Percent Pop In Poverty	2013 Census ACS Economic Summary File
PCT_CHLD_POV	Percent Pop Under 18 In Poverty	2013 Census ACS Economic Summary File
PCT_65_POV	Percent Pop 65+ In Poverty	2013 Census ACS Economic Summary File
GINI_INDX	Gini Index	2013 Census ACS Detailed Table B19083
MED_BLDG_AGE	Median Building Age	2013 Census ACS Detailed Table B25035

MED_YRS_UNIT	Median Year Householder Occupied	2013 Census ACS Detailed Table B25039
MED_YRS_RNT_RESIDE	Median Year Renter Occupied	2013 Census ACS Detailed Table B25039
PCT_HH_MORGE	Percent Households With Mortgage	2013 Census ACS Detailed Table B25081
PCT_HH_MORGE_LOAN	Percent Households With Second Mortgage and Home Equity Loan	2013 Census ACS Detailed Table B25081
PCT_POP_CHNG	Percent Change Total Pop	2013 Census ACS Demographic Summary File and 2000 Census Data
PCT_POP5_CHNG	Percent Change Under 5 Pop	2013 Census ACS Demographic Summary File and 2000 Census Data
PCT_POP65_CHNG	Percent Change 65+	2013 Census ACS Demographic Summary File and 2000 Census Data
PCT_VCNT_CHNG	Percent Change # Vacant Housing Units	2013 Census ACS Demographic Summary File and 2000 Census Data
PCT_RNTER_CHNG	Percent Change # Renters	2013 Census American Community Survey Housing Summary File and 200 Census Data
PCT_UNEMPL_CHNG	Percent Change Unemployed	2013 Census American Community Survey Economic Summary File and 2000 Census Data
PCT_TRVL_TIM_CHNG	Percent Change Travel Time to Work	2013 Census American Community Survey Economic Summary File and 2000 Census Data
PCT_HM_VAL_CHNG	Percent Change Median Home Value	2013 Census American Community Survey Housing Summary File and 2000 Census Data
PCT_MORTG_CHNG	Percent Change Median Monthly Mortgage	2013 Census American Community Survey Housing Summary File and 2000 Census Data
PCT_MED_RNT_CHNG	Percent Change Median Rent	2013 Census American Community Survey Housing Summary File and 2000 Census Data
NEAR_CTY_POP	Nearest City With Population 50,000+	City-Data: www.city-data.com
CST_LIV_INDEX	Cost of Living Index	City-Data: www.city-data.com
TOT_CRM_IND	Total Crime Index	CLR Search: www.clrsearch.com
PCT_WATER	Percent Water Cover	Census Tiger Shapefiles: Place and County Sub-Division
REC_FISH_RENTAL	Recreational Fishing Rental Mode Pressure	Marine Recreational Information Program (MRIP) Survey
REC_FISH_CHARTER	Recreational Fishing Charter Mode Pressure	Marine Recreational Information Program (MRIP) Survey
REC_FISH_SHORE	Recreational Fishing Shore Mode Pressure	Marine Recreational Information Program (MRIP) Survey

