Climate Change Vulnerabilities in the Coastal Mid-Atlantic Region

April 2018

Middlebury Institute of International Studies at Monterey
Center for the Blue Economy

Woods Hole Oceanographic Institution

Contents

List of Tables

List of Figures

Acknowledgments

This report was prepared jointly by the Center for the Blue Economy of the Middlebury Institute of International Studies at Monterey and the Marine Policy Center of the Woods Hole Oceanographic Institution.

Dr. Charles S. Colgan, Director of Research at the CBE, was the Principal Investigator of the project and was the author of Chapters 1, 3, and 7, with the assistance of Shaun Richards, Research Associate in the Center.

Dr. Juliano Calil, Senior Research Associate with the Center, was the author of Chapter 2 with the assistance Clesi Bennett and Emma Ross.

Dr. Hauke Kite-Powell, Research Specialist at the Marine Policy Center, was the author of Chapter 4.

Dr. Di Jin, Senior Scientist at the Marine Policy Center, was the author of Chapter 5, with the assistance of Dr. Lisa Colburn, at the NOAA Northeast Fisheries Science Center in providing data.

Dr. Porter Hoagland, Senior Research Specialist at the Marine Policy Center, was author of Chapter 6.

The authors wish to thank the members of the staff working group of MARCO who provided input and review to this report. Their contributions greatly strengthened the report.

The Mid-Atlantic Regional Council on the Ocean (MARCO) recognizes that information on climate change vulnerability and socio-economic assets is rapidly evolving, and continued research is important to understand the systems affected by the environment and management efforts. The information in this report will inform MARCO activities, but nothing in this document should be construed as a MARCO endorsement or MARCO policy.

Funding for the project was provided as part of “Mid-Atlantic Regional Resilience: Linking Coastal Ocean Information to Enhance Economic, Social and Ecological Resilience” funded by the National Oceanic and Atmospheric Administration through a Regional Coastal Resilience Grant (Award No. NA16NOS4730014).

Executive Summary

The Mid-Atlantic Regional Council on the Ocean (MARCO) has identified increased understanding of the possible effects of climate change on the socio-economic assets and systems of the region as a priority need. This is based both on recent experience studying climate change and concern for the economic values that have been placed at risk. Changes in ocean temperatures and chemistry are already affecting fisheries, while the critical marine transportation facilities of the region must now address concerns about sea level rise in addition to shifting global transportation markets. New research is showing that coastal and ocean ecosystems are already changing along with the services they provide to people, and millions of people in hundreds of thousands of homes are threatened by increases in the areas subject to flooding from oceans and estuaries as well as the depth and frequency of flooding.

The region examined here stretches across 63 counties and independent cities from Montauk Point to Virginia Beach and encompasses the Chesapeake Bay and the lower Delaware River. The 2016 population of these counties is more than 28.6 million with a shore-adjacent population (defined by Census tracts) of more than 14.6 million. The region is of great size and significant socio-economic diversity, ranging in population size from 2.6 million in Brooklyn (Kings County), New York, to less than 9,000 in Matthews County, Virginia. The region includes Manhattan Island (New York County), the heavily developed Jersey Shore, but also the wild dunes of Assateague and Chincoteague islands and the rural counties of the eastern shore of Chesapeake Bay.[1]

Vulnerability is the focus of this study, which seeks to integrate the current state of knowledge about the Mid-Atlantic region in order to identify the key pressure points on the socio-economic assets and activities of the region and to estimate the degree of vulnerability both in absolute terms and relative terms across the region. The results of this study should contribute to the already vigorous processes throughout the region that states and local communities are using to plan adaptation strategies. Vulnerability is a state of potential; effects may or may not actually occur. Identifying a vulnerable condition is not a forecast of a specific outcome but is an indicator of possible effects based on the assumptions used to generate the measurement of vulnerability.

The possible extent of climate change and its impacts on the Mid-Atlantic region have been extensively studied over the past decade. The climate-related changes that are likely to occur have been identified with increasing levels of confidence, including sea level rise as well as changes in marine and coastal ecosystems. However, the breadth and depth of available information varies across the region.

To assess socio-economic vulnerabilities for transportation, fisheries, and ecosystems, a range of studies of climate change in the region and relevant studies drawn from elsewhere are summarized. For sea level rise, a projection common to the whole Mid-Atlantic region is used: the NOAA Sea Level Rise Viewer provides consistent spatial projections of the areal extent (but not depth) of flooding that can be used to compare possible rates of sea level rise with the distribution of socio-economic assets across the region.

For this analysis, sea level rises of 3 feet and 6 feet (by 2100) are used. These two scenarios are roughly consistent with the planning assumptions used in the Mid-Atlantic region and were approved by project's advisory committee. These projections allow consistent analysis across the region, but do not reflect the most recent research which incorporates depth of possible flooding

[1] The Mid-Atlantic Regional Ocean Council does not include Pennsylvania, but for purposes of this study the Pennsylvania counties of Delaware, Philadelphia, and Bucks are included to complete the analysis of the lower Delaware River.

effects and are based on altering the underlying perspective on sea level rise from "this could happen by [year]" to "this has X % probability of happening within Y time period" which indicates that the 3 and 6 foot levels could occur sooner than the 2100 horizon.

For the analysis, the effects of sea level rise are measured as the proportion of area flooded (temporarily covered by water) or inundated (permanently covered by water) in shoreline areas of the region as projected by the NOAA Sea Level Rise Viewer. The area examined depends on the socio-economic data's geographic level. These range from the county at the broadest scale to the Census tract at the finest scale. Socio-economic characteristics examined included:

Population	The Summer Economy
Housing Stock	Fishing Communities
Total Employment	Energy and Water Infrastructure
Social Vulnerability	Road and Rail Infrastructure

The data on these indicators was drawn from a variety of sources, some of which were actual measures of the indicator and others were composite indexes compiled by other researchers. Data was compiled for each of 63 counties and cities[2] in the region. Some of the key findings:

- 14.6 million people live in Census tracts adjacent to the ocean, Chesapeake, or Delaware bays. In the 3-foot scenario, the resulting flooded area could affect 1.7 million people and in the 6-foot scenario, 2.1 million people. These are highly approximate numbers but are indicative of the magnitude of vulnerability.
- Shore-adjacent Census tracts contained 6.4 million housing units. 912,000 units are vulnerable to flooding in the 3-foot scenario and 1.1 million in the 6-foot scenario. These include 212,000 seasonal units in the 3-foot scenario and 248,000 in the 6-foot scenario.
- 6.8 million jobs were located in shore adjacent zip codes. 557,000 jobs are estimated to be vulnerable to flooding in the 3-foot scenario and 974,000 in the 6-foot scenario. In general, employment vulnerability increases more with sea level rise than population.
- It is the cumulative effect of disruptions caused by climate change-influenced flood events that will be the primary economic risk, rather than any single flood event.

Composite rankings across all indicators were calculated using the average ranking of each county across all indicators. The *lower* the mean ranking, the *higher* the vulnerability. (The county with the highest vulnerability on a measure has a rank of 1; the county with the lowest a rank of 63.) These mean composite rankings were also calculated for shoreline counties in each state and are shown in Figure 0-1. In the 3-foot sea level rise scenario, Delaware has the lowest average ranking (indicating higher vulnerability); this is in part a result of having only three counties in calculating the composite ranking. Maryland is ranked second. In the 6-foot scenario, New York and Virginia are most vulnerable among the MARCO states.[3]

---

[2] Cities in Virginia have the same status as counties. For simplicity, both counties and cities included in the study are generally referred to as "counties".

[3] That is, excluding Pennsylvania, which is not a member of MARCO.

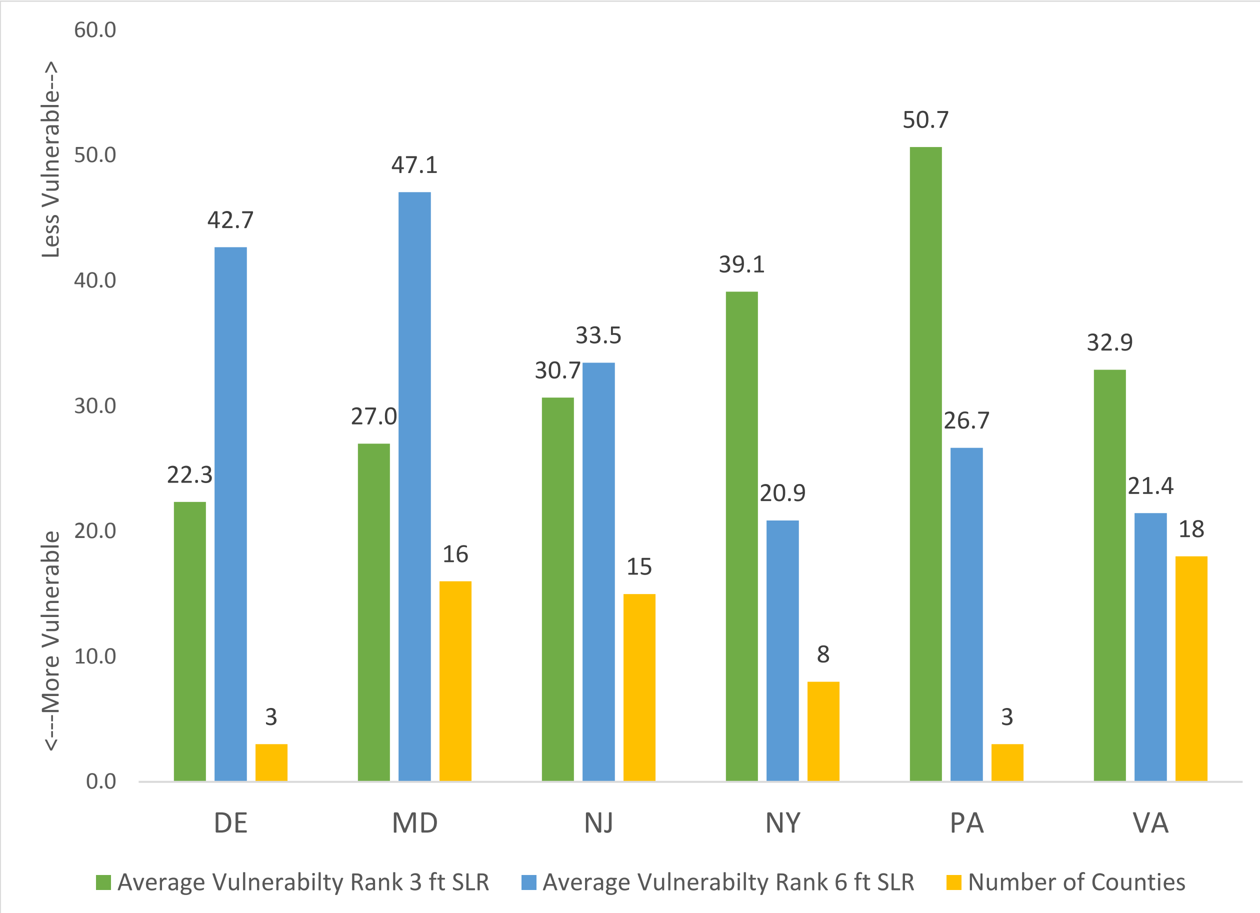
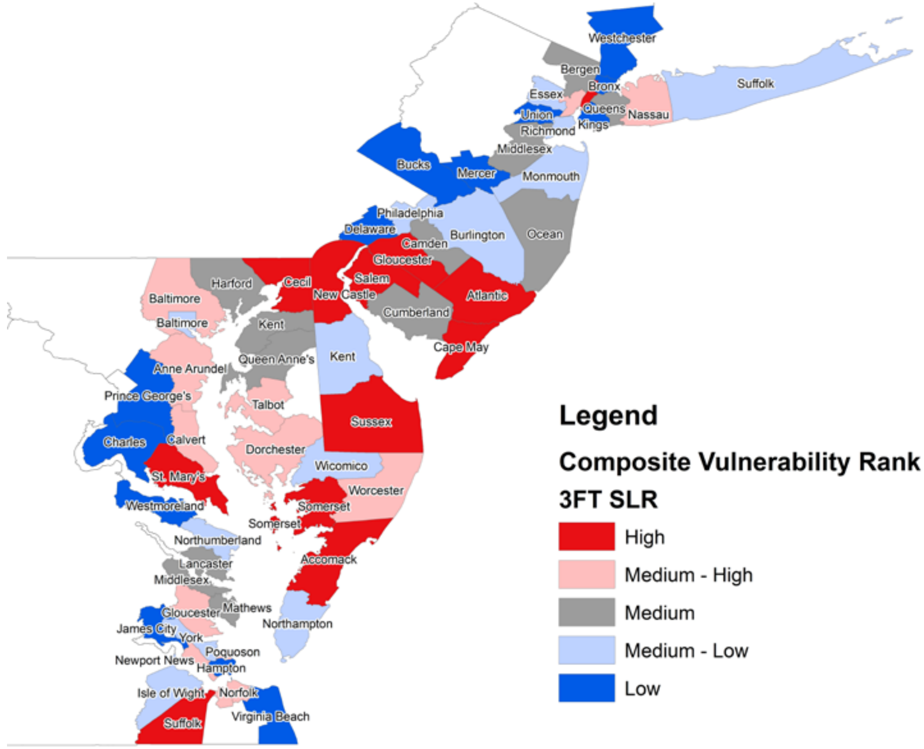


Figure 0-1 Number of shoreline counties and mean county vulnerability rankings under 3 foot and 6 foot SLR scenarios.

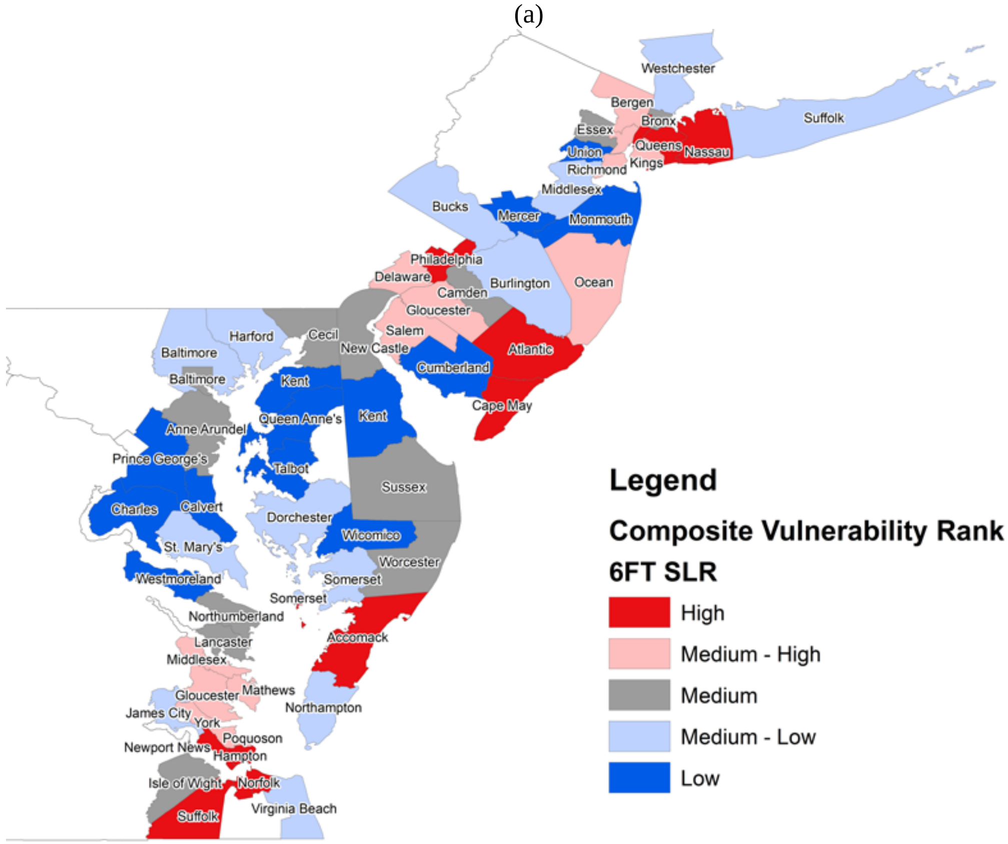
The composite ranking at the county level is shown in Figure 0-2. Again, lower rankings indicate higher vulnerability. The highest vulnerability group is spread across the region, with the highest in Suffolk County (NY), the southern New Jersey shore, the lower Delaware River, and southern Chesapeake Bay.

The vulnerability rankings change significantly with sea level rise of six feet. New York shifts to the highest average vulnerability, followed by Virginia, and then Pennsylvania. Delaware and Maryland change from the most vulnerable to the least vulnerable. The high vulnerability counties now include the urban areas around New York, Philadelphia, and the Virginia tidewater region of southern Chesapeake Bay. The higher areas of flooding are now creating much larger population and housing vulnerabilities in urban areas.

This ranking analysis does not imply that the lower ranked counties do not have problems with climate change. Rank order only implies that some counties have greater vulnerability because they have higher portions of their near-shore areas exposed to flooding or because they are more vulnerable on more of indicators than others. The analysis of the overall vulnerability and the detailed analysis of each indicator point to the regions with greater vulnerability *relative to other parts of the region.*



(a)



(b)

Figure 0-2 Rank order of counties in composite climate vulnerability scores (a) 3 foot SLR and (b) 6-foot SLR.

Three chapters in this report address vulnerability for specific economic assets in the region: marine transportation, fisheries, and ecosystem services.

Transportation

The region is home to several of the largest ports in the United States, most notably the Port of New York-New Jersey. Together, the ports were the transit points for $344 billion in imported, exported, and coastal transit goods in 2016. Ports are capital facilities that must continually plan for updates and upgrades to offset depreciation, modernize equipment and increase competitive positions in global transportation markets. Sea level rise is already being incorporated into this planning, both from the perspective of possible increases in sea levels and subsidence of the shoreline.

Fisheries

There is substantial evidence from studies undertaken in the coastal waters of the U.S. and around the world that fisheries will be affected by all aspects of climate change. The most unambiguous negative effects will be from the increasingly acidic nature of ocean waters on shellfish, where acid waters impede shell formation. The long-term negative effects of ocean acidification on the U.S. shellfish fisheries were estimated to be within 10% of the values of the fisheries. For other commercially and recreationally important species, the foreseeable effects are more ambiguous. Warming waters will upset the habitat conditions for many species, particularly in their larval and juvenile stages. As a result, some species currently common in the Mid-Atlantic region will shift northward to find cooler waters and become much less available. Other species currently found south of the region may also shift northward and become more abundant. This ambiguity is indicated by findings that, in the case of freshwater sport fishing, a doubling of atmospheric carbon dioxide could lead to between a $4.6 million loss and a $20.5 million net benefit for the northeast region.

The combination of changes in fishing needed to meet sustainability goals under state and federal management programs with these climate-related changes will stress the harvesting sector of commercial fisheries, but it will also put stress on the downstream seafood businesses such as wholesalers, retailers, processors, and restaurants.

Sea level rise threatens coastal communities and the support facilities on the shoreline. Mid-Atlantic communities in the low-lying coastal plain, especially those clustered around the Chesapeake Bay area and the New Jersey shore, were ranked high with regard to expected vulnerability to sea level rise because of their shoreline characteristics and leading roles in the commercial fishing industry of the region.

The actual future of the fisheries will be shaped by climate change, but also critical will be the decisions of fisheries managers and their approaches to incorporating climate change into their sustainability decisions. Managers must effectively respond to impacts on existing fisheries and take advantage of new opportunities as conditions change. Incorporating climate change in fisheries management decisions is at the early stages. In many existing recommendations the how, by whom, and under what conditions climate change modifications may be made to fisheries management plans are not yet clear.

Ecosystem Services

The importance of coastal and ocean ecosystem services is well-recognized in the Mid-Atlantic region. Measuring the change in economic values of the services provided by the ecosystem is much more methodologically complex than other types of economic values, but a solid foundation of economic valuation of these services exists. While many of the region's coastal and ocean ecosystem service used or valued directly by people (referred to in this report as ecosystem service "endpoints"), are either not exposed or are largely insensitive to the effects of climate change, there are several highly valued ecosystem service endpoints whose general vulnerability has been established (Figure 0-3). These include commercial and recreational fishing, wildlife viewing (birding and whale-watching), and the cultural and regulating services arising from natural and nature-based figures such as salt marshes, seagrass beds, and intertidal lands, including oyster reefs. Much uncertainty exists about the precise geographic scales and timing of impacts to the ecosystem services of the region but the evidence to date indicates that it will be important for its communities to address these vulnerabilities on several fronts.

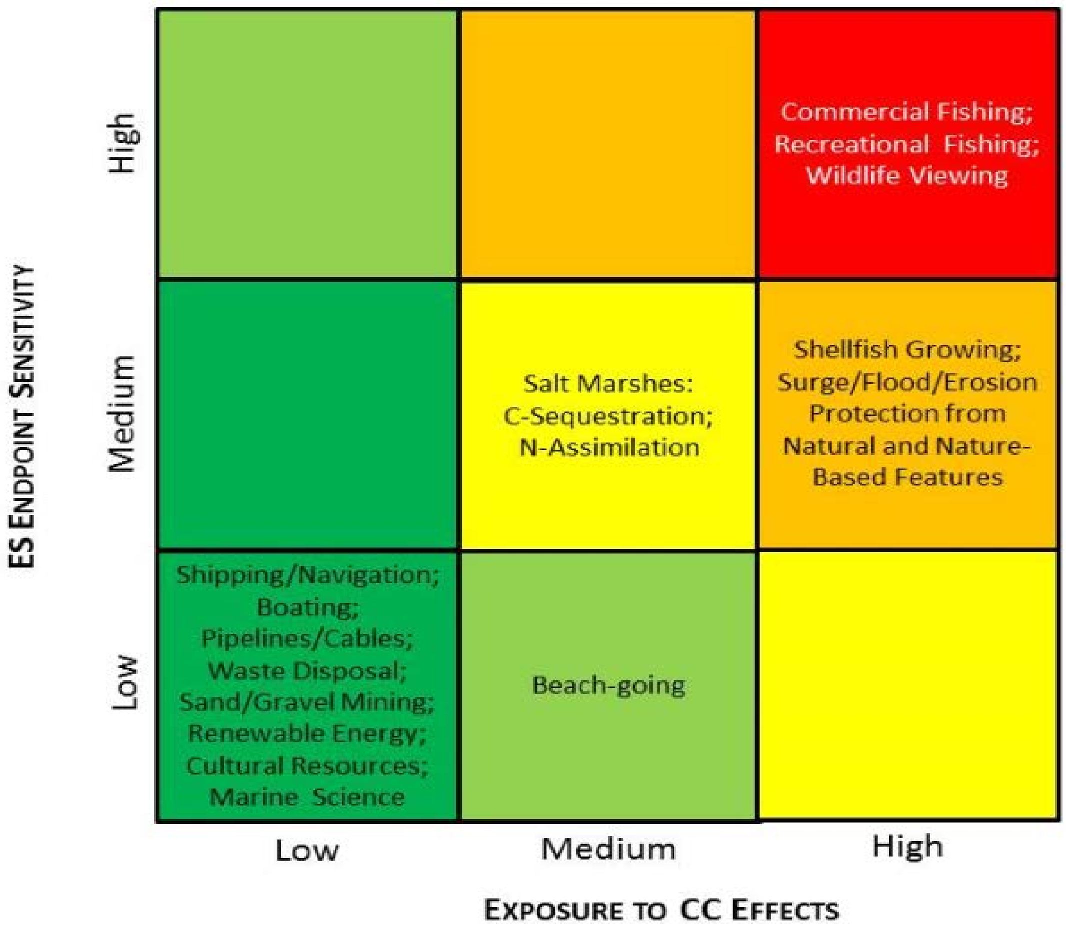


Figure 0-3 Possible ecosystem service effects from climate change.

Particular attention should be directed at maintaining or restoring the region's natural features, especially the extensive salt marsh wetlands of the region. Recent studies have provided evidence of very large ecosystem service economic values for the Delaware wetlands, the shorelines in New York and New Jersey that were affected by Hurricane Sandy, and large carbon sequestration capabilities of salt marshes. Natural and nature-based features constitute a clear priority for further protection and restoration to address the threats of retreating shorelines and encroachments from the expansion of human coastal development will need to be addressed.

Responding to Vulnerabilities

Three themes emerge from the survey and analysis undertaken in this study:

1. **Vulnerability assessment is the first stage in what is a long and complex process. The next steps are to move from vulnerability to risk assessment to action.**

Economic activity directly associated with the ocean, including fisheries, transportation, the summer tourism economy, and the ocean economy in general presents one set of issues. Severe climate change impacts on key sectors of the local economy, such as will be the case with fisheries and the summer economy, can have more deeply disruptive effects on the economies of coastal areas. The cumulative effects of repeated damages to infrastructure and business activity from continually increasing flood hazards will reduce economic advantages of coastal regions and the overall economies of the states and nation.

The next steps therefore should focus on using the information generated here to add to already ongoing planning process to accomplish several things:

- Public agencies can use the findings of this report with respect to the range of economic vulnerabilities that exist as a checklist for adaptation planning to make sure the full range of possible issues are addressed.
- Planners should shift sea level rise planning to the latest generation of models that identify the probabilities of different levels of sea level rise more explicitly.
- Communities, fisheries, transportation, and resource managers, should develop adaptation principles that are consistent with unavoidable uncertainty about the future; (a) a practical adaptation planning process to guide selection and integration of recommendations into existing policies and programs; and (b) greater integration of knowledge about socio-economic systems and values into the planning process.
    - Communities, led by resource managers and academic institutions, should engage in further research on the scales and spatial distributions of ecosystem services values for these environments, including the spatial distributions of services, human uses, and the values arising from those uses. Strategies to improve the understanding of socio-economic vulnerability include: Census tract data can be further localized to Census block groups and blocks using decennial census data for more precise measurement of possible flood risks.
    - Forecasts of local growth done for transportation planning purposes can be adapted to better defining future risks that may be substantially different than the most recent data used here can provide.
    - Employment establishments are located by latitude and longitude in the state Quarterly Census of Employment and Wages data sets; with special permission and rigorous protection for confidentiality, this data can yield very precise estimates of employment and economic impacts. If not available from the state government, such estimates are available from commercial firms.
    - State data sets can be used to refine the infrastructure analysis done here to more precise geographies.
    - Use the findings of this report as a checklist for adaptation planning. The focus may be on the issues of the summer economy or fisheries, but what are the social vulnerability issues that exist alongside?

2. **Climate change will affect every part of the Mid-Atlantic region's coastal and marine natural and socio-economic environments, but important differences across the region need to be recognized and used to shape adaptation strategies.**

Though vulnerabilities may be different in extent and intensity within a given region, it may also be that there are many synergies in the underlying ecological and social systems that would make it possible to address many risks at once. The information about vulnerabilities in each county in this report should provide an information base for the creation of more effective regional strategies. At the same time, attention should be focused on specific assets that can address multiple aspects of adaptation.

- Coastal wetlands, including beaches, serve as foundations for some economic activity and ecosystem value but may also serve as natural infrastructure reducing potential damages from the flood vulnerabilities identified. Addressing coastal wetlands issues can cover many different aspects of vulnerability.
- A capital plan for maintaining a port may also require updating of road, rail, and land use plans in the area to be effective. Those multiple asset plans address different vulnerabilities through common actions.

3. **Climate change poses unique challenges to the region's institutions.**

1. Adaptation is mostly a problem of addressing uncertainty. Much of the information needed to choose adaptation strategies with high confidence is not available and will not be available until after it is too late. Continuous investment in information is essential. This report presents the base layer of information needed to understand how climate change may affect the Mid-Atlantic region, but much more is needed. The information must be continually updated and refined to reduce uncertainty, better define options, and increase confidence in the choices to be made.

2. Adaptation is about building defense in depth, not simply coming up with a strategy sufficiently acceptable to be implemented today. Every adaptation action considered should be accompanied by backup plans in the event that the situation turns out to be much different than anticipated.

3. Finding the money is an underappreciated vulnerability, but it can be managed. Fear of the costs of adaptation is an impediment to effective action. However, climate change has also brought a number of innovations that make it much easier to deal with the issues of funding. New financial instruments such as catastrophe bonds, impact investing products such as climate bonds, and the creation of new local finance institutions such as hazard districts and infrastructure banks open up a whole new set of possibilities to find new ways of combining public and private resources to fund adaptation.

4. Adaptation is now … and in the future. The long time horizons of climate projections suggest most actions lie in the future. But decisions are being made today that will shape the region for the remainder of the century with or without consideration of climate change. Absent strong and effective action to reduce climate change beginning immediately, children born this year could see the effective destruction of the features that have defined the Mid-Atlantic coast from the Hamptons to Virginia Beach in their lifetimes.

Chapter 1 : Introduction

The Mid-Atlantic Regional Council on the Ocean (MARCO) has identified increased understanding of the possible effects of climate change on the socio-economic assets and systems of the region as a priority need. Hurricane Sandy in 2012 together with other weather events such as the winter storm in January 2018 have made it clear that the threats from climate change are clear and present. Changes in ocean temperatures and chemistry are already affecting fisheries, while the critical marine transportation facilities of the region must now address concerns about sea level rise in addition to shifting global transportation markets. Recent research (discussed in Chapter 5) indicates that the values of coastal and ocean ecosystems are already changing.

These changes potentially affect a region comprising 63 counties and cities across six states[4] (Figure 1-1). These counties contain a population (in 2016) of 28.7 million (of a regional total of 56.8 million). The economy employed 12.7 million people (of a regional total of 28 million), contributing $2.1 trillion to the U.S. economy (of a regional contribution of $3.7 trillion), and paying $848.8 million in wages (of a regional total of $1.6 trillion). The region spans landscapes from the most densely developed urban areas of New York City to the seasonal housing-dominated Jersey Shore to the wild barrier islands of Assateague, Chincoteague and Fire Island. It includes the nation's largest estuary in Chesapeake Bay as well as major estuaries in Delaware Bay, New York harbor, and the Peconic estuary.

Vulnerability, the identification of possible effects, is the focus of this study, which seeks to integrate the current state of knowledge about the Mid-Atlantic region to identify the key pressure points in the socio-economic conditions of the region which may be affected by climate change and to estimate the degree of vulnerability either in absolute terms or in relative terms across the region. This vulnerability assessment can inform the development of plans and actions for adaptation to climate change. The results of this study should contribute to the already vigorous processes throughout the region that states and local communities are using to plan adaptation strategies.

The challenge to the communities in the Mid-Atlantic is how to plan and act in response to climate change. There are two broad problems in responding to climate change.

One of these problems is that dealing with climate change upsets some of the most basic elements of planning. Traditional planning processes are grounded in the idea that future conditions can be foreseen with reasonable accuracy and that a relatively small and manageable set of variables, such as land use, can be used to achieve some agreed upon set of future conditions. Traditional planning takes some key factors as a given that can be safely ignored in the planning process. One of these is that the land on which people live and work remains constant, and the other is that there is no threat to the livability in the region so serious that significant out-migration may occur. But these are exactly the conditions that climate change creates. Changes in ocean temperatures and chemistry may completely reconfigure the distribution of natural resources on which people depend. Sea level rise could effectively eliminate the shoreline upon which so much development has taken place.

The second is that the effects of climate change are complex and interdependent across multiple and natural and social systems, some of which have been identified, but many of which are still not clear. A full accounting of all the known and possible effects would extend well beyond the

[4] The Mid-Atlantic Regional Council on the Ocean comprises New York, New Jersey, Delaware, Maryland, and Virginia. For purposes of this study, Pennsylvania and the counties of Bucks, Philadelphia, and Delaware are included where appropriate to provide a complete picture of regional economic conditions.

scope of this project. The major effects of climate change in ocean and coastal systems that have been most extensively studied are sea level rise, and changes in ocean temperature and chemistry, primarily increasing acidification. Sea level rise threatens socio-economic assets directly. It also threatens, in combination with changes in temperature and chemistry, ecosystems and natural resources upon which economic values depend. For that reason, these are the primary climate change effects examined in this report.

The science of climate change has advanced enough to be able to forecast with moderate accuracy the long-term changes in global and local temperatures and possible changes in ocean chemistry and levels. Projections of the possible rates of climate change and sea level rise are common and widely used (Intergovernmental Panel on Climate Change 2014). Such linear projections are very helpful in understanding the dimensions of the issue, but in fact say little about either the exact timing of changes. Even more difficult is the fact that many of the effects of climate change will not occur in small increments but will combine with highly episodic phenomena like tropical and extra-tropical cyclones to crate periodic crises interspersed with periods of little immediate threat that may stretch from years to decades. Threats can seem remote until they are all too present, at which time all energy is focused on the immediate crisis.

In short, responding to climate change happens in an environment in which the magnitude of the problem can only be approximately known, cannot be predicted with respect to timing, and thus leads to a decision environment in which the costs of taking action and of not taking action are very high.

To add to the confusion, the terms used to describe climate change and responses have become confusing with many terms used in different ways. Among the terms relevant to this study which require clarity are:

- **Mitigation,** which can refer to reducing the extent or pace of climate change, mostly through lowering greenhouse gas emissions but can also mean reducing adverse consequences of climate change, thus referring to both cause and effect. For purposes of this report, mitigation is any action that reduces the extent or pace of climate change.
- **Adaptation** is focused on reducing the actual or potential damage from climate change. Adaptation actions are generally most effective when taken sooner rather than later, so adaptation must begin with an appreciation of vulnerability.
- **Resilience** is the characteristic of a system that allows it to undergo high levels of stress and then return to its original state. Much of the discussion around climate change adaptation is about the establishment or maintenance of resilience in natural and social systems. The degree to which a return to conditions at a chosen baseline period may be quite low the longer that climate change takes place at "business as usual" rates.
- **Risk** as a noun refers to an event that has some probability of occurring. In broad definition, the probability may be known or unknown; a narrower definition distinguishes between a "risk", which has a known probability (such as a "50/50 chance"), and an "uncertainty", where we do not know the probability. This is an important distinction in the case of climate change vulnerability is the product of both risks and uncertainties.

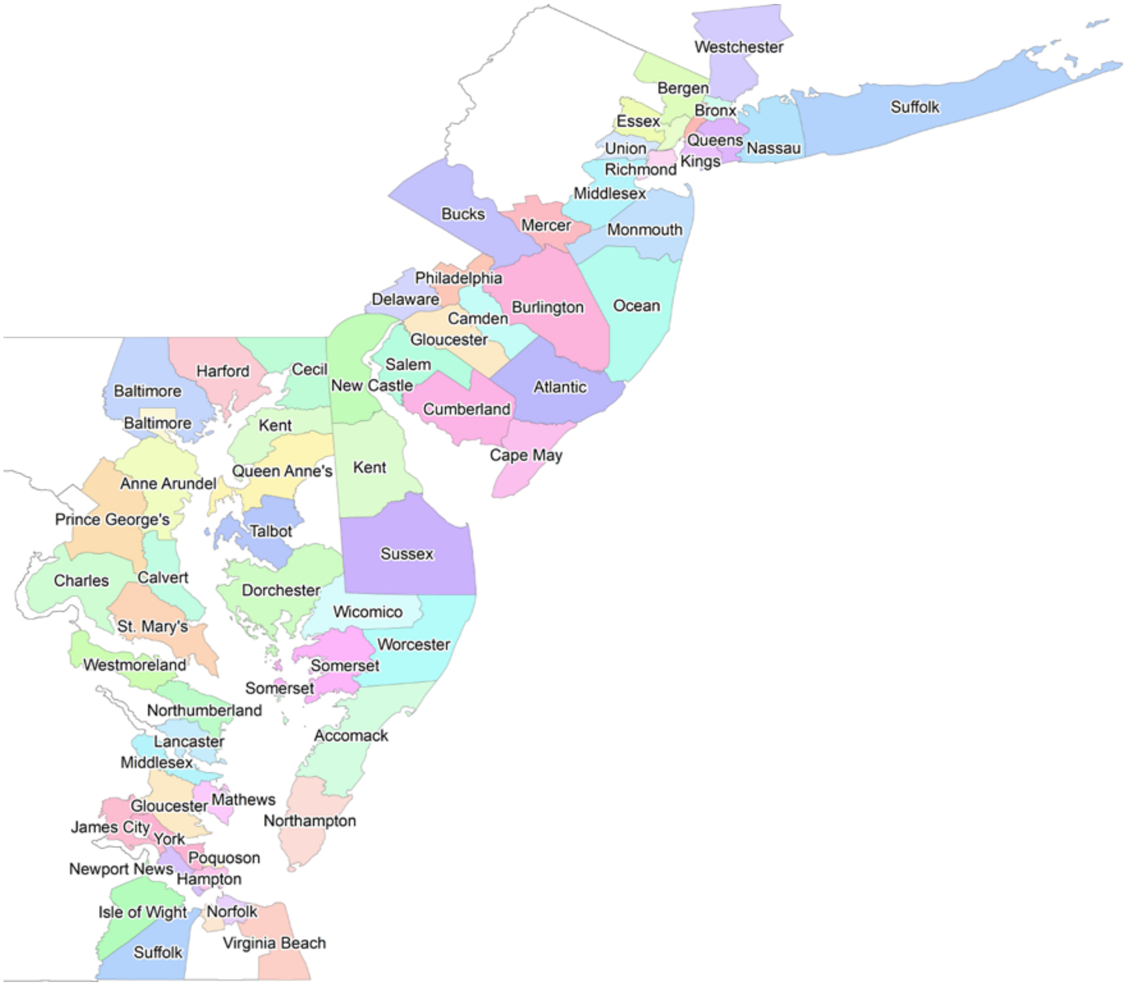


Figure 1-1 Counties and cities included in the study. Some names not included in image, for full list of 63 counties and cities see Appendix 1-A.

- **Flooding and inundation** are terms that are sometimes used as synonyms but can also be distinguished from one another by using “flood” to mean a temporary covering of land by water and “inundation” to mean a permanent shift from dry to wet. Both will occur with climate change, but floods will be more common than inundation at least within current projection horizons. In this study, we will use the term flooding, the more likely effect this century.
- **Vulnerability** arises where important assets or systems are potentially affected by climate change. Vulnerability is a state of potential; effects may or may not occur. Identifying a vulnerable condition is not a forecast of a specific outcome but is an indicator of potential effects based on the assumptions used to generate the measurement of vulnerability.

Vulnerability is listed last here but it is the key concept in this study. The information contained herein must be extensively supplemented with more detailed local information in order to transform information about general vulnerabilities into very specific information about risks, which can then be translated into plans that can be assessed for their costs, effectiveness and benefits.

Overview of the Report

To assess vulnerability, we examine five separate but related aspects of climate change:

In Chapter 2, we review the current state of the literature on climate change in general and on the Mid-Atlantic region in particular, with a focus on sea level rise, which is by far the most heavily studied effect of climate change. This chapter shows that there has been steady and significant improvement in our understanding of the physical processes resulting in and from sea level rise and that knowledge is being more widely disseminated and used but is not available throughout the Mid-Atlantic region.

Chapter 3 undertakes an analysis of the relationship between sea level rise and key characteristics of the socio-economic environment of coastal areas of the Mid-Atlantic. The study uses two sea level rise scenarios that approximate the scenarios being used by the various states in their planning efforts. The analysis examines vulnerabilities to population, housing, employment, the summer economy, the ocean economy, fishing dependent communities, energy and water infrastructure, and socially vulnerable populations. The chapter identifies the relative vulnerabilities across the states and the sixty-three counties in the region.

Chapter 4 examines the possible vulnerabilities in the marine transportation sector. The chapter documents the high importance of the region's principal cargo ports and indicates that this sector has some advantages in preparing for climate change because it is so capital intensive in an industry with high competitive pressures. It thus has more frequent opportunities to build climate change into its planning than most other sectors of the economy. Whether and how these opportunities will be seized remains unclear, however.

Chapter 5 examines vulnerabilities in commercial fisheries in the region. The current state of knowledge indicates high potential for disruptions in the distribution and abundance of a large number of commercially important species. Some species may see an increase in abundance from stocks moving northward from more southern waters, but a much larger number of species in the region are likely to be negatively affected. Climate change, which has not yet been factored into fisheries management to a great extent, will have to become a much larger and more explicit component. Moreover, the fisheries management system may struggle to adapt to much more rapid changes in fisheries ecosystems than it has dealt with in the past.

Chapter 6 explores vulnerabilities in the field of ecosystem services, those characteristics of ecosystems that provide goods and services of direct benefit to people. The current state of knowledge about ecosystem services in the Mid-Atlantic is summarized and related to what is known about how these services may be modified by climate change. Particular attention is drawn to coastal wetlands, which provide such a wide array of ecosystem services both related to, and unrelated to, climate change that their preservation and expansion requires urgent attention.

Chapter 7 provides a summary of findings and recommendations. The chapter focuses on three themes: the need to translate assessments of vulnerabilities into known risks upon which planning can be based; the need for continued regional perspectives on climate change and adaptation; and the challenges to the institutions to evolve in ways better capable of addressing the rapidly evolving but still highly uncertain challenges of climate change.

In addition to this report, the studies of the Mid-Atlantic region examined and the data sets upon which the analysis in Chapter 3 is based will be made available. For more information, contact the Mid-Atlantic Regional Council on the Ocean at www.midatlanticocean.org.

References for Chapter 1

Intergovernmental Panel on Climate Change. 2014. “Climate Change 2014 Synthesis Report Summary Chapter for Policymakers.” doi:10.1017/CBO9781107415324.

Appendix 1-A

State	County/City Name	State	County/City Name	State	County/City Name	State	County/City Name
DE	Kent	NJ	Bergen	NY	Suffolk	VA	Suffolk (city)
DE	New Castle	NJ	Burlington	NY	Westchester	VA	Virginia Beach (city)
DE	Sussex	NJ	Camden	PA	Bucks	VA	Westmoreland
MD	Anne Arundel	NJ	Cape May	PA	Delaware	VA	York
MD	Baltimore	NJ	Cumberland	PA	Philadelphia		
MD	Baltimore (city)	NJ	Essex	VA	Accomack		
MD	Calvert	NJ	Gloucester	VA	Chesapeake (city)		
MD	Cecil	NJ	Hudson	VA	Gloucester		
MD	Charles	NJ	Mercer	VA	Hampton (city)		
MD	Dorchester	NJ	Middlesex	VA	Isle of Wight		
MD	Harford	NJ	Monmouth	VA	James City		
MD	Kent	NJ	Ocean	VA	Lancaster		
MD	Prince Georges	NJ	Salem	VA	Mathews		
MD	Queen Anne’s	NJ	Union	VA	Middlesex		
MD	Somerset	NY	Bronx	VA	Newport News (city)		
MD	St. Mary’s	NY	Kings	VA	Norfolk (city)		
MD	Talbot	NY	Nassau	VA	Northampton		
MD	Wicomico	NY	New York	VA	Northumberland		
MD	Worcester	NY	Queens	VA	Poquoson (city)		
NJ	Atlantic	NY	Richmond	VA	Portsmouth (city)		

Chapter 2 : Climate change studies relevant to the Mid-Atlantic Region

Introduction

According to the “Fourth National Climate Assessment Volume I” (NAC-4), published in November 2017, global atmospheric CO_2 concentrations are now above 400 parts per million (ppm), a level that has not occurred for the last 3 million years, when global temperatures were between 1.8°C and 3.6°C higher than today, and sea levels were 30ft to 100ft (10m to 30m) higher than current levels (U.S. Global Change Research Program 2017).

This chapter surveys recent studies identifying risks from climate change in the MARCO region and discusses the range of possible impacts currently being considered, with a focus on sea level rise (SLR). This chapter contains a detailed review of 83 climate change studies, published between 2008 and 2017, categorized by individual states and regionally (*Table 2-1*), and by relevance and date.

Several of the reviewed studies, particularly ones from New York and New Jersey, as well as various regional studies, rely on and improve on the findings of the Intergovernmental Panel on Climate Change (IPCC)’s fifth assessment report (AR5) (IPCC 2013). AR5 proposed four future climate change scenarios, termed Representative Concentration Pathways (RCPs), which are widely used in SLR literature:

1. Declining emissions, RCP2.6 (with mean SLR of 1.3ft, by 2100);
2. Stabilizing emissions, RCP4.5 (with mean SLR of 1.54ft, by 2100);
3. Stabilizing emissions RCP6.0 (with mean SLR of 1.57ft, by 2100);
4. Rising emissions, RCP8.5 (with mean SLR of 2.06ft, by 2100).