REC_FISH_TOT_PRESS	Recreational Fishing Total Mode Pressure	Marine Recreational Information Program (MRIP) Survey
REC_FISH_RENTAL_CAPITA	Recreational Fishing Rental Mode Pressure By Population	Calculated With Marine Recreational Information Program (MRIP) Survey and 2013 Census ACS Demographic Summary File
REC_FISH_CHARTER_CAPITA	Recreational Fishing Charter Mode Pressure By Population	Calculated With Marine Recreational Information Program (MRIP) Survey and 2013 Census ACS Demographic Summary File
REC_FISH_SHORE_CAPITA	Recreational Fishing Shore Mode Pressure By Population	Calculated With Marine Recreational Information Program (MRIP) Survey and 2013 Census ACS Demographic Summary File
REC_FISH_TOT_PRESS_CAPITA	Recreational Fishing Total Mode Pressure By Population	Calculated With Marine Recreational Information Program (MRIP) Survey and 2013 Census ACS Demographic Summary File
SLIPS_PER_1000	Number of Boat Slips Per 1000 People	Marine Recreational Information Program (MRIP) Survey; RI Department of Environmental Management http://www.dem.ri.gov/programs/bnatres/fishwild/boatlnch.htm; MA Department of Environment and Energy http://www.mass.gov/eea/agencies/dfg/fba/access-sites.html and http://www.mass.gov/eea/agencies/dfg/dmf/recreational-fishing/boat-ramp-locations.html
RAMPS_PER_1000	Number of Boat Ramps Per 1000 People	Marine Recreational Information Program (MRIP) Survey; RI Department of Environmental Management http://www.dem.ri.gov/programs/bnatres/fishwild/boatlnch.htm; MA Department of Environment and Energy http://www.mass.gov/eea/agencies/dfg/fba/access-sites.html and http://www.mass.gov/eea/agencies/dfg/dmf/recreational-fishing/boat-ramp-locations.html

APPENDIX B

INTERVIEW GUIDE

Respondent Information

--Which Town Are You a Resident In?

- o How long have you lived on Cape Cod, MA?

--Organization:

- How many years have you worked here?
- What are some of your responsibilities?

--What has been your primary training or job background?

Coastal Hazards & Risk Perception

--In your opinion, what are the key coastal hazards you think will affect the Cape?

- Sea level rise, storm surge, hurricanes, nor'easters, etc.

--Have you noticed any changes in the frequency or magnitude of these events? If so, why?

Exposure & Vulnerability

--Which Cape Cod towns do you believe are being affected by these hazards?

- Which towns do you think are or will be most vulnerable to specific events? Can you tell me why?

--What are some of the factors that make Cape Cod communities vulnerable to coastal hazards?

    - Land use? Economic development? Tourism?

--Which groups of Cape Cod's population are most likely to be harmed or experience losses from a hazard? Why?

- What do you think it is about these groups that make them vulnerable?

--Which economic industries/activities are particularly vulnerable to coastal hazards? Why?

- How do you think they will be affected?

D) Hazard Preparedness & Mitigation Strategies

-- How prepared are Cape Cod towns to deal with coastal hazards?

- Is there anything you suggest communities could be doing be better prepared? To reduce risk and impacts?

--Does your organization have any existing policies and programs that try to include information about coastal hazards and how to minimize their impacts? Please describe.

--Are there any land use approaches that you know of that are being used to address/mitigate coastal hazards?

- Probe: restoration, land buy-backs, zoning, regulations, conservation programs?
- Are you or your organization involved in these efforts?

--Are any steps being taken to manage development on the coast? Can you give me some examples?

- Probe for details as to permits, building code changes, setbacks

--What do you think are some challenges to implementing these actions for hazard reduction?

- Probe: Lack of political support, lack of funding, lack of attention by public…?
- Are there tensions between different interest groups like preservation versus development?
    - Causes? Suggestions for resolving differences?

Organization/Community Activities & Collaboration: Policy & Program

--Is your organization planning any future efforts to address issues of hazard preparedness in relation to extreme events and coastal development? Describe.

- If not, why not?

--Is your organization considering the potential effects of climate change on coastal hazards (such as sea level rise etc.)? How so?

- If not, why not?

--Are there opportunities for collaboration with other organizations regarding hazard preparedness, coastal development, or climate change?

- Which organizations?

- Can you tell me about the nature of these collaborations?

--What are some challenges to collaboration? How are these overcome?

-- Are there people/organizations you would like to see more involved that would help improve preparedness and progress?

- Probe: State/federal officials, emergency managers, consultants, elected officials…?

Closing

--Is there anything else you'd like to share? Something that you are particularly concerned with that we did not discuss?

- Can you think of a question that I should have asked but didn't?
- Is there anyone you think I should speak with?