Given the similarities between RCP4.5 and RCP6.0 (with mean SLR of 1.54ft and 1.57ft, respectively, by 2100), these two scenarios are usually combined into a single “stabilizing emissions”, or intermediate scenario.

The numbers in each scenario’s name represent the resulting radiative forcing (energy imbalance) expected by 2100 in watts/meter^2. Each scenario has corresponding global mean sea level (GMSL) rise projections from IPCC, with an overall range between 0.55ft and 1.24ft, for the 2046-2065 period, and between 0.85ft and 2.78ft, for the 2081-2100 period. However, the IPCC’s scenarios are currently considered to underestimate potential SLR, as they do not fully incorporate the impacts of land-ice melt dynamics, a significant contributor to GMSL rise.

This review pays particular attention to recent studies as there have been significant advances in the theory and practice of climate modeling in the last few years. Specifically, studies published since 2015 rely on more detailed observations, which result in a better understanding of the underlying physical processes affecting climate change and its impacts. Additionally, recent studies use more sophisticated computational models with higher spatial resolution outputs, and take uncertainty into account more explicitly (Kopp et al. 2014; Garner et al. 2017; U.S. Global Change Research Program 2017). Moreover, recent models generally incorporate improved understanding of the process and extent of glacial ice melting, particularly in Greenland and West Antarctica (Miller et al. 2013; Kopp et al. 2014; DeConto and Pollard 2016). Finally, recent studies indicate that parts of the MARCO region are a hotspot for SLR (Sallenger, Doran, and Howd 2012; Ezer and Atkinson 2014; Kopp et al. 2014). Such areas include New York City, NY, and Norfolk, VA, where relative sea level rise is accentuated by local factors, including vertical land motion (Kopp et al. 2014).

Geography	Number of Reports
Regional	34
New York	14
New Jersey	7
Delaware	11
Maryland	7
Virginia	10
Grand Total	83

Table 2-1 Summary of climate change studies.

In addition to state-specific reports, a select number of recent scientific publications covering global and regional SLR was also included in this review. A compilation of SLR scenarios, related assumptions, and variables considered by the most relevant studies evaluated in this chapter, can be found in Table 2-5.

Note that studies from Maryland were published between 2008 and 2013, prior to the release of latest IPCC report. These studies were included as they are guiding state vulnerability assessments and adaptation policies. For completeness, we have also included updated information about a forthcoming study in Maryland (from email communications with the MARCO team).

	CBE Recommended Scenarios	Fourth National Climate Assessment (2017)	NOAA (2017)	NY (2014)	NJ (2014)	DE (2017)	MD (2013)	VA (ADAPTVA, Norfolk, VA, 2017)	MEAN	IPCC (2013)
MEDIUM	**3.0**	3.3	3.3	3.0	N/A	3.3	3.7	4.2	**3.5**	1.5
HIGH	**6.0**	6.6	6.6	6.3	4.5	4.9	5.7	7.5	**6.0**	2.1

Table 2-2 Sea level rise scenarios (in feet by year 2100).

Table 2-2 presents a summary of the sea level rise projected in the most up to date SLR scenarios included in this review (in feet, rounded to one decimal place). *Table 2-5*, at the end of the next section, provides additional details on the SLR scenarios above. Sea level rise scenarios considered by states in the Mid-Atlantic region are generally higher than the most recent IPCC scenario estimates. The Medium SLR scenarios are somewhat consistent across states, ranging between 3.0ft and 4.2ft (*Table 2-2*). There is more divergence among the states in the high SLR scenarios, which range between 4.5ft in New Jersey and 7.5 in VA. There is also variance in the geographies considered within state studies. Scenarios for VA for instance, are based on one study in the southeast region (recurrent flooding study for Tidewater VA).

The following sections summarize key studies covering the MARCO region and within each state.

<u>Studies Addressing the MARCO Region</u>

Regional reports included in this review are either directly or indirectly based on the findings of IPCC's AR5 (IPCC 2013), and the framework proposed by Kopp et al. (2014). The most recent document reviewed is the "Fourth National Climate Assessment | Volume I" (NCA-4) (U.S. Global Change Research Program 2017), which includes a detailed review of the most current climate science, and highlights past, current, and future climate changes for the U.S. The NCA-4 report concludes that it is extremely likely (95 to 100% certain) “that human activities, especially emissions of greenhouse gases, are the dominant cause of the observed warming since the mid-20th century.” The report cites already observed climate changes including: since 1901 global average temperatures increased 1.8˚F (1.0˚C) and GMSL has risen 7-8 inches. Observed climate changes in the U.S. cited in the report include: heavy rainfall frequency and intensity has increased; heatwaves have become more frequent since the 1960s; earlier spring melt is already affecting water resources in the western U.S.; and incidence of forest fires increased since the early 1980s. The report concludes that over the next few decades, annual average temperatures are expected to rise at least another 2.5˚F (1.4˚ C) in the U.S. (U.S. Global Change Research Program 2017).

Sea level rise scenarios included in NCA-4 were originally presented in the “Global and Regional SLR Scenarios for the United States” report (Sweet et al. 2017a), published by NOAA earlier in 2017 (Table 2-3). NOAA’s 2017 report was the result of the Coastal Flood Hazard Scenarios and Tools Task Force, established by the White House Council on Climate Preparedness and Resilience, in 2015. The task force, which includes the National Ocean Council (NOC) and the U.S. Global Change Research Program (USGCRP), was tasked with developing and disseminating, future relative sea levels with associated coastal flood scenarios, for the entire country. The NOAA 2017 SLR report focused on two important goals. The first was to generate global mean sea level (GMSL) projections and scenarios; the second objective was to adjust these GMSL scenarios to specific regional conditions for the entire U.S. coastline. The report increased the lowest SLR scenario at the year 2100 from 0.33ft to 0.98ft and included a revised extreme SLR scenario of up to 8.20ft (*Table 2-3*). This is considerably higher than the average high SLR scenarios from all other studies examined (of 5.6 foot). The NOAA 2017 report is one of a growing number of studies that incorporates land-ice melt in the models, which resulted in an upward revision of previously used GMSL rise scenarios, and that recommend the consideration of an extreme scenario in planning efforts. (Sweet et al. 2017a; Griggs et al. 2017).

The NOAA 2017 report confirms the findings from previous studies that sea level rise in the Mid-Atlantic region, (the Northeast Atlantic, or Virginia coast northward), “is projected to be greater than the global average for almost all future GMSL rise scenarios.” Regional sea levels in this area are intensified by the static equilibrium effects of Antarctic ice melt, glacial isostatic adjustment (GIA), sediment compactions, and possibly a reduction in water transport by the Gulf Stream (Sweet et al. 2017a). The report also provides guidelines for the selection of SLR scenarios, which that take into consideration the probabilities of each scenario occurrence, within a coastal planning and vulnerability assessment context.

The six GMSL rise scenarios included in the NOAA 2017 SLR report (Table 2-3) are: Low, Intermediate-Low, Intermediate, Intermediate-High, High and Extreme, corresponding to GMSL rise of 0.98ft, 1.64ft, 3.28ft, 4.92ft, 6.56ft, and 8.20ft (0.3m, 0.5m, 1.0m, 1.5m, 2.0m and 2.5m, respectively) (Sweet et al. 2017a). The values in Table 2-3 are for 19-year averages centered on decades through 2200 (showing only a subset after 2100) beginning in 2000. Only median values are shown.

GMSL Scenario (meters)	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2120	2150	2200
Low	0.03	0.06	0.09	0.13	0.16	0.19	0.22	0.25	0.28	**0.30**	0.34	0.37	0.39
Intermediate-Low	0.04	0.08	0.13	0.18	0.24	0.29	0.35	0.40	0.45	**0.50**	0.60	0.73	0.95
Intermediate	0.04	0.10	0.16	0.25	0.34	0.45	0.57	0.71	0.85	**1.0**	1.3	1.8	2.8
Intermediate-High	0.05	0.10	0.19	0.30	0.44	0.60	0.79	1.0	1.2	**1.5**	2.0	3.1	5.1
High	0.05	0.11	0.21	0.36	0.54	0.77	1.0	1.3	1.7	**2.0**	2.8	4.3	7.5
Extreme	0.04	0.11	0.24	0.41	0.63	0.90	1.2	1.6	2.0	**2.5**	3.6	5.5	9.7

Table 2-3. GMSL scenario probabilities from NOAA 2017 SLR report (meters).
Source (Sweet et al. 2017a).

GMSL Scenario (feet)	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2120	2150	2200
Low	0.10	0.20	0.30	0.43	0.52	0.62	0.72	0.82	0.92	**0.98**	1.12	1.21	1.28
Intermediate-Low	0.13	0.26	0.43	0.59	0.79	0.95	1.15	1.31	1.48	**1.64**	1.97	2.40	3.12
Intermediate	0.13	0.33	0.52	0.82	1.12	1.48	1.87	2.33	2.79	**3.28**	4.27	5.91	9.19
Intermediate-High	0.16	0.33	0.62	0.98	1.44	1.97	2.59	3.28	3.94	**4.92**	6.56	10.17	16.73
High	0.16	0.36	0.69	1.18	1.77	2.53	3.28	4.27	5.58	**6.56**	9.19	14.11	24.61
Extreme	0.13	0.36	0.79	1.35	2.07	2.95	3.94	5.25	6.56	**8.20**	11.81	18.04	31.82

Table 2-4. GMSL scenario probabilities from NOAA 2017 SLR report (feet).
Source: Sweet et al. (2017).

The second regional report reviewed in more detail during this analysis is the *"Probabilistic 21st And 22nd Century Sea-Level Projections at a Global Network of Tide-Gauge Sites"* from Kopp et al. (2014). The report has provided a comprehensive probabilistic framework of SLR projections, which are being adopted by various states in the MARCO regions, and beyond (including California). The report also delivers regional SLR projections for various coastal locations in the U.S., including New York City, NY, and Norfolk, VA.

Factors affecting global mean sea level rise considered by Kopp et al. (2014) include ice sheet dynamics, thermal expansion, and changes in land water storage. Factors driving regional, or relative SLR consider in the report include regional oceanographic processes, GIA, sediment compaction, and vertical land motion.

Table 2-5 provides a summary of SLR scenarios included in the most comprehensive and recent studies reviewed. Note that reports from the foundational, earlier generation of SLR studies (which were mostly focused on understanding the factors affecting GMSL and producing SLR forecasts without considering impacts to coastal areas) were not included in the review. Examples of such reports include the work from Rahmstorf and Vermeer from the late 2000s (Rahmstorf 2007; Vermeer and Rahmstorf 2009). These second generation SLR studies may account for regional drivers of SLR including vertical movement of the land, GIA, ground water extraction, and sediment compaction. The majority of the state-focused studies examined here may be described as "second generation SLR studies", which use "bathtub" models to project the impacts of coastal inundation to littoral communities. Such studies overlay inundation maps with spatially-explicit economic and socio-economic information, including: infrastructure, properties, people and ecosystems.

A known limitation of studies that rely on bathtub-fill models, is that such models calculate inundated areas based on terrain elevation, regardless of land connectivity and other hydrodynamics considerations - e.g. stormwater drainage systems, rivers and streams. Moreover, these studies do not fully assess the probabilities associated with the various scenarios they use to examine vulnerabilities, including the probability of a specific set of factors affecting sea levels occurring, and the shifting probabilities associated with coastal storms that will drive much of the actual impacts from climate change.

More recently, SLR studies are entering a third generation of modeling by starting to discuss future SLR scenarios using sophisticated probabilistic models (Kopp et al. 2014; Garner et al. 2017). This is a critical step, as future SLR scenarios are heavily dependent on the speed and intensity of the onset of climate change and corresponding global warming - which will be driven by future greenhouse gases (GHG) emissions. Moreover, the impacts from various SLR scenarios will also depend on non-climatic factors, including economic and urban development, building codes, population growth, and their corresponding uncertainty.

Finally, several sub-regional, multi-state studies were reviewed but were not directly cited in this chapter, as they were either based on first generation SLR studies or were heavily referenced in the regional studies discussed above. See section 'Non-Cited References' for a complete list of studies read during this analysis.

Geography	Study	Variables Considered	SLR Scenarios
MARCO Region	2017 - Global and Regional SLR Scenarios for the United States (NOAA) (Sweet et al. 2017a)	**GMSL Rise Factors:** Thermal Expansion Ice sheet mass changes Glacier mass changes **Local SLR Factors:** Land-water storage GIA Sediment compaction Atmosphere-ocean dynamics	**2100 Projections (GMSL)** Low 0.98ft (0.3m) Medium* Low 1.64ft (0.5m) Medium 3.28ft (1m) Medium High 4.92ft (1.5m) High 6.56ft (2m) Extreme 8.20ft (2.5m) Notes from the study: "For almost all scenarios, regional SLR is projected to be higher than the global average along the coast of the U.S. Northeast and western Gulf of Mexico." SLR elevations in the report are in meters. * The medium scenarios are referred to as the "intermediate" scenarios in this report.
	2014 - Probabilistic 21st and 22nd century sea-level projections at a global network of tide -gauge sites (Kopp et al. 2014).	**GMSL Rise Factors:** Thermal Expansion Ice sheet mass changes Glacier mass changes **Local SLR Factors:** Oceanographic Processes (e.g. changes in the Gulf Stream) Land-water storage GIA Rotational effects (West Antarctica Ice Sheet loss) Sediment compaction	**2100 Projections** **Global Ranges:** RCP 2.6, very likely: 0.98ft to 2.62ft (0.3m to 0.8m) RCP 4.5, very likely: 1.31ft to 2.95ft (0.4m to 0.9m) RCP 8.5, very likely: 1.64ft to 3.94ft (0.5m to 1.2m) (Very Likely = 90% probability). **Local Ranges:** <u>Regional SLR (2100 (likely Range, RCP 8.5):</u> New York City: 2.29ft to 4.27ft (0.7m to 1.3m) Norfolk, VA: 2.62ft to 4.27ft (0.8m to 1.3m)
New York	2015 Climate Change in New York State (Horton et al. 2015)	**GMSL Rise Factors:** Thermal expansion Changes in the mass of glaciers Ice caps, and ice sheets Water storage on land **Local SLR Factors:** Vertical land motion Gravitational, elastic, and rotational effects resulting from ice mass loss Local changes in ocean height, due to Changes in ocean water density and circulation	New York City Values (see Table 4a in the referenced report) **2020:** 0.16ft to 0.83ft (2in to 10in) **2050:** 0.67 to 2.5ft (8in to 30in) **2080:** 1.91ft to 4.91ft (13in to 58in) **2100:** 1.25ft to 6.25ft (15in to 75in) Notes from the study: 10th to 90th Percentile ranges Baseline: 2000 to 2004 SLR elevations in the report are in inches.
New Jersey	2016 - Assessing New Jersey's Exposure to Sea-Level Rise and Coastal Storms: Report of the	**GMSL Rise Factors:** Thermal expansion Mass loss from glaciers, ice caps, and ice sheets, and	 **2030:** 0.6 to 1.0ft **2050:** 1.0 to 1.8ft

Geography	Study	Variables Considered	SLR Scenarios
	New Jersey Climate Adaptation Alliance Science and Technical Advisory Panel (Kopp et al. 2016)	Changes in land water storage. **Local SLR Factors:** GIA Vertical land motion due to natural sediment compaction and groundwater Changes in ocean circulation and winds, and associated changes in the distribution of heat and salt within the ocean, Static-equilibrium effects (changes in the height of Earth's gravitational field and crust associated with the large shifts of mass from ice to the ocean), which diminish the effect of Greenland melt and increase the effect of Antarctic melt.	**2100 (Low emissions):** 1.7 to 3.1ft **2100 (High emissions):** 2.4 to 4.5ft Likely scenarios = 67% probability Based on (Kopp et al. 2014)
	2014 - Understanding New Jersey's Vulnerability to Climate Change (Georgetown Climate Center and Rutgers University Climate Institute 2014). Note: SLR scenarios based on Miller et al. 2013.	**GMSL Rise Factors:** Warming Oceans Melting of land ice **Local SLR Factors:** Subsidence or uplift (including thermal subsidence, sediment loading, flexural, and glacial isostatic adjustment (GIA) effects) Gravitational, rotational, and flexural effects due to changing ice sheets (collectively known as "static equilibrium" effects) Oceanographic effects (including dynamic topography and tidal-range change effects) "In the Mid-Atlantic region, the rate of relative sea-level rise was nearly double the rate of global average sea-level rise during the 20th century (…) due to GIA, sediment compaction (natural and groundwater effects), and oceanographic effects."	**2030** Low: 0.62ft (19cm) Medium: 0.82ft (25cm) High: 1.12ft (34cm) Higher: 1.35ft (41cm) **2050** Low: 1.08ft (33cm) Medium: 1.48ft (45cm) High: 1.94ft (59cm) Higher: 2.33ft (71cm) **2100** Low: 2.49ft (76cm) Medium: 3.48ft (106cm) High: 4.92ft (150cm) Higher: 5.91ft (180cm) (Estimates from Miller et al. 2013) SLR elevations in the report are in centimeters.
Delaware	2017 – Recommendation of Sea-Level Rise Planning Scenarios for Delaware: Technical Report (Callahan et al. 2017).	**GMSL Rise Factors:** Land-based ice melt Ocean thermal expansion **Local SLR Factors:** Weakening of the Gulf Stream Weakening of the gravitational force of the Greenland and Antarctic ice sheets Ocean-atmosphere climate patterns Vertical land motion	**2100 Projections** Low (5%): 1.71ft Medium* (50%): 3.25ft High (95%): 5.02ft * The medium scenario is referred to as the "intermediate" scenario in this report.

Geography	Study	Variables Considered	SLR Scenarios
	2009 - Recommended SLR Scenarios for Delaware (Delaware Department of Natural Resources and Environmental Control Sea Level Rise Technical Workgroup 2009)	**GMSL Rise Factors:** Factors included in IPCC AR4 (2007): Ocean thermal expansion Ice melt **Local SLR Factors:** Land subsidence from tectonic subsidence (glacio-isostatic adjustment, regional tectonic subsidence of the Atlantic Coast)	**2100 Projections** Low: 1.6ft (0.5m) Medium*: 3.3ft (1.0m) High: 4.9ft (1.5m) * The medium scenario is referred to as the "intermediate" scenario in this report. SLR elevations in the report are in meters.
Maryland	2013 - Updating Maryland's Sea-level Rise Projections (Boesch et al. 2013) Note: these projections are currently in the process of being updated with an expected release in 2018.	**GMSL Rise Factors:** Factors included in NRC report (2012): Ocean thermal expansion Ice melt **Local SLR Factors:** Regional ocean dynamics Vertical land motion Changes in tides and storm surges	**2050 Projections** Low: 0.9ft Medium*: 1.4ft High: 2.1ft **2100 Projections** Low: 2.1ft Medium*: 3.7ft High: 5.7ft * The medium scenario is referred to as "best" in this report.
Virginia	2017 – ADAPT-VA: Sea Level in Virginia, Historic Data and Projections (ADAPT Virginia 2017)	**GMSL Rise Factors:** Thermal Expansion Ice sheet mass changes Glacier mass changes **Local SLR Factors:** Land subsidence	**2100 Projections** Low: 1.9ft Medium Low: 2.5ft Medium*: 4.2ft Medium High: 5.8ft High: 7.5ft Extreme: 9.1ft * The medium scenarios are referred to as the "intermediate" scenarios in this report.
Virginia (cont.)	2013 - Recurrent Flooding Study for Tidewater Virginia (Mitchell et al. 2013)	**GMSL Rise Factors:** Factors included in NCA report (2012): Ocean thermal expansion Ice melt **Local SLR Factors:** Land subsidence	**2033-2063:** 1.5ft **2100:** Low: 3.2ft High: 5.5ft Highest: 7.5ft

Table 2-5. Summary of reviewed studies.

State by State Summary

All five states included in the MARCO region have undertaken significant efforts to understand the potential impacts of SLR to their coastal zones and are considering different SLR scenarios in various ways. New York, Delaware, and Maryland have officially adopted SLR scenarios in various aspects their planning efforts.

This review focuses on the most up-to-date and comprehensive studies available for each state. Such studies are important as they have higher spatial resolution, and consider local factors influencing sea level rise in more details than regional studies (including vertical land motion, ground water extraction, and sediment compaction).

New York

A close coordination between the New York State Energy Research and Development Authority (NYSERDA) and the New York City Panel on Climate Change (NPCC) resulted in a series of reports, published between 2011 and 2015. These reports include the NPCC 2015 report, and the ClimAID study from NYSERDA, which was initially published in 2011 and updated in 2014. The CLimAID study was funded by New York State to assess the potential impacts of climate change statewide and to identify ways to mitigate such impacts. Climate change impacts included in the 2014 update of CLimAID include: marine and coastal impacts (e.g. SRL, and extreme events), as well as other impacts including: lightning, and intense precipitation events of short duration.

These three reports provide the foundation for state legislation related to planning for sea level rise incorporated in the New York Community Risk and Resiliency Act (CRRA). Mandated sea level rise planning scenarios in CRRA range between 1.25ft (15 inches) and 6.25ft (75 inches) by 2100 (New York State Department of Environmental Conservation, n.d.) (*Table 2-6* in bold). Table 2-6, below, provides more details on currently adopted SLR projections in New York State.

	Region	**Long Island**					**New York City/Lower Hudson**					**Mid-Hudson**				
	Descriptor	Low	Low-Mid.	Mid.	High-Mid.	High	Low	Low-Mid.	Mid.	High-Mid.	High	Low	Low-Mid.	Mid.	High-Mid.	High
Time Interval	2020s	2	4	6	8	10	2	4	6	8	10	1	3	5	7	9
	2050s	8	11	16	21	30	8	11	16	21	30	5	9	14	19	27
	2080s	13	18	29	39	58	13	18	29	39	58	10	14	25	36	54
	2100	**15**	21	34	47	72	15	22	36	50	**75**	11	18	32	46	71

Table 2-6: SLR scenarios for New York from NYCRR Part 490 (inches).
Source: (New York State Department of Environmental Conservation, n.d.)

New Jersey

In 2016, the New Jersey Climate Adaptation Alliance (NJCAA) tasked Rutgers University to convene a Science and Technical Advisory Panel (STAP) to identify planning options to enhance New Jersey's resilience to sea level rise, coastal storms, and flooding. Based on projections of SLR and changes in coastal storms, the study identified vulnerabilities of people, places, and assets in New Jersey. The Rutgers study relies on SLR scenarios, developed by Kopp et al. (2014), as discussed above (Table 2-7).

	Central Estimate	Likely Range	1-in 20 Chance	1-in 200 Chance	1-in 1000 Chance
Year	50% probability SLR meets or exceeds…	67% probability SLR is between…	5% probability SLR meets or exceeds…	0.5% probability SLR meets or exceeds…	0.1% probability SLR meets or exceeds…
2030	0.8	0.6 – 1.0	1.1	1.3	1.5
2050	1.4	1.0 – 1.8	2.0	2.4	2.8
2100 Low Emissions	2.3	1.7 – 3.1	3.8	5.9	8.3
2100 High Emissions	3.4	2.4 – 4.5	5.3	7.2	10

Table 2-7: SLR scenarios for New Jersey (feet).
Source: (Kopp et al. 2016)

In 2014, a team of researchers from Rutgers, led by Robin Leichenko, published a study entitled “Economic Vulnerability to Climate Change in Coastal New Jersey: A Stakeholder-Based Assessment” (Leichenko et al. 2014). The study employed a stakeholder engagement approach to identify the main risks, vulnerabilities, and economic stresses related to climate change in Ocean County, NJ. The scope of the study did not include the analysis of possible future scenarios, but rather the identification of the key perceived vulnerabilities in Ocean County. Climate risks identified by the study were classified into two categories: gradual changes (e.g. SLR, marsh die-back due to salt water intrusion, and coastal erosion), and extreme events (e.g. flooding, tropical, and extra-tropical cyclones. Additionally, a number of non-climatic stresses were identified during stakeholder discussions: (i) demographic stresses (e.g. population growth and high proportion of senior citizens); (ii) economic stresses (e.g. budget cuts and lack of public transit); and (iii), environmental stresses (e.g. pollution and changes in sediment transport). Furthermore, the study compiled a list of resources at risk, including: natural assets (e.g. beaches, fresh-water, and estuaries); built assets (e.g. properties, roads, and recreational infrastructure); and economic activities (e.g. tourism, fishing, construction, and real estate insurance). Finally, the study identified a handful of especially vulnerable groups (e.g. low-income residents and property owners, farmers, and small business owners) (Leichenko et al. 2014).

Delaware

In November of 2017, following DNREC’s directions, and in response to executive Order 41, which dictates that all state agencies must consider and incorporate SLR into appropriate long-range planning (Delaware Department of Natural Resources and Environmental Control 2013), the Delaware Sea-Level Rise Technical Committee published update SLR scenarios for the state (Callahan et al. 2017). The report recommends the state should rely on the Kopp et al. (2014) framework; specifically, the report recommends the state should use “the 5, 50, and 95 percent probability levels of sea-level rise in Delaware, determined by the Kopp et al. (2014) methodology, under the IPCC RCP 8.5 emissions scenario, as the low, intermediate, and high SLR planning scenarios, respectively,” (Callahan et al. 2017). These scenarios translate to 1.71ft, 3.25ft, and 5.02ft of SLR, relative to year 2000 mean sea level (Callahan et al. 2017) (*Table 2-8*).

Delaware's Executive Order 41, also dictates that DNREC must periodically update and distribute SLR scenarios, based on the best available science (Delaware Division of Energy & Climate 2017).

Previously, in 2010, the Delaware Sea Level Rise Advisory Committee was established to help the state plan for SLR by assessing vulnerabilities and recommending adaptation planning. The committee identified that the impacts of inundation and increased coastal flooding would impact various critical resources in the state, including: beaches and dunes; coastal impoundments; dams, dikes, and levees; evacuation routes; freshwater tidal wetlands; future development areas; habitats of conservation concern; heavy industrial areas; the Port of Wilmington; protected lands statewide; roads and bridges; railroad lines; tidal wetlands; tourism and coastal recreation; USFWS Refuges; and fresh water wells (Delaware Coastal Programs of the Department of Natural Resources and Enviornmental Control 2012; Delaware Sea Level Rise Advisory Committee and Delaware Coastal Programs 2013). In 2009, the Delaware Department of Natural Resources and Environmental Control (DNREC) published the state's first SLR policy document, recommending that three SLR planning scenarios (0.5ft, 1.0ft, and 1.5ft) should be adopted, and that these scenarios should be periodically updated (Delaware Department of Natural Resources and Environmental Control Sea Level Rise Technical Workgroup 2009).

SLR Planning Scenario	**SLR by 2100 (meters)**	**SLR by 2100 (feet)**
Low (5%)	0.52	1.71
Intermediate (50%)	0.99	3.25
High (95%)	1.53	5.02

Table 2-8: SRL Planning Scenarios for Delaware.
Source: (Callahan et al. 2017).

Maryland

In 2012, Governor O'Malley's Executive Order on Climate Change and "Coast Smart" Construction required the consideration of flooding risk and SLR to capital projects (Boesch et al. 2013). Currently, Maryland is in the process of updating SLR projections, which were previously based on the National Research Council (NRC) assessment (Boesch et al. 2013).

The planning horizon most commonly used in Maryland is 2050, with an anticipated SLR of 0.9ft to 2.1ft (*Table 2-9*). Boesch et al. 2013 recommends planning for at least ("best") 3.7ft by 2100 and 5.7ft as a worst-case scenario with 6.6ft as a plausible worst-case scenario (Boesch et al. 2013) (local SLR rates in Maryland are amplified by vertical land movement).

Previously, in 2008, the Adaptation and Response Working Group (ARWG) of the Maryland Commission on Climate Change (MCCC) produced the initial phase of a strategy to reduce the state's vulnerability to climate change and the impacts of SLR (Chen et al. 2008). The report identified coastal impacts such as shoreline erosion, coastal flooding, inundation, impacts to barrier and bay islands, and higher water tables and salt water intrusion (Chen et al. 2008). In 2010, the Scientific and Technical Working Group (STWG) and ARWG produced phase two of this strategy, identifying various sectors vulnerable to SLR, including: agriculture; terrestrial, bay and aquatic ecosystems; water resources; and population growth and infrastructure (Boicourt and Johnson 2010).

Maryland Relative SLR	Thermal	Glaciers	Greenland	Antarctica	Dynamic	VLM	Relative SLR
2050 best	0.3	0.2	0.1	0.3	0.3	0.2	**1.4**
2050 low	0.1	0.2	0.1	0.1	0.2	0.2	**0.9**
2050 high	0.6	0.2	0.2	0.5	0.3	0.3	**2.1**
2100 best	0.8	0.4	0.3	1.0	0.6	0.5	**3.7**
2100 low	0.3	0.4	0.3	0.3	0.4	0.4	**2.1**
2100 high	1.5	0.6	0.6	1.9	0.6	0.6	**5.7**
Land ice change fingerprint scale factors		3.0	1.6	4.1			

Table 2-9: SLR projections for Maryland (feet).
Source: Boesch et al. 2013

Virginia

Recently, ADAPT-VA, a clearinghouse for individuals, agencies, and local programs engaged in climate change adaptation in the state, has adopted the recommendations of NOAA's 2017 report (Sweet et al. 2017a)(*Table 2-10*). In NOAA's 2017 report, GMSL rise scenarios in the Southern Chesapeake Bay region were adjusted for land subsidence using the National Geodetic Survey's 3.1mm/year rate (2013). However, it is still unclear how these recommendations are being officially incorporated by state agencies in Virginia (ADAPT Virginia 2017).

Previously, in 2015, drawing from expertise from the Virginia Institute of Marine Science (VIMS), the Virginia's Governor's Climate Change and Resiliency Update Commission proposed various recommendations related to climate change and sea level rise. The commission recommended the state should adopt SLR scenarios developed by the National Climate Assessment, with adjustments to reflect local subsidence rates (which were previously determined by VIMS' 2013 recurrent flooding study [J.Ward and Honorable B. Moran 2015]). In the 2013 study, VIMS recommended that the state should anticipate SLR of 1.5ft over the next 20 to 50 years and between 3.2ft and 7.5ft by 2100 (Mitchell et al. 2013). The study identified multiple vulnerabilities related to developed areas and transportation infrastructure from impacts including increased precipitation events, high tides, and storm surge (Mitchell et al. 2013).

Climate Change Scenario (in feet)	**Year**									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Low	0.1	0.3	0.5	0.7	0.9	1.1	1.3	1.5	1.7	1.9
Intermediate-low	0.1	0.4	0.6	0.9	1.2	1.4	1.7	2	2.3	2.5
Intermediate	0.1	0.4	0.7	1.1	1.5	2	2.5	3	3.6	4.2
Intermediate-high	0.2	0.4	0.8	1.3	1.8	2.5	3.2	4	4.7	5.8
High	0.2	0.5	0.9	1.5	2.2	3	3.9	5	6.4	7.5
Extreme	0.1	0.5	1	1.6	2.5	3.4	4.5	5.9	7.4	9.1

Table 2-10: SLR projections at Sewell's Point, Norfolk, VA in feet relative to NAVD88.
Source: (ADAPT Virginia 2017)

Conclusions

The possible extent of climate change and its impacts on the Mid-Atlantic region have been extensively studied over the past decade. In general, the nature of climate change and its effects have become better understood, and the kinds of changes that are likely to occur in the region have been identified with relatively high levels of confidence, including sea level rise as well as changes in marine and coastal ecosystems. However, as climate change and sea level rise studies can only express their understanding of the future in terms of multiple possible scenarios, little is known about the exact pace and extent of changes. This is true of the IPCC and of each of the sea level rise studies examined. Moreover, the impacts from various SLR scenarios will also depend on non-climatic factors, including: economic and urban development, building codes, and population growth.

But information is improving and there is increasing ability to downscale global models to reflect the unique circumstances of local conditions through the coastal ocean regions. Analysis is shifting from rather simple sea level rise models, based solely on interactions between shoreline elevations and thermally-driven sea level rise, to models that incorporate much more sophisticated understanding of ocean and coastal processes. Recent research on the possible effects of glacial melting have raised the possibility of much more significant sea level rises occurring either much sooner than expected or much higher than had been expected in the usual reference time frame (usually though the year 2100). Furthermore, climate change models are being integrated with storm models that provide more detailed pictures of impacts through analysis of the ocean-atmosphere interface in a changing climate, and a combination of coastal and inland flooding. Understanding of climate change is shifting from “this could happen” to “this has X % probability of happening within Y time period.”

The studies examined here show that different methodologies and the judgments of different experts and policy makers can result in fairly significant expectations about the possible range and timing of sea level rise. At this point, there can be no meaningful assessment of the accuracy of any of these projections beyond a few decades, so studies examining climate change vulnerabilities remain in the realm of probabilities. Nonetheless, it is necessary to make some selection of the possible futures to be examined. Based on the most up-to-date and comprehensive studies available, we propose the use of two sea level rise scenarios: 3.0ft and 6.0ft. For the reasons outlined above, these scenarios are not specifically tied to a time range, however, they cover the most likely SLR projections for the 21st century. The next chapter identifies the ranges of climate change to be used in this study and applies the resulting estimates of sea level rise to an assessment of socio-economic impacts in coastal areas of the Mid-Atlantic.

References Cited in Chapter 2

ADAPT Virginia. 2017. "Virginia Sea Level." http://www.adaptva.org/info/virginia_sea_level.html.

Boesch, Donald F., Larry P. Atkinson, William C. Boicourt, Robert. A Rymple, John D. Boon, Donald R. Cahoon, Robert A. Dalrymple, et al. 2013. "Updating Maryland's Sea Level Rise Projections. Special Report of the Scientific and Technical Working Group to the Maryland Climate Change Commission." Cambridge, MD.

Boicourt, Kate (Editor), and Zoe (Editor) Johnson. 2010. "Comprehensive Strategy for Reducing Maryland's Vulnerability to Climate Change, Phase II: Building Societal, Economic, and Ecological Resilience." *Report of the Maryland Commision on Climate Change, Adaptation and Response and Scientific and Technical Working Groups.* Cambridge, MD.

Callahan, John A., Benjamin P. Horton, Daria L. Nikitina, Christopher K. Sommerfield, Thomas E. McKenna, and Danielle Swallow. 2017. "Recommendation of Sea-Level Rise Planning Scenarios for Delaware: Technical Report, Prepared for Delaware Department of Natural Resources and Environmental Control (DNREC) Delaware Coastal Programs."

Chen, Shih-Nan, Wanda Cole, Jane Hawkey, Adrian Jones, Mary Jane Rutowski, and Jane Thomas. 2008. "Comprehensive Strategy for Reducing Maryland's Vulnerability to Climate Change, Phase I: Sea-Level Rise and Coastal Storms." *Report of the Maryland Commission on Climate Change Adaptation and Response Working Group*. Annapolis, MD. http://dnr2.maryland.gov/ccs/Publication/Comprehensive_Strategy.pdf.

DeConto, Robert M., and David Pollard. 2016. "Contribution of Antarctica to Past and Future Sea-Level Rise." *Nature* 531 (7596). Nature Publishing Group: 591–97. doi:10.1038/nature17145.

Delaware Coastal Programs of the Department of Natural Resources and Enviornmental Control. 2012. "Preparing for Tomorrow's High Tide: Sea Level Rise Vulerability Assessment for the State of Delaware." Dover, DE.

Delaware Department of Natural Resources and Environmental Control. 2013. "The Climate Framework for Delaware." http://www.dnrec.delaware.gov/energy/Pages/Climate-Framework.aspx.

Delaware Department of Natural Resources and Environmental Control Sea Level Rise Technical Workgroup. 2009. "Recommended Sea Level Rise Scenarios for Delaware." Dover, DE. http://www.dnrec.delaware.gov/coastal/Documents/SeaLevelRise/Final and Signed DNREC SLR scenarios.pdf.

Delaware Division of Energy & Climate. 2017. "The Climate Framework for Delaware." Accessed October 27. http://www.dnrec.delaware.gov/energy/Pages/Climate-Framework.aspx.

Delaware Sea Level Rise Advisory Committee, and Delaware Coastal Programs. 2013. "Preparing for Tomorrow's High Tide: Recommendations for Adapting to Sea Level Rise in Delaware." Dover, DE.

Ezer, Tal, and Larry P Atkinson. 2014. "Accelerated Flooding along the U.S. East Coast: On the Impact of Sea-Level Rise, Tides, Storms, the Gulf Stream, and the North Atlantic Oscillations." *Earth's Future*. doi:10.1002/2014EF000252.

Garner, Andra J., Michael E. Mann, Kerry A. Emanuel, Robert E. Kopp, Ning Lin, Richard B. Alley, Benjamin P. Horton, Robert M. DeConto, Jeffrey P. Donnelly, and David Pollard. 2017. "Impact of Climate Change on New York City's Coastal Flood Hazard: Increasing Flood Heights from the Preindustrial to 2300 CE." *Proceedings of the National Academy of*

Sciences, 1–6. doi:10.1073/pnas.1703568114.
Georgetown Climate Center, and Rutgers University Climate Institute. 2014. “Understanding New Jersey’s Vulnerability to Climate Change.” *Climate Information*.
Griggs, G, Árvai, J, Cayan, D, DeConto, R, Fox, J, Fricker, HA, Kopp, RE, Tebaldi, C, Whiteman. EA. 2017. “Rising Seas in California.” Sacramento CA. http://www.opc.ca.gov/webmaster/ftp/pdf/docs/rising-seas-in-california-an-update-on-sea-level-rise-science.pdf.
Griggs, Gary, Dan Cayan, Claudia Tebaldi, Helen Amanda Fricker, Joseph Árvai, and Robert E. Kopp. 2017. “Rising Seas in California: An Update on Sea-Level Rise Science.,” no. April: 71. http://www.opc.ca.gov/webmaster/ftp/pdf/docs/rising-seas-in-california-an-update-on-sea-level-rise-science.pdf.
Horton, Radley, Daniel Bader, Yochanan Kushnir, Christopher Little, Reginald Blake, and Cynthia Rosenzweig. 2015. “New York City Panel on Climate Change 2015 Report Chapter 1: Climate Observations and Projections.” *Annals of the New York Academy of Sciences*. doi:10.1111/nyas.12586.
Intergovernmental Panel on Climate Change. 2014. “Climate Change 2014 Synthesis Report Summary Chapter for Policymakers.” doi:10.1017/CBO9781107415324.
IPCC. 2013. “Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.” *Intergovernmental Panel on Climate Change, Working Group I Contribution to the IPCC Fifth Assessment Report (AR5)(Cambridge Univ Press, New York),* 1535. doi:10.1029/2000JD000115.
J.Ward, Honorable M., and Honorable B. Moran. 2015. “Governor Terence R. McAuliffe’s Climate Change and Resiliency Update Commisison.”
Jepson, Michael, and Lisa L Colburn. 2013a. “Development of Social Indicators of Fishing Community Vulnerability and Resilience in the U.S. Southeast and Northeast Regions.” NOAA Tech. Memo. NMFS-F/SPO-129.
———. 2013b. “Development of Social Indicators of Fishing Community Vulnerability and Resilience in the U.S. Southeast and Northeast Regions. NOAA Tech. Memo. NMFS-F/SPO-129,” no. April: 64.
Kopp, R., A Broccoli, B Horton, D Kreeger, R Leichenko, J A Miller, J K Miller, et al. 2016. “Assessing New Jersey’s Exposure to Sea-Level Rise and Coastal Storms: Report of the New Jersey Climate Adaptation Alliance Science and Technical Advisory Panel.” New Brunswick, NJ. http://njadapt.rutgers.edu/docman-lister/conference-materials/167-njcaa-stap-final-october-2016/file.
Kopp, R, Radley M. Horton, Christopher M. Little, Jerry X. Mitrovica, Michael Oppenheimer, D. J. Rasmussen, Benjamin H. Strauss, and Claudia Tebaldi. 2014. “Probabilistic 21st and 22nd Century Sea-Level Projections at a Global Network of Tide-Gauge Sites.” *Earth’s Future* 2: 383–407. doi:10.1002/2014EF000239.
Leichenko, Robin, Melanie McDermott, Ekaterina Bezborodko, Michael Brady, and Erik Namendorf. 2014. “Economic Vulnerability to Climate Change in Coastal New Jersey: A Stakeholder-Based Assessment.” *Journal of Extreme Events*. doi:10.1142/S2345737614500031.
Miller, Kenneth G, Robert E Kopp, Benjamin P Horton, James V Browning, and Andrew C Kemp. 2013. “A Geological Perspective on Sea-Level Rise and Its Impacts along the U . S . Mid-Atlantic Coast Earth’s Future.” *Earth’s Future*, 1–16. doi:10.1002/2013EF000135.
Mitchell, Molly, Carl Hershner, Herman Julie, Dan Schatt, Pam Mason, and Emily Eggington.

2013. “Recurrent Flooding Study for Tidewater Virginia.” *Virginia Institute of Marine Science, Center for Coastal Resources Management, William and Mary*. doi:10.21220/V5TG79.

New York State Department of Environmental Conservation. n.d. “Community Risk and Resiliency Act (CRRA).” http://www.dec.ny.gov/energy/102559.html.

Rahmstorf, Stefan. 2007. “A Semi-Empirical Approach to Projecting Future Sea-Level Rise.” *Science (New York, N.Y.)* 315 (5810): 368–70. doi:10.1126/science.1135456.

Sallenger, Asbury H., Kara S. Doran, and Peter A. Howd. 2012. “Hotspot of Accelerated Sea-Level Rise on the Atlantic Coast of North America.” *Nature Climate Change* 2. Nature Publishing Group. doi:10.1038/nclimate1597.

Sweet, William V, Robert E Kopp, Christopher P Weaver, Jayantha Obeysekera, Radley M Horton, E Robert Thieler, and Chris E Zervas. 2017a. “Global and Regional Sea Level Rise Scenarios for the United States.” Silver Spring, MD.

———. 2017b. “Global and Regional Sea Level Rise Scenarios for the United States.”

U.S. Global Change Research Program. 2017. “USGCRP, 2017: Climate Science Special Report: Fourth National Climate Assessment, Volume I.” Edited by D.J. Wuebbles, K.A. D.W. Fahey, D.J. Hibbard, B.C. Dokken, Stewart, and T.K. Maycock. Vol. I. Washington, DC, USA. doi:doi: 10.7930/J0J964J6.

Vermeer, Martin, and Stefan Rahmstorf. 2009. “Global Sea Level Linked to Global Temperature.” *Proceedings of the National Academy of Sciences of the United States of America* 106 (51): 21527–32. doi:10.1073/pnas.0907765106.

Mid-Atlantic Sea Level Rise Studies Not Cited in Chapter 2

Accomack - Northampton Planning District Commission. 2015. “Eastern Shore of Virginia Transportation Infrastructure Inundation Vulnerability Asssessment.”

Arcadis U.S. Inc. 2016. “Estimate of Storm Surge Sensitivity To Sea Level Rise on Virginia’s Eastern Shore.”

Callahan, John A. 2017. “Determination of Future Sea-Level Rise Planning Scenarios for Delaware.” Accessed October 27. http://www.dgs.udel.edu/projects/determination-future-sea-level-rise-planning-scenarios-delaware.

Canick, Michelle R., N. Carlozo, and D. Foster. 2016. “Maryland Coastal Resiliency Assessment.” Edited by The Nature Conservancy. Bethesda, MD.

Chesapeake Bay Program (CBP) Partnership. 2016. “Chesapeake Bay TMDL 2017 Mid-Point Assessment. Recommendations on Incorporating Climate-Related Data Inputs and Assessments: Selection of Sea Level Rise Scenarios and Tidal Marsh Change Models.”

City of New York. 2012. “New York City Wetlands Strategy.” NYC Government. New York, NY.

———. 2013. “A Stronger More Resilient New York.” New York, NY.

Delaware Coastal Programs. 2017. “What Is the Value of Tidal Wetlands?” Dover, DE: Delaware Coastal Programs. doi:10.1038/sj.bdj.2015.43.

Grannis, Jessica, Sara Hoverter, Annie Bennett, Melissa Deas, and Jamie DeWeese. 2017. “Policy Considerations for the Maryland Commission on Climate Change.”

Hampton Roads Planning District Commission. 2015. “Hampton Roads Sea Level Rise Planning and Technical Assistance.”

Honorable L. Preston Bryant. 2008. “Governor’s Commission on Climate Change.”