Thank you for your time and participation in this study

APPENDIX C

INSTITUTIONAL REVIEW BOARD APPROVAL

EXEMPTION GRANTED

Robert Bolin
Human Evolution and Social Change, School of (SHESC)
480/965-6421
bob.bolin@asu.edu

Dear Robert Bolin:

On 2/16/2015 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Sand, Storms, & Tourism: A Case Study of the Hazards and Vulnerabilities of Cape Cod, MA.
Investigator:	Robert Bolin
IRB ID:	STUDY00002216
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• Gentile_Interview_Consent, Category: Consent Form; • Gentile_Interview_Guide, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Gentile_IRB_Protocol, Category: IRB Protocol; • Gentile_Recruitment_Script, Category: Recruitment Materials;

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 2/16/2015.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc: Lauren Gentile

APPENDIX D

INTERVIEW CODEBOOK

Limitations

Code Name: Social Vulnerability

(Theory Area: Hazards/Disasters)

Kappa: .857

Detailed Description:	Social characteristics of a population that makes them more susceptible to the impacts of hazards
Inclusion Criteria:	Demographic and economic features of a population, which makes them less able to cope with and respond to hazards
Exclusion Criteria:	Physical exposure to hazard
Typical Exemplars:	Socioeconomic status, gender, age, ethnicity, disability, education
Atypical Exemplars:	Occupation, renters, tourists, homeless
Close But No:	Economic industries may face greater exposure but that does not refer to actual groups of people

Code Name: Biophysical Vulnerability

(Theory Area: Hazards/Disasters)

Kappa: .905

Detailed Description:	Potential risk of harm or loss to biophysical conditions from physical exposure to a hazard due to geographic, ecological, or climatic conditions
Inclusion Criteria:	Spatial distribution of hazardous conditions and hazard impacts on the physical environment
Exclusion Criteria:	Socio-economic characteristics of the people living in the hazardous conditions
Typical Exemplars:	Natural infrastructure like beaches and marshes; built infrastructure like residential, commercial, roads, and marinas

Code name: Risk Awareness

(Theory Area: Risk/Hazard Perception)

Kappa: .867

Detailed Description:	Individual or group opinion about the likelihood and characteristics (e.g., magnitude and frequency) of a risk
Inclusion Criteria:	Recognizes that different risks can exacerbate each other
Exclusion Criteria:	Descriptions of hazards, social, or biophysical vulnerability
Typical Exemplars:	Climate change; acknowledging that risks exist through direct or indirect experience; "making things worse"; climate change will increase frequency and intensity of storms; costal hazards exacerbate one another
Close But No:	Education of risks (belongs under Public Awareness Code)

Barriers

Code Name: Planning Capacity

(Theory Area: Management/Mitigation)

Kappa: .909

Detailed Description:	Constrained by the ability to manage and mitigate hazard impacts due to internal institutional barriers
Inclusion Criteria:	Planning group has reduced resources, staffing, and expertise
Exclusion Criteria:	Laws or policies that constrain planning (laws and policies code)
Typical Exemplars:	Underfunded, understaffed, lack of expertise and time
Atypical Exemplars:	Differing priorities within planning organization; "silos" where communication and collaboration with others inhibits effective planning

Code Name: Political Will

(Theory Area: Management/Mitigation)

Kappa: 1.00

Detailed Description:	Extent of support for hazard mitigation planning and implementation by the public or decision-makers
Inclusion Criteria:	Can encompass conflicting political, economic, educational interests or viewpoints that cause opposition to proactive mitigation planning
Exclusion Criteria:	Lack of support for hazard mitigation within planning groups (planning capacity code)
Typical Exemplars:	Voting against a hazard mitigation project because it impinges on private property rights; Reducing funding for resiliency projects
Atypical Exemplars:	Resisting implementing a policy but doing so to get flood insurance

Code Name: Short-Term Thinking

(Theory Area: Management/Mitigation)

Kappa: .857

Detailed Description:	Tendency to focus on addressing immediate issues at the expense of considering long-term implications of decisions
Inclusion Criteria:	Making decisions that are temporary (e.g., band aid like), reactive responses
Exclusion Criteria:	Being proactive and finding more long-term, semi-permanent solutions
Typical Exemplars:	Allowing rebuilding in known flood-zones; armoring the coastline; siting new infrastructure without considering effects of sea level rise or subsidence

Code Name: Laws and Policies

(Theory Area: Management/Mitigation)

Kappa: 1.00

Detailed Description: Regulatory rules that no longer reflect/support the current needs for hazard management and mitigation.