Horton, Radley, Daniel Bader, Lee Tryhorn, Art Degaetano, and Cynthia Rosenzweig. 2011. “Climate Risks.” ClimAID, 16–47.

Horton, Radley, Christopher Little, Vivien Gornitz, Daniel Bader, and Michael Oppenheimer. 2015. “New York City Panel on Climate Change 2015 Report Chapter 2: Sea Level Rise and Coastal Storms.” Annals of the New York Academy of Sciences 1336 (1). New York, NY: 36–44. doi:10.1111/nyas.12593.

Johnson, Z., M., L. Linker Bennett, S. Julius, R. Najjar, M. Mitchell, D. Montali, and R. Dixon. 2016. “The Development of Climate Projections for Use in Chesapeake Bay Program Assessments.”

Johnson, Z., M. Bennett, L. Linker, S. Julius, R. Najjar, M. Mitchell, D. Montali, and R. Dixon. 2016. “The Development of Climate Projections for Use in Chesapeake Bay Program Assessments STAC Workshop Report STAC Publication 16-006.” Edgewater, MD.

Kaplan, M, M Campo, L Auermuller, and J Herb. 2016. “Assessing New Jersey’s Exposure to Sea-Level Rise and Coastal Storms: A Companion Report to the New Jersey Climate Adaptation Alliance Science and Technical Advisory Panel Report.” New Brunswick, NJ.

Kaplan, Marjorie, and Jeanne Herb. 2016. “Integrating Climate Science into Coastal Resilience Planning and Decision Making in New Jersey.” New Brunswick, NJ.

Kemp, A. C., B. P. Horton, J. P. Donnelly, M. E. Mann, M. Vermeer, and S. Rahmstorf. 2011. “Climate Related Sea-Level Variations over the Past Two Millennia.” Proceedings of the National Academy of Sciences 108 (27): 11017–22. doi:10.1073/pnas.1015619108.

Kopp, R., Andrew C. Kemp, Klaus Bittermann, Benjamin P. Horton, Jeffrey P. Donnelly, W. Roland Gehrels, Carling C. Hay, Jerry X. Mitrovica, Eric D. Morrow, and Stefan Rahmstorf. 2016. “Temperature-Driven Global Sea-Level Variability in the Common Era.” Proceedings of the National Academy of Sciences 113 (11): E1434–41. doi:10.1073/pnas.1517056113.

Kreeger, D., J. Adkins, P. Cole, R. Najjar, D. Velinsky, P. Conolly, and J. Kraeuter. 2010. “Climate Change and the Delaware Estuary: Three Case Studies in Vulnerability Assessment and Adaptation Planning. Partnership for the Delaware Estuary.” PDE Report 10–01: 1–117.
Kreeger, D., J. Adkins, P. Cole, R. Najjar, D. Velinsky, P. Conolly, and J. Kraeuter. 2010. “Climate Change and the Delaware Estuary: Three Case Studies in Vulnerability Assessment and Adaptation Planning. Partnership for the Delaware Estuary.” PDE Report 10–01: 1–117.
Little, Christopher M, Radley M Horton, Robert E Kopp, Michael Oppenheimer, Gabriel A Vecchi, and Gabriele Villarini. 2015. “Joint Projections of US East Coast Sea Level and Storm Surge.” Nature Climate Change 5: 1114–21. doi:10.1038/NCLIMATE2801.

Long Island Sound Study, New England Interstate Water Pollution Control Commission, and WaterVision LLC. 2015. “Long Island Sound Comprehensive Conservation and Management Plan 2015.”

Management, NOAA Office for Coastal. 2017. “Sea Level Rise Viewer,” no. January.

Maryland Commission on Climate Change. 2016. “Maryland 2016 Annual Report.” doi:10.1039/C1DT90165F.

Mid-Atlantic Coastal Acidification Network. 2017. “Meeting Summary: The Mid-Atlantic Coastal Acidifcation Network.”

Mid-Atlantic Regional Council on the Ocean, and the Mid-Atlantic Regional Association Coastal Ocean Observing System. 2017. “Changing Ocean Conditions Related to Fisheries Workshop.”

Mitchell, Molly. 2014. “Climate Change Projections and State Adaptation Efforts.” Virginia Institute of Marine Science, William and Mary.

Najjar, Raymond, Andrew Ross, Danielle Kreeger, and Susan Kilham. 2012. “Chapter 7 – Climate Change in the Technical Report for the Delaware Estuary & Basin,” no. 12–01: 225–41.

Neil Berg, Debra Knopman, Benjamin F. Hobbs, Klaus Keller, and Robert E. Nicholas. 2016. “Resilience to a Changing Climate in the Chesapeake Bay Watershed.”

New Jersey Department of Environmental Protection. 2007. “Valuing New Jersey’s Natural Capital: An Assessment of the Economic Value of the State’s Natural Resources.” Environmental Protection.

New York Academy Sciences. 2015. “New York City Panel on Climate Change 2015 Report Executive Summary.” Annals of the New York Academy of Sciences. New York, NY. doi:10.1111/nyas.12591.

New York Department of Environmental Conservation. 2015. “Community Risk and Resiliency Act: Mainstreaming Climate Change Considerations.” New York Department of Enviornmental Conservation.

New York Rising Community Reconstruction Program. 2014. “NY Rising: Community Reconsturction Committee Plans.”

New York State Energy Research and Development Authority. 2015. “Observed and Projected Climate Change in New York State: An Overview.” U.S. Global Change Research Program. doi:10.7930/J0Z31WJ2.

NYS 2100 Commission. 2007. “Recommendations to Improve the Strength and Resilience of the Empire State’s Infrastructure.” IEEE Journal of Solid-State Circuits. doi:10.1109/JSSC.2006.889391.

Orton, Philip M. 2017. “Mid-Atlantic Sea Level Rise and Coastal Development.” West Long Branch.

Papiez, Chelsie. 2012. “Coastal Land Conservation in Maryland : Targeting Tools and Techniques for Sea Level Rise Adaptation and Response.”

Pflicke, Kelly M, Michael Greenberg, D Ph, Jennifer Whytlaw, Jeanne Herb, and Marjorie Kaplan. 2015. “Populations Vulnerable to Climate Change in New Jersey: Update of a Statistical Analysis.” New Brunswick, NJ.

Pyke, C.R., R.G. Najjar, Mary Beth Adams, Denise Breitburg, Carl Hershner, Robert Howarth, Michael Kemp, et al. 2008a. “Climate Change and the Chesapeake: Bay State-of-the-Science Review and Recommendations.” Annapolis, MD.

———. 2008b. “Climate Change and the Chesapeake: Bay State-of-the-Science Review and Recommendations. A Report from the Chesapeake Bay Program Science and Technical Advisory Committee (STAC).” Annapolis, MD.

Report, Techncial, Delaware Estuary, Basin Pde, and Report No. n.d. “Chapter 7 – Climate Change,” no. 12: 225–41.

Rosenzweig, Cynthia, William Solecki, Arthur DeGaetano, Megan O’Grady, Susan Hassol, and Paul Grabhorn. 2011. “Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation in New York State. Technical Report.” Albany, NY.

Rosenzweig, Cynthia, William Solecki, Arthur DeGaetano, Megan O’Grady, Susan Hassol, and P. Grahborn. 2011. “Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. Synthesis Report.” Albany, NY.

Santoni, Amanda, Bonnie Arvay, and Dr. Robert Scarborough. 2017. “Delaware Tidal Wetland Ecosystem Services Valuation: Technical Report.” Dover, DE.
Senator J. Watkins, and Jim Redick. 2014. “Recommendations to the Secure Commonwealth Panel on the Issue of Sea Level Rise and Recurrent Flooding in Coastal Virginia.”
Smith, Lawrence C, Kang Yang, Lincoln H Pitcher, Brandon T Overstreet, Vena W Chu, K Rennermalm, Jonathan Ryan, et al. 2017. “Direct Measurements of Meltwater Runoff and Retention on the Greenland Ice Sheet Surface,” 1–10. doi:10.1073/pnas.1707743114.
Sweet, W.V., R. Horton, R.E. Kopp, A.N. LeGrande, and A. Romanou. 2017. “Sea Level Rise.” Washington D.C. doi:10.7930/J0VM49F2.12.1.
Thieler, E. Robert, and Erika S. Hammar-Klose. 1999. “National Assessment of Coastal Vulnerability to Sea-Level Rise Preliminary Results for the U.S. Atlantic Coast.” Woods Hole: United Stated Geological Survey.
Titus, James. G, K. Eric Anderson, Donald R. Cahoon, Dean B. Gesch, Stephen K. Gill, Benjamin T. Guiterrez, E. Robert Thieler, and S. Jeffress Williams. 2009. “Coastal Sensivity to Sea Level Rise: A Focus on the Mid-Atlantic Region.”
U.S. Global Change Research Program. 2017a. “Climate Science Special Report: Fourth National Climate Assessment, Volume I.” Vol. I. Washington, DC.
Watershed, Bay. 2016. “Resilience to a Changing Climate in the Chesapeake Bay Watershed.”
Workgroup, Climate Resiliency. 2016. “Chesapeake Bay TMDL 2017 Mid-Point Assessment Recommendations.”
Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, B. DeAngelo, S. Doherty, K. Hayhoe, R. Horton, et al. 2017. “Highlights of the U.S. Global Change Research Program Climate Science Special Report,” 10–34. doi:10.7930/J0DJ5CTG.U.S.

Chapter 3 : Coastal Vulnerability Analysis

In this chapter, we present an analysis of the socio-economic vulnerability of the coastal Mid-Atlantic region to the effects of flooding that will be exacerbated by climate change-related rises in sea levels. Flooding is a threat to all coastal areas in the region; flooding can occur year-round and result from both tropical and extra-tropical storm systems. As Chapter 2 points out, the interactions between sea level rise and flooding are one of the aspects of climate change that have been most heavily researched, with the Mid-Atlantic region being one of the more intensively studied areas. The research is producing models that represent ever more complex aspects of sea level rise and its impacts in shoreline areas, with greater detail available for many specific local areas.

This analysis assesses several dimensions of socio-economic vulnerability in a manner that is consistent across the entire region. This is a formidable task. Stretching across 63 counties and independent cities with a population of more than 28.6 million and a shore-adjacent population of more than 14.6 million the region presents not only great size but also significant diversity. County populations in the region, range from 2.6 million in Brooklyn (Kings County), New York to less than 9,000 in Matthews County, Virginia. The region includes Manhattan Island, the heavily developed "Jersey Shore", but also the wild dunes of Assateague, Chincoteague, Fire Island, and the rural counties of the eastern shore of Chesapeake Bay.

Data and methods had to be developed to reflect the interaction between sea level rise and flooding risks with socio-economic characteristics so that both the absolute magnitude of vulnerability (how many people are residents of shore-adjacent Census tracts) and the relative magnitude of vulnerability (where does a county rank among the 63 regional counties in the number of residents of shore-adjacent Census tracts) can be analyzed. A brief introduction to the methods developed for this purpose is thus required proceeding to the results.

Analysis Methods

As indicated in Chapter 1, we use the term "vulnerability" to refer to the possibility of effects on valuable assets and systems from climate change. It is measured at the intersection between some indicator of climate change effects (in this case, sea level rise) and an indicator of valuable assets or systems. Vulnerability is not a forecast of any particular damage level; rather it measures the *change* in possible damages that is made more likely because of climate change.

The basic method of this analysis involves intersecting measures of sea level rise with indicators of socio-economic status and then determining the places with the highest and lowest levels of vulnerability based on this intersection. The ranking of vulnerabilities can then be used to create composite indicators that reflect the differing socio-economic conditions found across the region and the differing exposure to sea level rise-related flooding.

Vulnerability is best expressed in relative terms, through comparison across different spaces, at different times, or both. The core analysis presented here compares the vulnerability of different spaces in the Mid-Atlantic region with one another using two different scenarios of sea level rise: 3 feet or 6 feet.

The measurement of the sea level rise component of vulnerability is quite difficult for the reasons discussed in Chapter 2. While there is very high confidence that the climate is changing primarily as a result of human activities, the actual pace and extent of that change remains unknown. The IPCC can do no better than offer several scenarios based primarily on the extent to which societies are successful or not in reducing greenhouse gas emissions. Within these scenarios, different changes in the marine environment wrought by the overall change in the climate depend on interactions among local and global factors. Layered on top of these factors are issues related to data availability and the structure and performance of the computer simulation models needed to effectively integrate the complex natural systems in order to see possible futures.

The studies examined for this project do not yield a consensus with respect to either the extent or timing of climate change, although the differences are not large as shown in Table 2-2 above. In general, however, it is possible to identify a small number of scenarios that will be consistent with previous research and which can be used to estimate vulnerabilities on a consistent basis across the region. These are a 3-foot rise in sea levels above historical levels and a 6-foot rise.

Recommended SLR scenario	Elevation above 2000 levels
Medium emissions	3ft
High emissions	6ft

Table 3-1 SLR scenarios recommended for study.

The models used to make these projections iterate change year by year out to 2100; the 3 and 6 foot scenarios are the usual end points of this projection process. But these are models, and the actual experience with sea level rise may not be as constant as they suggest. The 3-foot scenario could, likewise, represent a nearer term risk and the 6-foot a more distant risk. Recent research in sea level rise emphasizes the possibility of much higher and more sudden rates of glacial collapse which would push what had been foreseen in 2100 to much earlier periods. That is, what had been 80-100 year predictions in previous models might now happen in 40-50 years.

Simulations of sea level rise, however, have explicit time scales. These 3- and 6-foot scenarios usually indicate sea levels rising by those amounts by 2100, with additional rise beyond that date. When considered as linear trends, intermediate points can be calculated, meaning that the 6-foot scenario could see a 3-foot rise by mid-century or shortly thereafter. However, as discussed in chapter 2, the most recent studies (Sweet et al. 2017b; Griggs, G, Árvai, J, Cayan, D, DeConto, R, Fox, J, Fricker, HA, Kopp, RE, Tebaldi, C 2017) have begun expressing sea level rise not by reference to a specific year but to a specific probability of a given rise in a future year. While this is the preferred approach, we do not employ it here because it has not been consistently applied across the region. We do not, however, attach these two scenarios to any specific time frame, as discussed above.

The Mid-Atlantic is fortunate in having the large and varied pool of sea level rise studies, but that abundance presents a problem when the area being studied is the entire region rather than specific sub-areas. The precision that allows geographic detail fine enough to identify effects on specific properties is a burden to analyses at the regional level. Furthermore, the latest generation of models is not available for the entire region, so any cross-regional comparisons using different models would become distorted by different modeling assumptions and specifications. To assure that the vulnerability measurements reflect primarily the specific characteristics of each coastal location in the region, we used data from the NOAA Sea Level Rise viewer as our basic model.

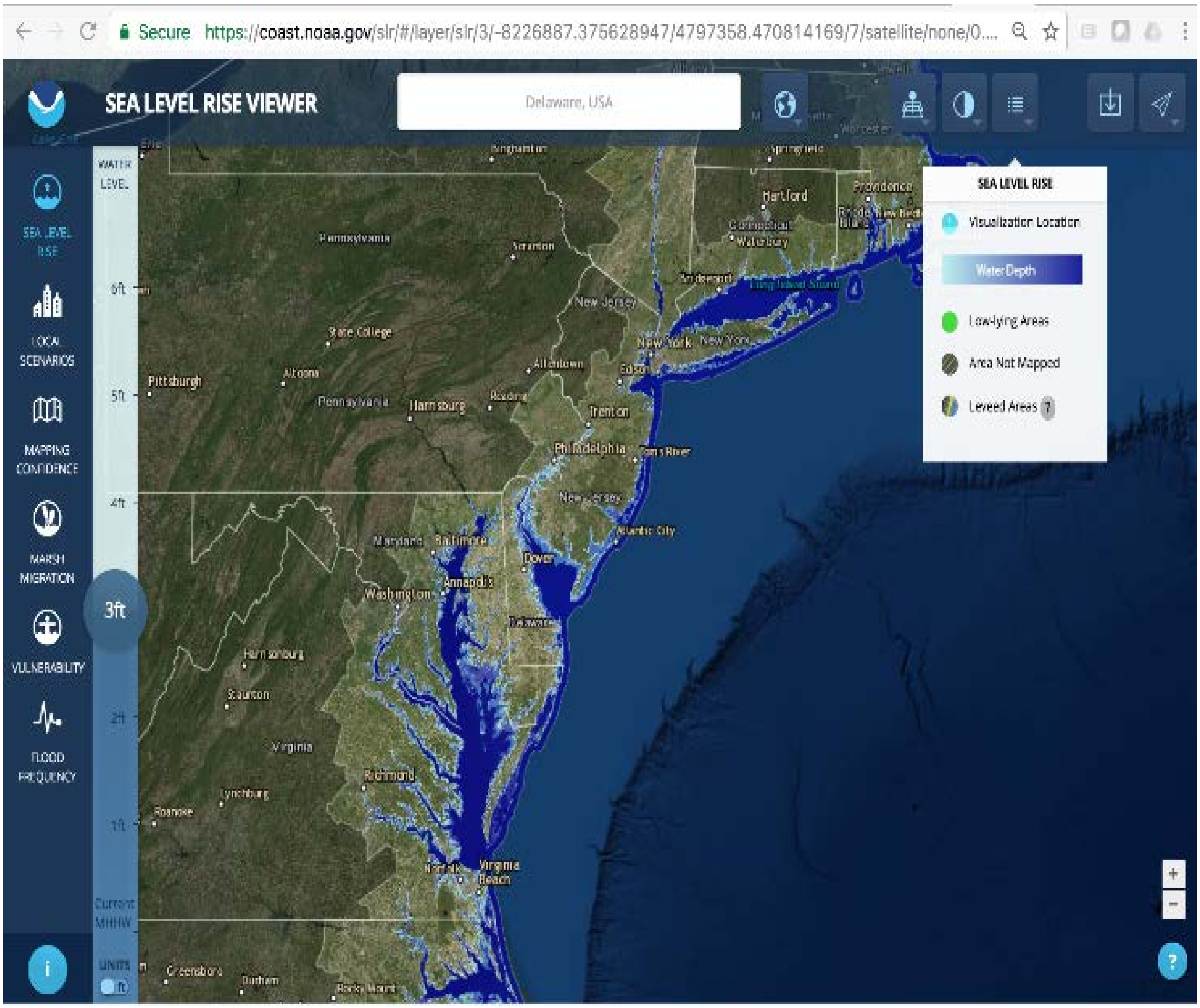


Figure 3-1 NOAA SLR Viewer results for 3 foot SLR.

By using a single data source and model, we ensure that our methods and results are consistent for the entire study region. NOAA’s SLR data for Virginia, Maryland, Delaware, New Jersey, and New York have been recently remapped (August 2016) based on Post-Sandy LIDAR elevation data. NOAA’s SLR data are the result of a modified bathtub approach, which considers the hydro-connectivity of flooded areas, but also allows some low lying unconnected areas to be flooded.

There are two important limitations of the NOAA model. It does not take into account future changes in the coastline; such models are referred to as “modified bathtub” models. As sea level rise continues, shorelines erode and the reach of floods increases. This increase is not accounted for. Second, the NOAA SLR viewer estimates the area of potential flooding but not the depth of flooding. Depth is primarily determined by the extent of water being abnormally distributed on land through storm events, so depth requires not only a modeling of sea levels and shoreline characteristics but also storm intensity. Models with these capabilities are available in parts of the country but not everywhere. Depth matters because increased depth of flooding increases the extent and duration of damage to the built and natural environments.

Our measurement of the sea level rise component of vulnerability is derived from overlaying the NOAA SLR data onto the relevant geographies used for measuring socio-economic characteristics (discussed below). This was done in a GIS model, after correcting for any discrepancies in spatial data. The result yields a figure that represents a percent of the land area of each geography (Census tracts, zip codes, county subdivisions, and counties) subject to flooding under the 3-foot or 6-foot scenarios. The geographies could then be ordered by the extent of possible flooding under each scenario.

It is also important to emphasize that the results of the SLR viewer analysis cannot differentiate between single flood events and long-term inundation. The effects may be those of a single event which produces a flood of the modeled magnitude or the results of a long series of events that leaves the land permanently inundated at least to the extent that present uses are no longer possible. The socio-economic effects may be short-lived or substantially permanent. At this stage, we can only say that the estimated extent of sea level rise for a given place would be X, where X is the percent of the geography flooded.

The sea level rise-related flood analysis is then compared with nine different socio-economic indicators, defined as follows:

- **Population** We used data from the 2015 American Community Survey (ACS) for Census tracts that are adjacent to or touched by shoreline. Shoreline is measured by the NOAA shoreline definition. For all data from the ACS, we used the median estimates.
- **Housing Units** This data is also taken from the 2015 American Community Survey.
- **Total Employment** The smallest geography for which employment is publicly reported is the zip code, using the Zip Code Business Patterns data from the Census. We analyzed zip codes that are shore adjacent (using the same definition as for population and housing). To derive total employment values, we combined data from the Zip Code Business Patterns with data from the Quarterly Census of Employment & Wages published by the U.S. Bureau of Labor Statistics.
- **Summer Employment** The Mid-Atlantic coast is heavily utilized in the summer for tourism and recreation. To capture the increases in economic vulnerability from the different levels of activity in the summer, the ratio of the third quarter employment in the “leisure and hospitality” sector to year-round employment in that sector in each county was identified as a marker. This “summer ratio”, along with the share of land subject to flooding in each sea level rise scenario, was then used to rank order all zip codes by the size of their summer dependence and the extent of possible flooding. Ranks for counties were then calculated as the mean rankings for all zip codes in that county.
- **Summer Housing** Again using American Community Survey, we identified the number of housing units which are “vacant for seasonal use” in each shore-adjacent tract. We added together all seasonal housing in shore-adjacent Census tracts in a county and then ranked all counties based on these totals.
- **Infrastructure** Infrastructure examined falls into two categories: The first is energy and water infrastructure, for which we used data from the Environmental

Protection Agency's (EPA) Facility Registry System (FRS)[5] to calculate the number of energy- and water-related infrastructure. This data comes at the resolution of county subdivision. The second is primary roads (e.g. Interstate highways) and rail, for which we used linear miles of spatially located data from the U.S. Census for roads[6] and the U.S. Geological Survey for rail.[7]

- **Ocean Economy Employment** The ocean economy represents industries that have a direct connection to the ocean, including: marine construction, ship & boat building, minerals extraction, tourism & recreation, marine transportation, and living resources. Employment in these six sectors at the county level is used as an indicator, but unlike the other socio-economic indicators used for this analysis, this indicator is ambiguous as to the impact. Within the ocean economy, some sectors may be adversely affected (tourism), while others (marine construction) may be positively affected (from the construction of adapted structures or reconstruction of wetlands). The net direction of possible effects will depend on more precise information about the local economy. For this reason the ocean economy is not matched with flooding data; the size of the ocean economy (measured as employment) alone is used.
- **Social Vulnerability** Effective adaptation is a product of many different characteristics of a region, one of which is the capacity of communities to mobilize resources and people to respond to increased vulnerabilities. This capacity is not evenly distributed. It is known that areas with certain characteristics, such as predominance of low income households, elderly people, or linguistic minorities have greater challenges than those with higher incomes and more evenly distributed age populations. The Social Vulnerability Index (SoVI) was developed to measure those social characteristics that contribute to increased vulnerability to climate change and other natural hazards. (Cutter, Carolina, and Boruff 2003) The Social Vulnerability Index data is regularly updated by the Hazards and Vulnerability Research Institute.[8] Data for fourteen variables using American Community Survey data is retrieved at the Census tract level and then combined into four different index groups. (Figure 3-2)

[5] Environmental Protection Agency's Dataset Gateway. *Facilities Registry Service*, 2017. Available at: https://www.epa.gov/enviro/geospatial-data-download-service.

[6] Spatial Data Collection and Products Branch Geography Division, U.S. Census Bureau. *TIGER/Line Shapefile, 2017, nation, U.S., Primary Roads National Shapefile, 2017. Available at: ftp://ftp2.census.gov/geo/tiger/TIGER2017/PRIMARYROADS/.*

[7] U.S. Geological Survey, National Geospatial Technical Operations Center. *USGS National Transportation Dataset (NTD) Downloadable Data Collection, 2016.*
Available at: https://prd-tnm.s3.amazonaws.com/index.html?prefix=StagedProducts/Tran/GDB/.

[8] Available at: http://artsandsciences.sc.edu/geog/hvri/sovi%C2%AE-0

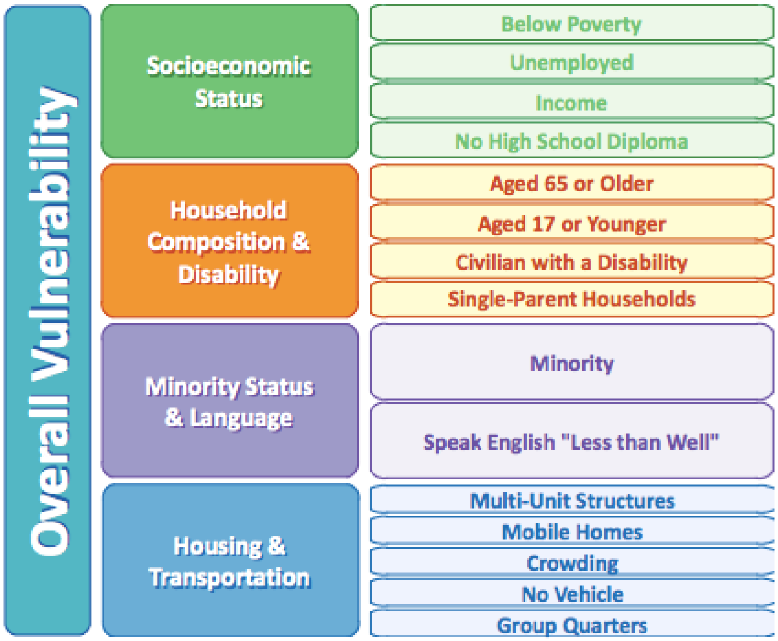


Figure 3-2 Social Vulnerability Index (SoVI) structure.

- **Fishing Community Vulnerability** Fishing communities are frequently small communities that rely on fishing for all, or nearly all, their income. As such, they present a special case of possible climate change vulnerability. An index to measure this vulnerability has been developed by NOAA (Jepson and Colburn 2013a; Colburn et al. 2016a). The NOAA fisheries index combines measures that are used in the SoVI with coastal-community specific measures related to fishing. The analysis here used the measures related to engagement with and reliance on both commercial and recreational fisheries. The NOAA vulnerability index is measured at the community level; data is available for 1,263 communities in the Mid-Atlantic region. Additional analysis of NOAA fishing community index is provided in Chapter 5.

Results

In this section, we first present summary information at the state level, then consider the county level for each of the socio-economic measures. To keep the discussion about counties simple, we will focus on the top ten counties in terms of whatever variables are being discussed. Tables showing data for all counties and all measures are found in the data appendix to this chapter.

The results of the analysis are presented below in the following order: Region-wide summary of rankings across states and counties are discussed first. Then, results for each of the indicators is presented, starting with the sea level rise analysis, followed by each of the socio-economic indicators. Each indicator is examined in terms of its distribution within each state (where appropriate), and at the county level.

The analysis utilizes a rank order score; for each set of variables analyzed, the counties are ranked from 1 to 63 where *lower rank order indicates higher vulnerability and higher rank order indicates lower vulnerability*. (The county with the highest vulnerability has a rank of 1; the county with the lowest a rank of 63). Means of rank scores follow the same pattern, with lower mean ranking indicating higher vulnerability.

Three approaches are used to calculate the rank scores: (i) for some of the socio-economic indicators, the magnitude of the indicator matters. For example, areas with very high populations are defined as more vulnerable than very small populations. These “magnitude” indicators” are population, housing, employment, ocean employment, and infrastructure; (ii) summer employment and summer housing are measures of summer dependence in the economy (the growth in tourism and hospitality employment in the summer versus the annual average and the proportion of housing stock in seasonal housing.) This focuses attention on the most tourism-dependent counties; (iii) and finally, the social vulnerability and fisheries’ inputs are already multi-scale rank orders scores. These are originally calculated on a national basis; for this analysis, they are re-sorted for the Mid-Atlantic region.

Regional Summary Analysis

We first examine the extent of projected flooding based on the NOAA Sea Level Rise Viewer’s data. Table 3-2 shows the total area estimated to be flooded in each state under the 3-foot and 6-foot scenarios, plus the additional area flooded by the 6 foot scenario. The additional area is defined as the total area increase from a 3-foot flooding scenario to a 6-foot flooding scenario. This base analysis uses flood areas calculated at the shore-adjacent Census tract level, the smallest geography used in this study; the state total is summed across the shore adjacent Census tracts in that state (the number of which is shown).

	N Tracts	**Flood Area 3 foot SLR**	**Flood Area 6 foot SLR**	**6 foot Increment**
DE	127	155.6	186.9	31.4
MD	1108	2,145.1	2,408.9	263.9
NJ	715	495.5	581.9	86.4
NY	819	372.4	398.7	26.3
PA	446	16.1	22.9	6.9
VA	388	915.7	1,024.9	109.2
Regional Total	3603	4,100.2	4,624.3	524.1

Table 3-2 Projected flood areas by state (thousands of acres).

	N Tracts	Flood Area 3ft SLR	Flood Area 6ft SLR	6ft Addition
DE	3.5%	3.8%	4.0%	6.0%
MD	30.8%	52.3%	52.1%	50.4%
NJ	19.8%	12.1%	12.6%	16.5%
NY	22.7%	9.1%	8.6%	5.0%
PA	12.4%	0.4%	0.5%	1.3%
VA	10.8%	22.3%	22.2%	20.8%

Table 3-3 Distribution of flood area by state.

Table 3-3 shows the distribution of flooded area within the states of the region, including distribution of tracts. Maryland has the largest area in terms of the number of shore adjacent Census tracts with 30% of the region, but Maryland has an even larger share of the flooded area under both the 3- and 6-foot scenarios. Virginia is fourth in terms of the number of Census tracts, but second in flooded area. Pennsylvania is the least affected by flooding.

Rank	State	County Name	Average Share of Tract Flooded with 3 foot SLR	Rank	State	County Name	Average Share of Tract Flooded with 6 foot SLR
1	MD	Dorchester	76.3%	1	VA	Poquoson (city)	89.4%
2	VA	Poquoson (city)	75.2%	2	MD	Dorchester	83.9%
3	NY	Kings	72.5%	3	NY	Queens	82.1%
4	NY	Bronx	67.3%	4	NY	Kings	78.7%
5	NY	Queens	65.0%	5	MD	Somerset	74.4%
6	MD	Somerset	64.3%	6	NY	Bronx	71.0%
7	NY	Nassau	63.6%	7	NY	Nassau	70.8%
8	VA	Newport News (city)	62.6%	8	VA	Accomack	67.2%
9	VA	Northampton	61.3%	9	VA	Newport News (city)	66.1%
10	VA	Accomack	60.7%	10	VA	Northampton	64.3%
Rank	State	County Name	Area Flooded with 3 Foot SLR (acres)	Rank	State	County Name	Area Flooded with 6 Foot SLR (acres)
1	MD	Dorchester	2388.8	1	MD	Dorchester	2625.2
2	MD	Somerset	1406.2	2	MD	Somerset	1626.9
3	VA	Accomack	1176.5	3	VA	Accomack	1301.2
4	NY	Suffolk	1045.8	4	NY	Suffolk	1100.4
5	MD	Worcester	893.5	5	MD	Worcester	1050.1
6	VA	Northampton	579.9	6	VA	Northampton	608.9
7	MD	St. Mary’s	507.0	7	MD	Talbot	606.7
8	MD	Talbot	490.7	8	MD	St. Mary’s	563.9
9	NJ	Ocean	487.0	9	NJ	Ocean	548.6
10	MD	Harford	409.5	10	NJ	Cape May	422.7

Table 3-4 Top 10 counties by SLR scenarios.

Table 3-4 shows the top ten counties ranked by percentage of shore adjacent tracks projected to be flooded as well as the the total estimated area (in acres) of tract flooding for each scenario. Several counties show up on all of top ten lists, including Dorchester, MD, Poquoson, VA[9], and Somerset, MD. A number of tracts with high percentages of potential flooding are located in urban areas such as the Bronx, Queens, Kings and Newport News. The other noteworthy finding from Table 3-4 is that Maryland and Virginia counties dominate the list in the size of

[9] Cities in Virginia, of which Poquoson is one, are independent of any counties and are administratively similar to counties. These are indicated in the tables with a “city” denotation, but they will still be referred to as “counties” in the text.

flooded area; only Ocean County in New Jersey makes the top 10. The Maryland-Virginia counties shown in Table 3-4 explain these two states ranking as highest in projected flooding area and number of flooded tracts (Table 3-2 and Table 3-3).

But note that the difference in ranking between the upper and lower sections of Table 3-4 is partly explained by the use of Census tracts for analysis. Census tracts are designed to be similar in population size, so the area of tracts in urban areas is generally to be much smaller than in rural area. All else equal, a smaller area flooded will produce a higher percentage in an urban county and a larger area flooded will result in a smaller percentage.

Each county was ranked according to the nine socio-economic indicators described above. In order to provide a summary overview of regional vulnerability a rank score consisting of the means of each indicator rankings was constructed. A rank score of 1 would mean a 1 rank on all 9 indicators; a rank score of 63 would mean a 63 rank on all indicators. Table 3-5 shows the rank mean scores, in order for the 3-foot and 6-foot scenarios for all counties.

When all socio-economic factors are considered together, the most vulnerable counties in the 3 foot scenario lie in New York (Suffok), in the Atlantic and lower Delaware River counties of New Jersey and Delaware, and in the lower Chesapeake in Virgina. The highest vulnerability counties in the 6 foot scenario change, however. (Figure 3-3) The New York City area (including Nassau, Queens, and New York counties) together with counties in southern Chesapeake Bay and souther New Jersey rise to the most vulnerable group. In southern Virginia, the cities of Newport News, Norfolk, and Portsmouth are shifted to the most vulnerable group.

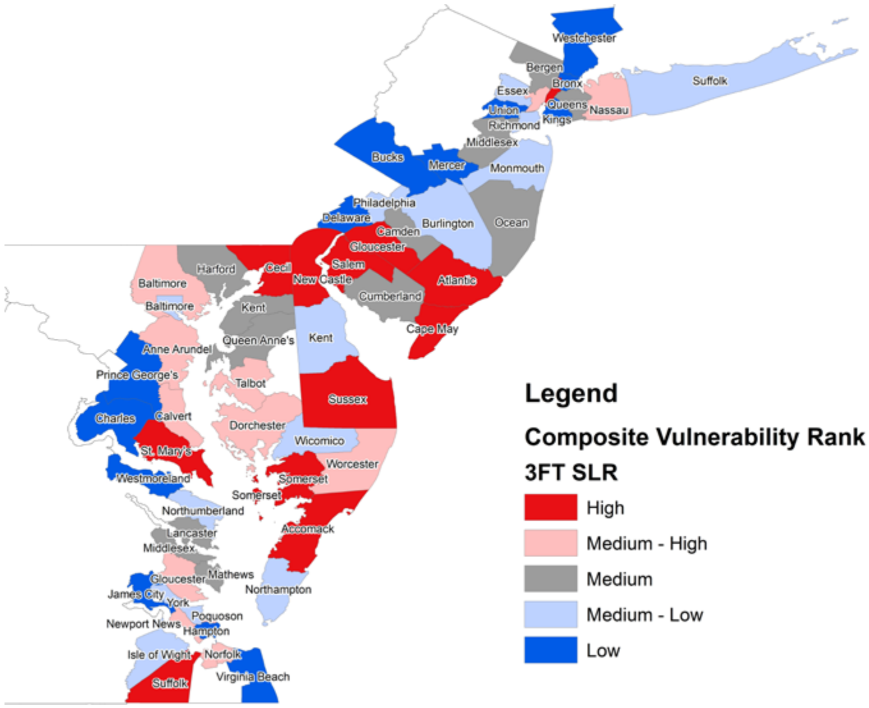
Table 3-5 provides the detaile rankings of each county on the average of all indicators in both scenarios.

It is important to remember that these are are rank orderings, not absolute measures of vulnerability. The vulnerability of counties whose rankings decline in the 6 foot scenario, will still see significantly increased vulnerability on many measures. Their *relative* ranking may fall because of the increases in ranks in counties like New York and Queens, but all counties will still see a steady increase in vulnerability as sea level rises.

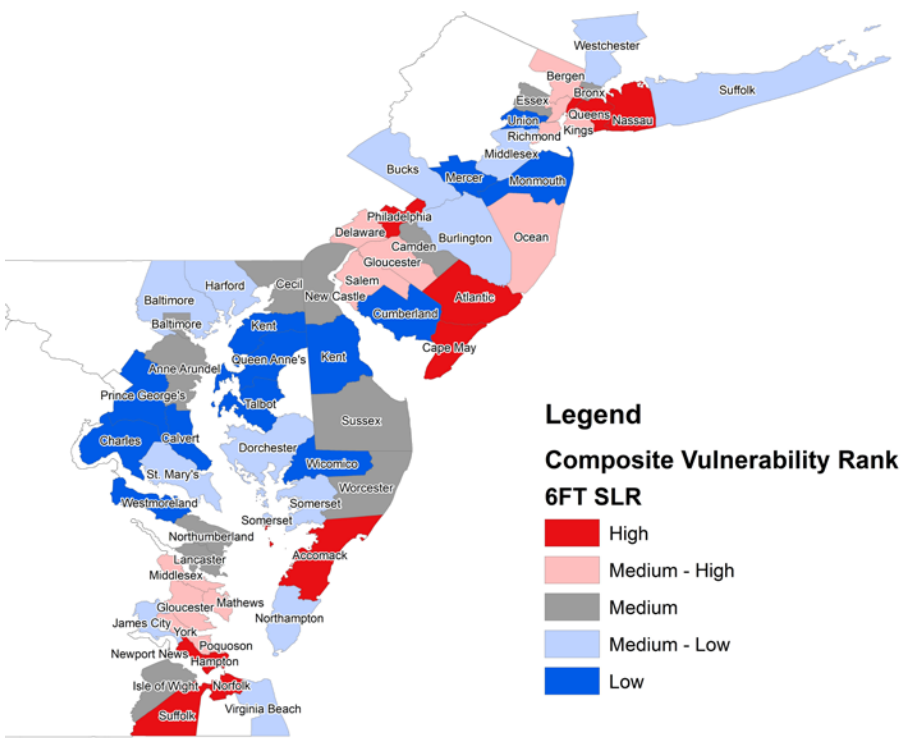
Table 3-6 deconstructs the ranking of vulnerability factors for each county by showing each indicator's rank for each county. The highlighted cells are the lowest ranked indicators *for that county row*. These highlighted cells indicate the factor on which each county is *most* vulnerable. It is possible for a county to have multiple high vulnerability factors because of the use of rank ordering for scoring and the possibility of the same ranking on more than one factor. The table can also be read in columns. The county with the highest vulnerability on each factor has a rank of 1.

Some indicators were more likely to be the lowest ranked (highest vulnerability) than others. This was the case for the fisheries index, which showed the highest vulnerability for nine counties. Seasonal housing units in the 3-foot SLR scenario were highest (lowest rank order) in seven counties. Infrastructure was the highest factor for six counties. On the other hand, the housing indicator the highest vulnerability factor for only two counties.

There are few patterns of geographic consistency in, but one is noteworthy. There is a group of counties in Virginia (Isle of Wight, Lancaster, Matthews, Middlesex, and Northampton) show very high vulnerability on the social vulnerability index under the 6-foot scenario. Matthews and Northampton counties also show high ranking in the social vulnerability index in the 3-foot scenario.



(a)



(b)

Figure 3-3 Composite rank scores by county for (a) 3 foot SLR and (b) 6 foot SLR.

	3-foot SLR Scenario		6-foot SLR Scenario	
Rank	State	County (City)	State	County (City)
1	NJ	Salem	NY	New York
2	NJ	Atlantic	VA	Norfolk (city)
3	NY	New York	VA	Hampton (city)
4	NJ	Cape May	NY	Queens
5	MD	St. Mary's	VA	Newport News (city)
6	VA	Accomack	NJ	Cape May
7	MD	Cecil	VA	Portsmouth (city)
8	DE	Sussex	VA	Suffolk
9	VA	Suffolk	NY	Nassau
10	NJ	Gloucester	NJ	Atlantic
11	MD	Somerset	VA	Accomack
12	DE	New Castle	PA	Philadelphia
13	MD	Talbot	NY	Richmond
14	VA	Norfolk (city)	NJ	Hudson
15	VA	Portsmouth (city)	NY	Kings
16	VA	Poquoson (city)	VA	York
17	MD	Baltimore	VA	Poquoson (city)
18	MD	Worcester	NJ	Salem
19	MD	Dorchester	VA	Mathews
20	NY	Nassau	VA	Gloucester
21	MD	Anne Arundel	VA	Middlesex
22	NJ	Hudson	NJ	Bergen
23	VA	Newport News (city)	NJ	Ocean
24	MD	Calvert	PA	Delaware
25	VA	Gloucester	NJ	Gloucester
26	NJ	Camden	VA	Northumberland
27	VA	Mathews	MD	Baltimore (city)
28	NJ	Ocean	MD	Worcester
29	NY	Queens	VA	Isle of Wight
30	NJ	Middlesex	VA	Lancaster
31	MD	Harford	DE	Sussex
32	VA	Middlesex	NJ	Essex
33	MD	Queen Anne's	NY	Bronx
34	NJ	Cumberland	DE	New Castle
35	NJ	Bergen	NJ	Camden
36	MD	Kent	MD	Anne Arundel

	3-foot SLR Scenario		6-foot SLR Scenario	
37	VA	Lancaster	MD	Cecil
38	VA	York	VA	Northampton
39	PA	Philadelphia	VA	Virginia Beach
40	MD	Baltimore (city)	MD	St. Mary's
41	VA	Northampton	VA	James City
42	VA	Northumberland	MD	Baltimore
43	VA	Isle of Wight	NJ	Middlesex
44	NY	Suffolk	PA	Bucks
45	MD	Wicomico	NY	Suffolk
46	NY	Richmond	MD	Harford
47	NJ	Burlington	NY	Westchester
48	DE	Kent	MD	Somerset
49	NJ	Essex	MD	Dorchester
50	NJ	Monmouth	NJ	Burlington
51	PA	Delaware	MD	Talbot
52	VA	Hampton (city)	NJ	Monmouth
53	NY	Kings	MD	Calvert
54	NY	Bronx	VA	Westmoreland
55	VA	Westmoreland	NJ	Union
56	MD	Charles	MD	Wicomico
57	VA	James City	NJ	Cumberland
58	NJ	Union	MD	Kent
59	MD	Prince Georges	MD	Queen Anne's
60	VA	Virginia Beach	NJ	Mercer
61	NY	Westchester	MD	Charles
62	PA	Bucks	MD	Prince Georges
63	NJ	Mercer	DE	Kent

Table 3-5 Composite ranking of counties for 3 and 6 foot SLR scenarios.