Inclusion Criteria: Places limitations on coastal zone managers and planners abilities to develop and implement more proactive hazard mitigation measures

Exclusion Criteria: Straightforward description of laws and policies without describing how conflicts/inhibits proactive planning

Typical Exemplars: Statewide building code applies uniformly regardless of coastal versus inland conditions; building code preempts local ordinances that could be more restrictive; building height restrictions prevent people from elevating structures to reduce flood impacts

Atypical Exemplars: Can't de-zone existing properties or already built up areas

Solutions

Code Name: Resiliency Efforts

(Theory Area: Management/Mitigation)

Kappa: 1.00

Detailed Description: Efforts to strengthen communities' coping and adaptive capacities for the long-term through proactive mitigation measures

Inclusion Criteria: Making it easier for towns and citizens' to reduce their vulnerabilities

Exclusion Criteria: Projects or plans that are reactive or more short-term in thinking

Typical Exemplars: Project to analyze erosion by looking at sediment movement; green infrastructure like dune restoration; amending town bylaws to increase building height making it easier for citizens to freeboard

Code Name: Hold The Line

(Theory Area: Management/Mitigation)

Kappa: 1.00

Detailed Description:	Coastal management techniques to minimize impacts from coastal hazards and protect shorelines
Inclusion Criteria:	Protect private property through installation of hard or soft infrastructure
Exclusion Criteria:	Pulling back from hazardous areas
Typical Exemplars:	Revetments, groins, beach re-nourishment, dune restoration
Atypical Exemplars:	Green infrastructure that helps minimize hazard impacts by enhancing natural features (e.g., restoring wetlands; removing barriers to allow salt marshes to migrate; creating reefs to attenuate storm surge)

Code Name: Managed Retreat

(Theory Area: Management/Mitigation)

Kappa: 1.00

Detailed Description:	Reducing human presence in high-hazard zones and letting natural coastal processes (i.e., flooding, erosion, deposition, etc.) occur
Inclusion Criteria:	Long-term thinking and planning to minimize hazard impacts by preventing new development and limiting re-building in known coastal hazard areas
Exclusion Criteria:	Installation of hard and soft infrastructure to protect property
Typical Exemplars:	Land buy-outs; relocation of structures farther inland; increasing building setbacks from coastline

Code Name: Regional/Collaborative Planning

(Theory Area: Management/Mitigation)

Kappa: .867

Detailed Description:	Cooperative efforts in hazard mitigation planning between towns, organizations, the state, etc.
Inclusion Criteria:	Attempts to address hazards and coastal processes more holistically and uniformly since they cross municipal boundaries
Exclusion Criteria:	Collaborating within your own department
Typical Exemplars:	Conducting workshops that bring towns together to address coastal hazard issues; projects undertaken jointly between towns and NGOs; planning efforts between different departments within towns

Code Name: Improving Public Awareness

(Theory Area: Risk/Hazard Perception)

Kappa: .857

Detailed Description:	Increasing public knowledge of current and future hazards/risks, their impacts, and mitigation strategies to garner support for hazard mitigation initiatives
Inclusion Criteria:	Use of outreach and education to increase awareness and understanding of local and regional concerns
Exclusion Criteria:	Thinking/talking about improving education without providing a strategy or plan of action
Typical Exemplars:	Public meetings on hazard issues and ways to address them; lectures on climate-related coastal risks like sea level rise and its impacts