State	County	Housing 3fT SLR	Housing 6fT SLR	Population 3ft SLR	Population 6ft SLR	Seasonal Housing 3ft SLR	Seasonal Housing 6ft SLR	Summer Employment 3ft SLR	Summer Employment 6ft SLR	Infrastructure 3ft SLR	Infrastructure 6ft SLR	Employment 3 ft SLR	Employment 6 ft SLR	Ocean Employment	Social Vulnerability 3ft SLR	Social Vulnerability 6ft SLR	Fisheries	Road and Rail 3 Foot SLR	Road and Rail 6 Foot SLR
DE	Kent	55	54	55	54	26	25	40	39	33	34	15	20	29	21	62	14	35	61
DE	New Castle	54	52	53	52	8	10	13	12	31	21	8	9	46	48	63	16	17	42
DE	Sussex	19	15	22	21	43	46	60	59	10	9	14	16	15	15	61	38	32	54
MD	Anne Arundel	46	47	46	47	34	32	21	17	15	18	10	15	20	54	60	11	42	46
MD	Baltimore	41	42	40	42	40	39	15	13	14	16	26	28	54	28	51	13	50	53
MD	Calvert	30	36	31	37	28	28	30	29	30	35	37	42	19	43	56	21	31	49
MD	Cecil	31	37	33	38	32	29	34	31	23	25	48	48	13	27	50	7	26	39
MD	Charles	56	56	56	56	24	23	7	7	27	28	53	54	42	29	52	12	54	63
MD	Dorchester	12	16	12	14	63	58	57	57	21	23	36	36	8	20	49	15	19	55
MD	Harford	48	51	48	51	20	18	27	25	22	24	41	44	26	45	58	9	49	47
MD	Kent	23	24	23	23	36	34	47	46	29	33	60	60	17	5	45	27	34	57
MD	Prince Georges	53	55	54	55	30	26	20	16	18	22	54	53	61	47	59	25	62	60
MD	Queen Annes	18	18	13	15	44	45	55	54	40	45	39	41	6	38	55	2	20	58
MD	St. Marys	34	39	34	40	35	33	44	42	5	10	34	37	1	44	57	1	18	51
MD	Somerset	1	2	4	6	57	54	36	38	4	6	62	62	59	11	46	5	46	62
MD	Talbot	24	23	26	24	48	51	54	55	20	27	38	40	11	12	47	22	23	56
MD	Wicomico	14	13	9	10	42	43	22	20	24	19	61	61	62	30	53	20	43	59
MD	Worcester	6	4	16	13	56	59	58	58	32	26	23	22	3	16	48	36	25	48
MD	Baltimore (city)	60	61	60	62	9	9	9	8	3	2	11	14	39	37	54	63	56	44
NJ	Atlantic	11	8	15	12	61	62	50	50	8	5	1	2	24	17	33	29	14	32
NJ	Bergen	27	31	27	30	23	19	42	35			20	27	48	57	42	34	21	16
NJ	Burlington	37	29	41	32	15	31	31	30	50	44	30	31	47	41	41	8	7	31
NJ	Camden	43	34	42	34	17	22	38	44	42	32	25	23	56	24	36	10	12	35
NJ	Cape May	4	3	6	3	58	61	63	63	2	1	12	12	4	10	31	57	36	29
NJ	Cumberland	10	14	18	20	59	56	41	41	34	39	42	45	45	3	30	28	40	45
NJ	Essex	62	62	62	61	4	4	6	5	52	47	19	13	51	35	38	37	24	17
NJ	Gloucester	22	21	19	16	54	53	43	40	25	20	21	26	52	22	35	4	45	40
NJ	Hudson	42	40	44	44	38	37	17	23	17	17	7	3	33	58	43	40	53	27
NJ	Mercer	57	60	58	60	19	16	1	1	45	48	55	56		25	37	62	58	41
NJ	Middlesex	44	45	45	45	12	13	26	28	26	29	24	25	50	40	40	24	51	43
NJ	Monmouth	28	27	29	31	27	30	49	51	38	40	16	18	36	36	39	41	38	38
NJ	Ocean	17	17	21	22	62	60	62	62	7	7	5	8	28	19	34	53	55	52
NJ	Salem	15	10	10	8	45	50	56	56	19	13	27	29	35	14	32	6	22	37
NJ	Union	61	59	61	57	5	5	12	14	53	53	29	24	44	61	44	35	39	24

State	County	Housing 3fT SLR	Housing 6fT SLR	Population 3ft SLR	Population 6ft SLR	Seasonal Housing 3ft SLR	Seasonal Housing 6ft SLR	Summer Employment 3ft SLR	Summer Employment 6ft SLR	Infrastructure 3ft SLR	Infrastructure 6ft SLR	Employment 3 ft SLR	Employment 6 ft SLR	Ocean Employment	Social Vulnerability 3ft SLR	Social Vulnerability 6ft SLR	Fisheries	Road and Rail 3 Foot SLR	Road and Rail 6 Foot SLR
NY	Bronx	52	53	51	53	16	11	18	18	13	14	40	38	55	33	24	56	63	50
NY	Kings	59	57	59	59	6	6	8	10	16	15	18	11	43	56	27	59	60	34
NY	Nassau	8	7	8	4	53	57	33	36	6	4	4	6	49	55	26	47	52	33
NY	New York	32	38	30	36	14	12	5	6	12	12	13	1	27	63	29	52	41	4
NY	Queens	21	12	20	9	50	47	24	37	11	8	35	21	53	32	23	51	57	23
NY	Richmond	50	50	50	49	7	7	11	11	37	36	22	19	32	49	25	50	16	9
NY	Suffolk	7	11	5	11	52	48	51	52	1	3	2	5	40	23	22	48	30	28
NY	Westchester	47	49	47	50	21	17	19	19	35	41	44	39	57	59	28	43	61	36
PA	Bucks	58	58	57	58	3	3	2	2	41	42	28	32	60	53	20	61	59	26
PA	Delaware	49	48	49	48	2	2	3	4	43	38	45	33	58	51	19	17	29	21
PA	Philadelphia	63	63	63	63	1	1	4	3	36	31	3	4	38	62	21	33	44	12
VA	Accomack	3	5	3	5	55	52	59	61	9	11	46	46	25	8	6	26	47	30
VA	Gloucester	20	22	17	19	39	38	37	33	39	43	59	59	22	13	8	42	27	10
VA	Isle of Wight	25	25	24	25	31	27	29	27	51	55	51	51	30	31	11	19	11	11
VA	James City	26	26	25	26	37	35	52	49			33	35	9	18	9	60	28	14
VA	Lancaster	16	20	14	18	46	42	46	43			52	52	41	4	3	32	10	18
VA	Mathews	9	9	7	7	47	49	39	45			58	55	34	2	2	45	5	19
VA	Middlesex	13	19	11	17	49	44	28	26	44	49	63	63	37	6	4	54	33	15
VA	Northampton	2	6	1	2	60	55	61	60	28	30	50	49	23	1	1	39	15	25
VA	Northumberland	29	30	28	28	22	20	53	53			56	57	5	7	5	46	1	6
VA	Westmoreland	45	46	43	46	13	14	48	47	57	57	57	58	12	9	7	31	6	22
VA	York	33	35	36	35	25	24	35	34	54	56	43	43	7	42	14	23	13	7
VA	Hampton (city)	40	28	38	27	29	40	23	22	49	46	31	30	21	46	15	55	37	3
VA	Newport News (city)	35	41	32	39	10	8	10	9	46	50	32	34	31	34	12	58	3	5
VA	Norfolk (city)	39	33	37	29	11	21	14	15	55	54	9	10	18	52	17	49	2	1
VA	Poquoson (city)	5	1	2	1	51	63	32	32			49	50	16	26	10	30	8	8
VA	Portsmouth (city)	38	32	39	33	41	41	16	21	47	37	17	17	2	39	13	18	4	2
VA	Suffolk	36	44	35	41	18	15	25	24	48	52	47	47	14	50	16	3	9	20
VA	Virginia Beach	51	43	52	43	33	36	45	48	56	51	6	7	10	60	18	44	48	13

Table 3-6 Ranks of each socio-economic indicator by county.

Note: Highlighted Cell is Highest Vulnerability factor(s) for each county

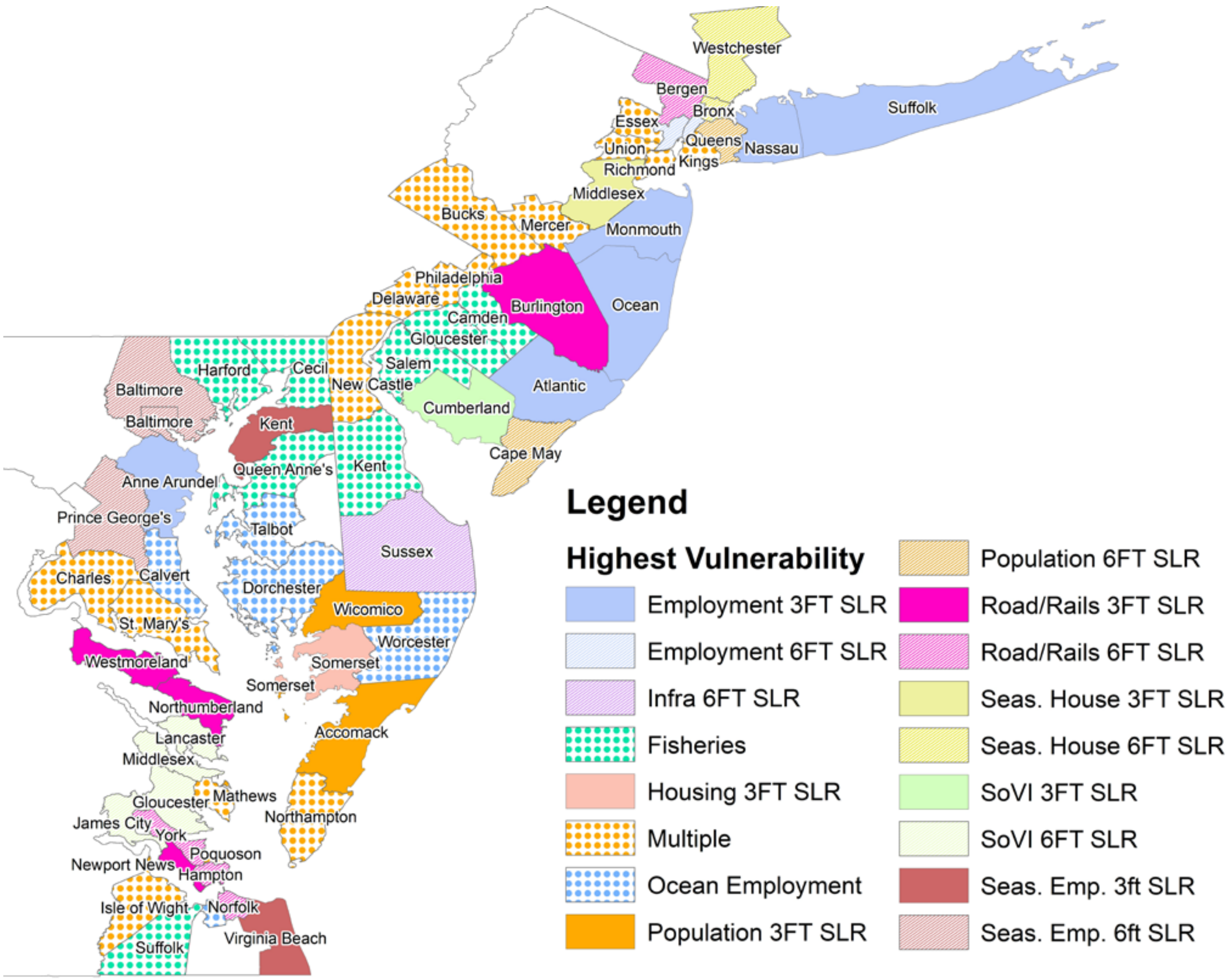


Figure 3-4 Highest socio-economic vulnerability indicator for each county.

Population and Housing

A basic element of vulnerability to SLR-related flood risks is the size of the population in the shoreline area. Housing units are the principal asset at risk, so they must be measured along with population. For this purpose, the 2015 American Community Survey (ACS) data was used. The geography selected was Census tracts, the smallest geography for which data is available in the ACS. Census tracts at the shoreline were selected for the analysis. A total of 3,603 tracts were selected.

The measure of vulnerability used is the flood area-weighted population and housing units. The 2015 population (median estimate) and the number of housing units are multiplied by the share of the tract estimated to be flooded using the NOAA SLR viewer. This indicator has some obvious flaws. It does not take into account where the housing or population is actually located within the tract, nor does it consider local topography, including shoreline elevation, except to the extent these are incorporated in the flood estimates from the SLR viewer. The indicator essentially assumes that population and housing are equally distributed across a flat landscape and that the probability of being affected by flooding depends on being in the wrong location at the wrong time. But for comparative purposes, the weighted population and housing adequately reflect relative vulnerabilities.

Table 3-7 provides state-level summaries of the shoreline-adjacent tracts by state, including the estimates from the 2015 ACS as well as the flood weighted population and housing units. The 2015 population of the shoreline adjacent tracts is estimated at 14.6 million. The “vulnerable population” with a 3-foot sea level rise is 1.7 million and with a 6-foot sea level rise is 2.1 million. Out of a total of 6.5 million housing units, 912 thousand can be said to be vulnerable under the 3-foot scenario and 1.1 million under the 6-foot scenario. (Table 3-7)

	Population in Shore Adjacent Tracts	Population Weighted by 3ft SLR	Population Weighted by 6ft SLR	Housing Units	Housing Units Weighted by 3ft SLR	Housing Units Weighted by 6ft SLR
DE	509,600	51,100	65,700	241,800	35,800	47,000
MD	4,521,100	484,600	554,300	1,987,700	256,200	299,600
NJ	2,780,700	438,900	579,100	1,253,700	267,600	352,500
NY	3,489,100	466,900	566,600	1,525,900	228,600	272,500
PA	1,790,600	28,900	38,200	766,700	13,100	17,300
VA	1,522,300	242,000	325,300	652,700	110,500	145,600
TOTAL	14,613,300	1,712,500	2,129,200	6,428,500	911,800	1,134,400

Table 3-7 Population and housing weighted by SLR scenario: state-wide summary.

These figures should not be taken too literally. They do not account for population growth that is likely to occur in the region. Moreover, the actual exposed population will vary over time. Storms will reduce the populations in some periods, but reconstruction may replace it in others. Future populations will be a balance between growth, retreat, and reconstruction that cannot be accurately predicted.

The effects of the additional sea level rise are illustrated in Table 3-8. Again, these are approximations. Overall both vulnerable population and housing increase by 24% with an additional 3 feet of sea level rise, but there are considerable differences among the states. New

Jersey and Pennsylvania show about the same difference in housing and population, but Maryland and Delaware would see more vulnerable housing than population, and Virginia would see a larger increase in vulnerable population than housing.

	Change in Population	**Change in Housing**
DE	28.4%	31.2%
MD	14.4%	17.0%
NJ	31.9%	31.7%
NY	21.4%	19.2%
PA	31.9%	31.8%
VA	34.4%	31.7%
TOTAL	24.3%	24.4%

Table 3-8 Percent change in vulnerable population and housing in 6 foot SLR v. 3 foot SLR.

The counties with the largest populations and quantities of vulnerable housing are shown in Table 3-9. This includes both SLR scenarios. As would be expected, the vulnerabilities with these two variables will tend to focus on the larger urban areas found in the larger metro areas, with New York County (Manhattan) leading on both measures and scenarios. Depending on the scenario examined, these top 10 counties account for an estimated vulnerable population between 800,000 and 950,000 of the 1.7 to 2.2 million residents in shore-adjacent tracts. These top ten counties held between 480,000 to 590,000 vulnerable housing units, which represents about half of the total housing units in shore-adjacent tracts. The percentage of population and housing in these top 10 counties decreases somewhat between the 3 and 6 foot scenarios because the 6 foot scenario has larger effects on more counties.

	Housing					
	3ft Scenario			6ft Scenario		
1	NY	New York	80,999	NY	New York	88,659
2	NJ	Ocean	67,330	NJ	Ocean	83,463
3	MD	Worcester	56,334	MD	Worcester	74,166
4	NJ	Cape May	51,892	NJ	Cape May	72,313
5	MD	Anne Arundel	51,233	MD	Anne Arundel	56,840
6	NY	Suffolk	50,407	NJ	Atlantic	56,261
7	NJ	Atlantic	39,584	NY	Suffolk	53,974
8	NJ	Hudson	31,508	NJ	Hudson	39,860
9	NJ	Monmouth	28,096	NJ	Monmouth	33,991
10	MD	Baltimore	25,986	NY	Nassau	32,677
	Population					
	3ft Scenario			6ft Scenario		
1	NY	New York	158,475	NY	New York	172,548
2	MD	Anne Arundel	128,671	MD	Anne Arundel	144,234
3	NJ	Ocean	87,629	NJ	Ocean	109,809
4	NY	Suffolk	71,396	NY	Suffolk	76,089
5	NJ	Hudson	68,430	NJ	Hudson	87,394
6	NJ	Atlantic	66,958	NJ	Atlantic	95,150
7	MD	Baltimore	61,766	MD	Baltimore	72,565
8	NY	Nassau	55,593	NY	Nassau	75,929
9	NJ	Monmouth	55,471	NJ	Monmouth	67,665
10	NY	Westchester	51,040	NY	Westchester	54,959

Table 3-9 Top 10 counties by population and housing vulnerabilities.

The distribution of population and housing and vulnerable populations and housing is shown in Figure 3-5 and Figure 3-8. The maps show the county level similar to the tables above, but the underlying data is at the shore-adjacent Census tract level. While population is, as expected, concentrated in the major urban areas when the population is adjusted for possible flood exposure (the cases illustrate the 3-foot scenario) the distribution shifts towards the central New Jersey shore and Nassau and Suffolk counties in Long Island. Housing is also concentrated in the larger cities but vulnerable housing is housing at key points along the shore from Suffolk County, NY, to Ocean County, NJ, to Cape May, NJ, and Dorchester, NJ. Anne Arundel County (MD) is the one county that is found in the highest-ranked group for both total and flood-adjusted housing.

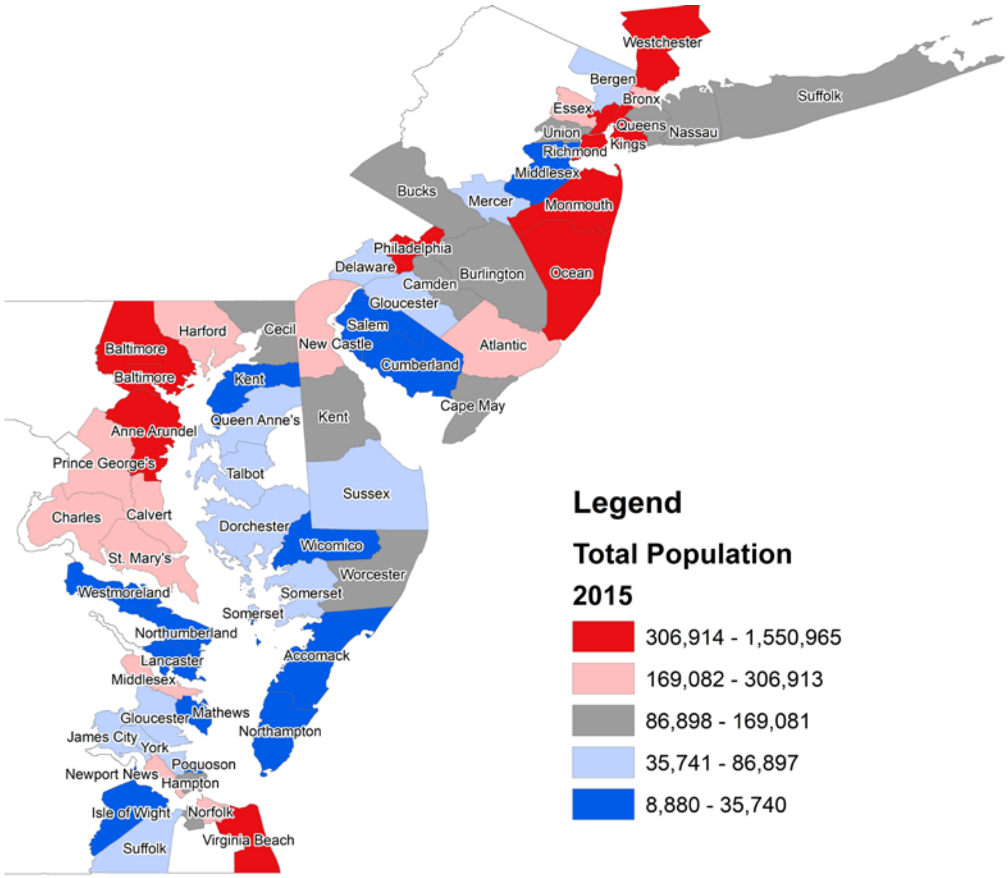
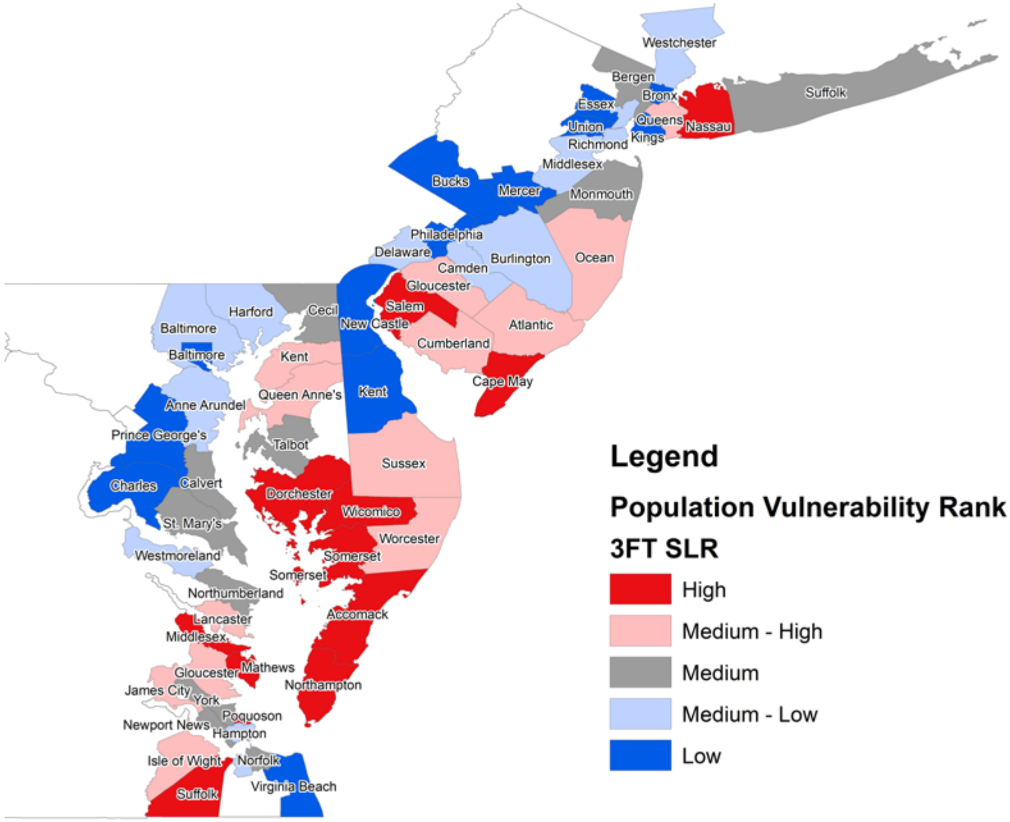
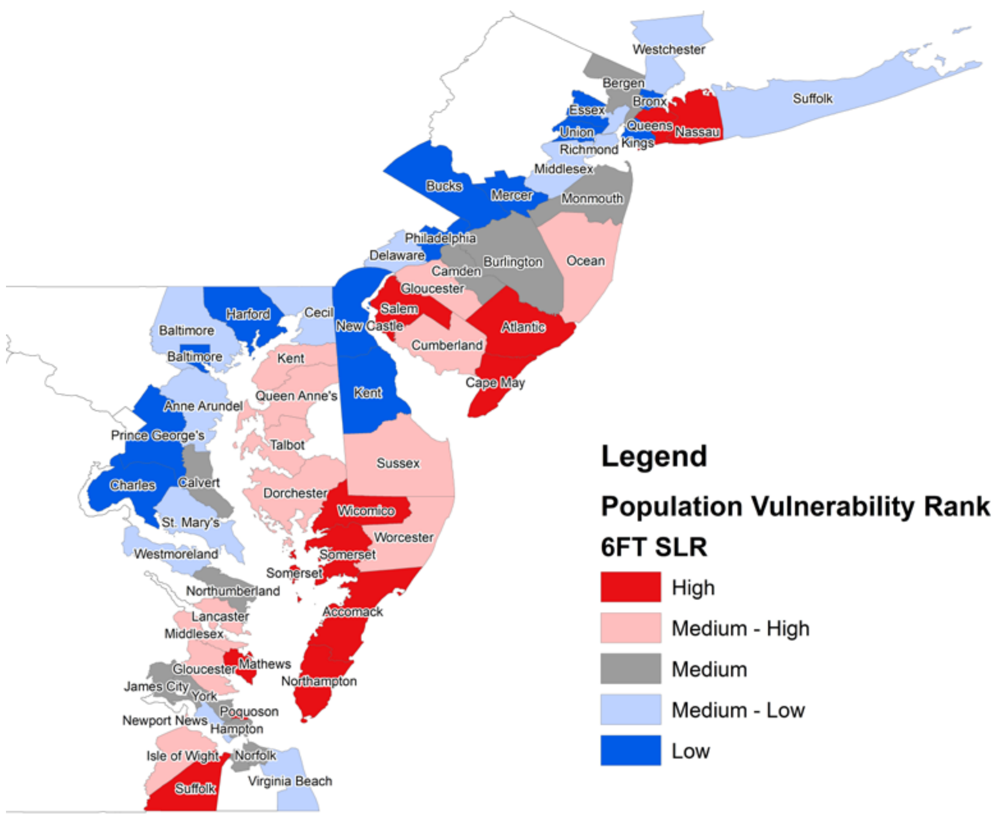


Figure 3-5 Total 2015 population in shore adjacent census tracts.



(a)



(b)

Figure 3-6 Population in census tracts adjusted for (a) 3 foot SLR and (b) 6 foot SLR.

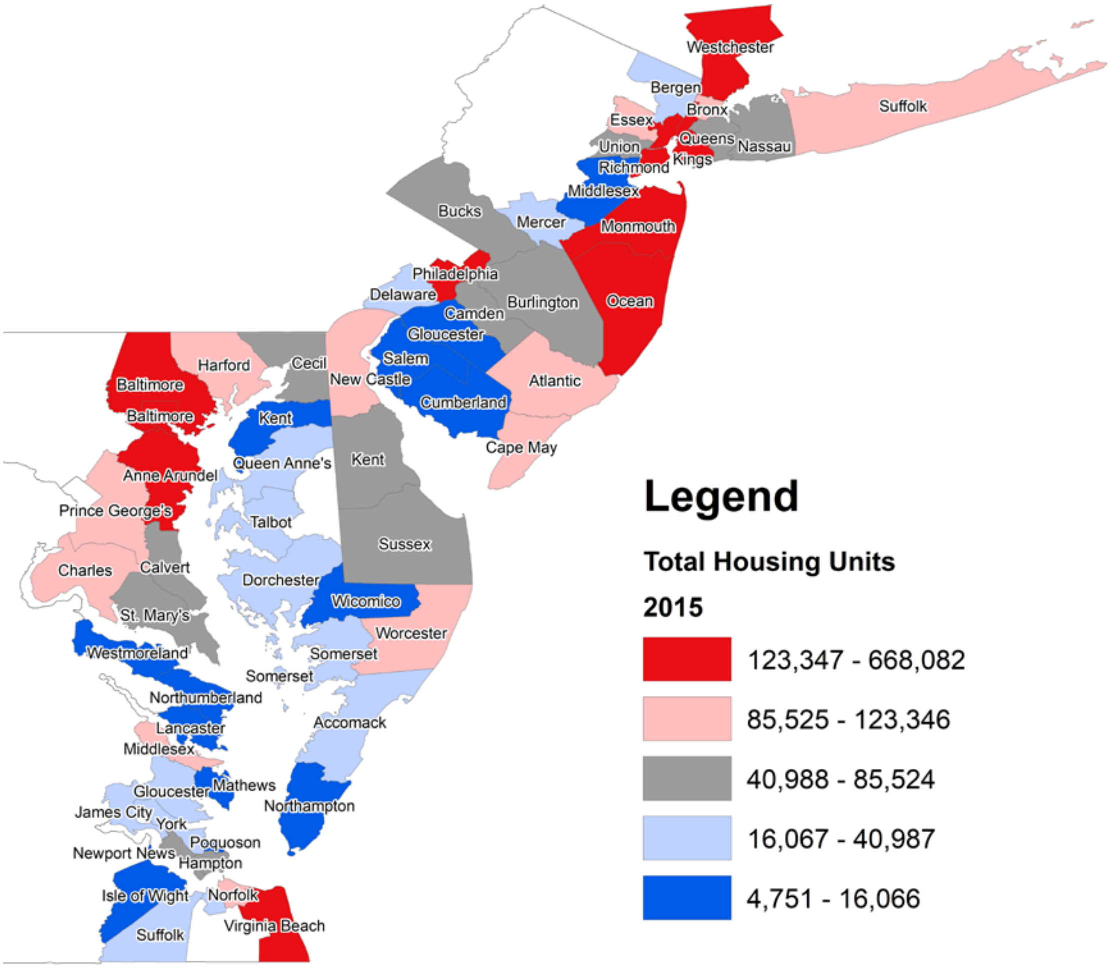
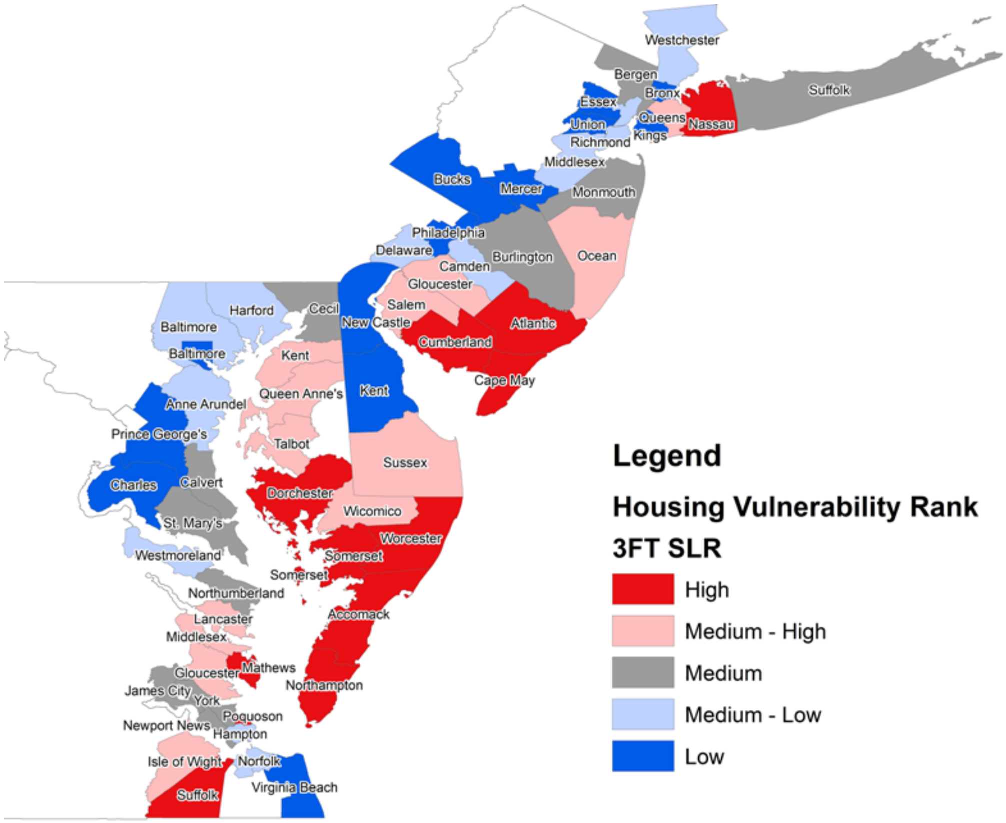
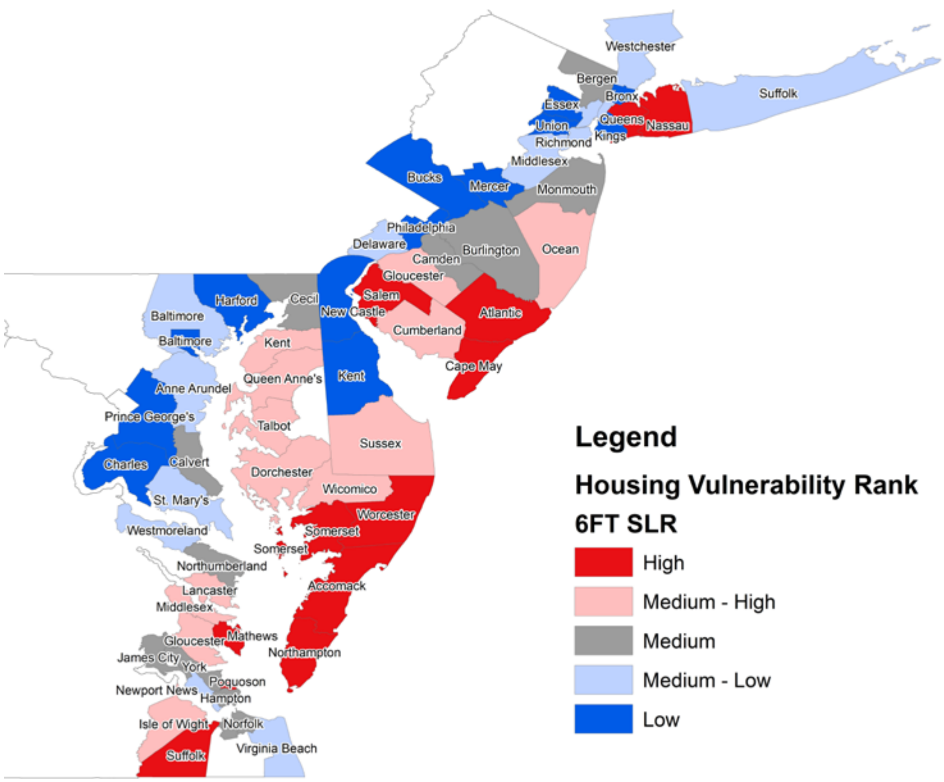


Figure 3-7 Total housing units in shore adjacent census tracts.



(a)



(b)

Figure 3-8 Housing units in shore adjacent census tracts adjusted for (a) 3 foot SLR and (b) 6 foot SLR.

Employment and Ocean-Related Employment

Employment vulnerabilities were calculated using a two-stage process. The first stage involves creating an estimate of employment from the Zip Code Business Pattern (ZBP) data. This is the smallest publicly available employment data set that can be accessed for all states. The Zip Code Business Pattern reports used show the total employment in a zip code on March 1, which is the date for this Census. The ZBP data is approximate; it only shows the number of establishments within specific employment ranges. To derive an actual total employment figure, the ZBP data is used to calculate a share of county employment for each zip code. This share can then be used to estimate data from the Bureau of Labor Statistics Quarterly Census of Employment and Wages, which provides the most detailed county level employment data and is most consistent with other employment data series.[10]

As with the population and housing data, the adjustment for flood vulnerability is made using the area subject to flooding given by the NOAA Sea Level Rise viewer. In this case the calculation is made based on the area of the zip code rather than the Census tract. The flood-weighted employment figure for a given scenario is the percent of the zip code subject to flooding multiplied by total employment in the zip code. As with population and housing, the same limitations apply with respect to the depiction of the actual geographic risks of flooding.

State	Employment in Shore-Adjacent Zip Codes	Employment Weighted for 3ft SLR	Employment Weighted for foot SLR	Change in vulnerable employment in 6ft scenario compared with 3 foot scenario	Number of Shore-Adjacent Zip Codes
DE	232,000	46,000	64,000	18,000	35
MD	907,000	76,600	94,300	17,700	210
NJ	1,014,300	192,100	301,400	109,300	173
NY	3,306,200	115,500	318,400	202,900	229
PA	756,800	49,900	76,400	26,500	65
VA	609,400	76,500	118,900	42,300	152
TOTAL	6,825,600	556,600	973,300	416,700	864

Table 3-10 Employment in shore adjacent zip codes and SLR vulnerability.

Table 3-10 provides an overview of the employment indicator summed to the state level. Not surprisingly, New York has the largest employment in shore-adjacent zip codes, and the largest in the 6-foot scenario vulnerability scenario. But New Jersey shows the largest vulnerability metric for the 3-foot SLR scenario. The share of employment on the different measures is quite different between the base case and the two SLR scenarios. New York accounts for nearly half of the base employment but only one-fifth of the 3-foot scenario employment and one-third of the 6-foot scenario. New Jersey is the state with the greatest vulnerability effect from flooding. New Jersey's share of the regional employment doubles in the two flood scenarios.

Another notable factor in Table 3-10 is the effects of the additional 3 foot of SLR in the 6 foot scenario. Across the entire region, the estimated vulnerable employment increases by 75% with the 6-foot scenario, with vulnerable employment increasing by 175% in New York. Delaware

[10] This same method is used to calculate the ocean economy data for New York discussed in the next section.

and Maryland have relatively modest increases in vulnerable employment with the 6-foot scenarios. These increases should be interpreted cautiously because of the limitations on being able to analyze the specific locations of employment establishments. But the large margins in the higher scenario should be taken as a clear warning that it is employment rather than population and housing the faces the greater increase in vulnerability as sea level rise continues. This actually reflects a long-standing trend of employment in near-shore areas increasing substantially faster than populations. (Colgan 2004)

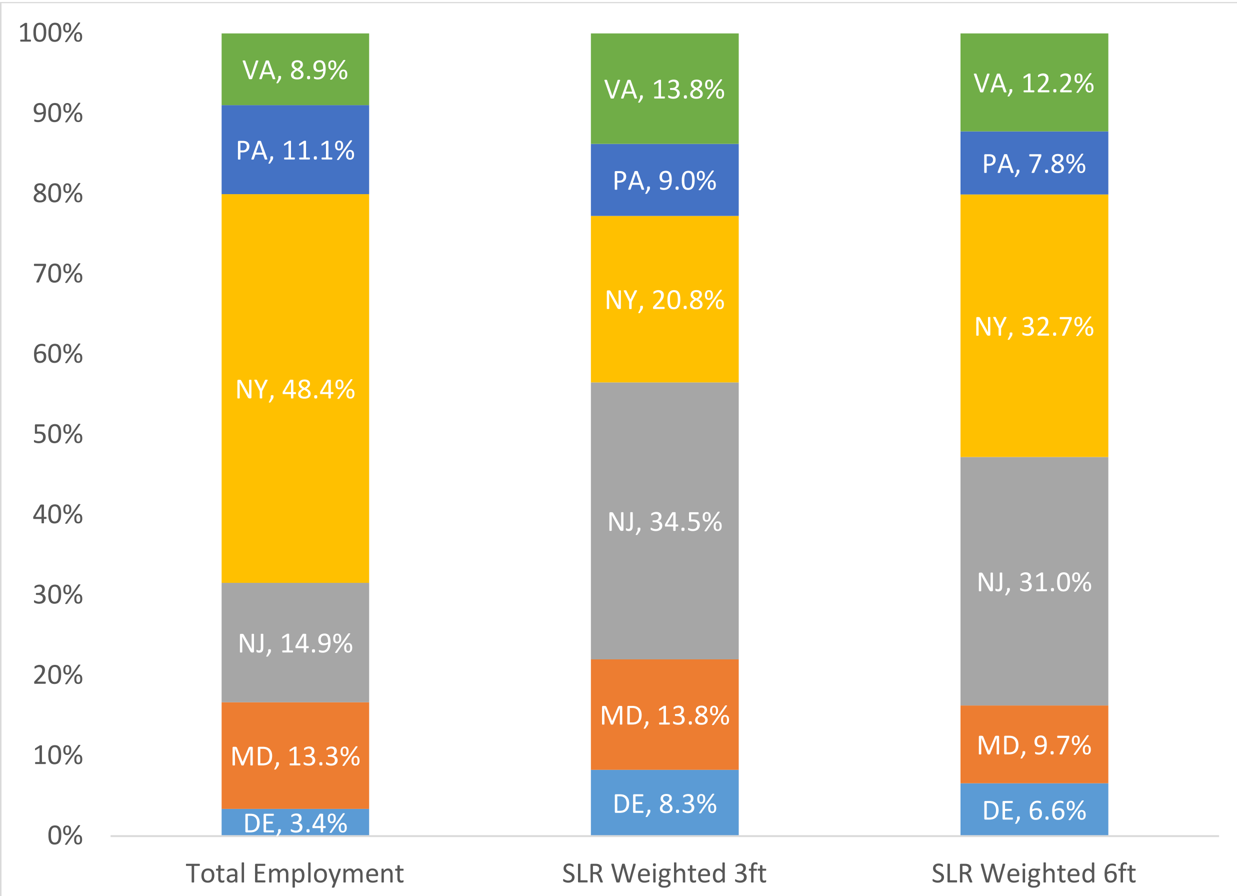


Figure 3-9 Regional shares of employment and flood weighted employment by state.

Figure 3-10 and Figure 3-11 compare the distribution of employment across the region. Figure 3-10 shows total employment in shore adjacent zip codes in each county (NOTE: not total county employment). As expected, the largest employment is found in the major metro areas, also indicated in Table 3-11. But when the employment adjusted for possible flooding under the 3 foot sea level rise is shown, the largest vulnerabilities shift to Long Island, the central coast of New Jersey, southern Chesapeake Bay, and New Castle County, DE. This shift from the urban areas to the major shore areas reflects the importance of shoreline topography in shaping vulnerabilities. It is not the biggest employment that determines vulnerability; it is the largest employment in low lying areas that matters.

	State	County	Employment in Shore	State	County	Employment in Shore	State	County	Employment in Shore

			Adjacent Tracts			Adjacent Tracts Weighted by 3ft SLR			Adjacent Tracts Weighted by 6ft SLR
1	NY	New York	1,881,694	NJ	Atlantic	53,706	NJ	Atlantic	138,258
2	PA	Philadelphia	647,119	NY	Suffolk	42,691	NY	Kings	65,954
3	NY	Kings	423,895	PA	Philadelphia	42,388	DE	New Castle	65,169
4	NY	Suffolk	326,921	NY	Nassau	27,356	NY	Suffolk	63,651
5	MD	Baltimore (city)	316,945	NJ	Ocean	25,232	NY	Nassau	59,892
6	MD	Anne Arundel	260,229	VA	Virginia Beach City	21,545	VA	Norfolk (city)	52,745
7	NY	Westchester	207,033	NJ	Hudson	21,323	MD	Anne Arundel	35,381
8	NJ	Hudson	194,541	DE	New Castle	20,351	VA	Portsmouth (city)	33,256
9	NY	Nassau	189,982	VA	Norfolk (city)	19,240	MD	Baltimore (city)	33,033
10	VA	Virginia Beach City	169,517	MD	Anne Arundel	19,218	NJ	Cape May	32,956

Table 3-11 Top 10 counties employment in shore adjacent tracts and weighted by SLR.

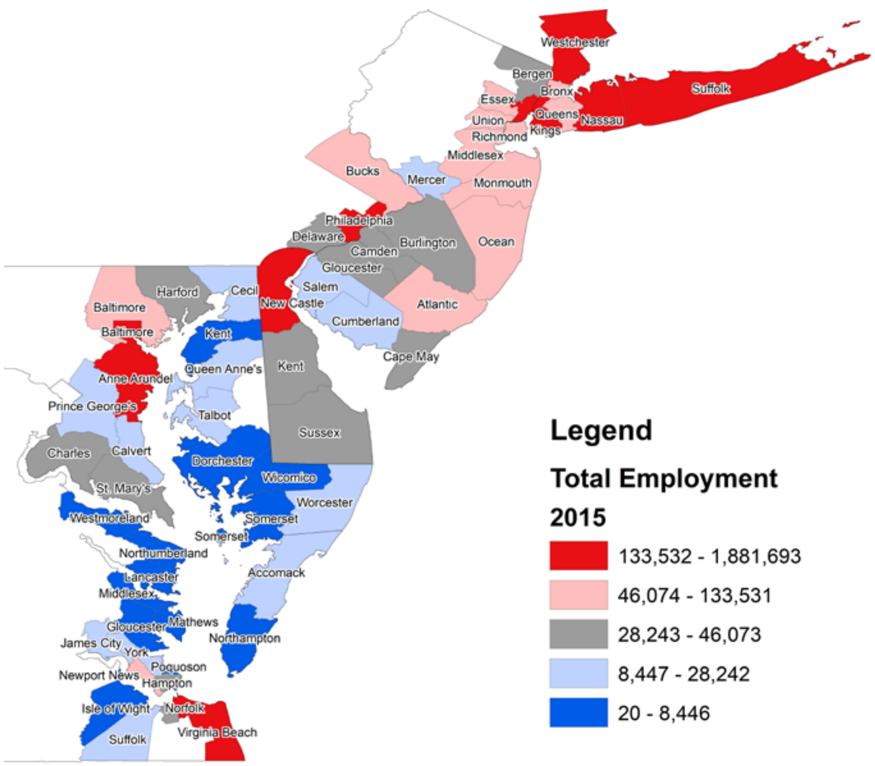
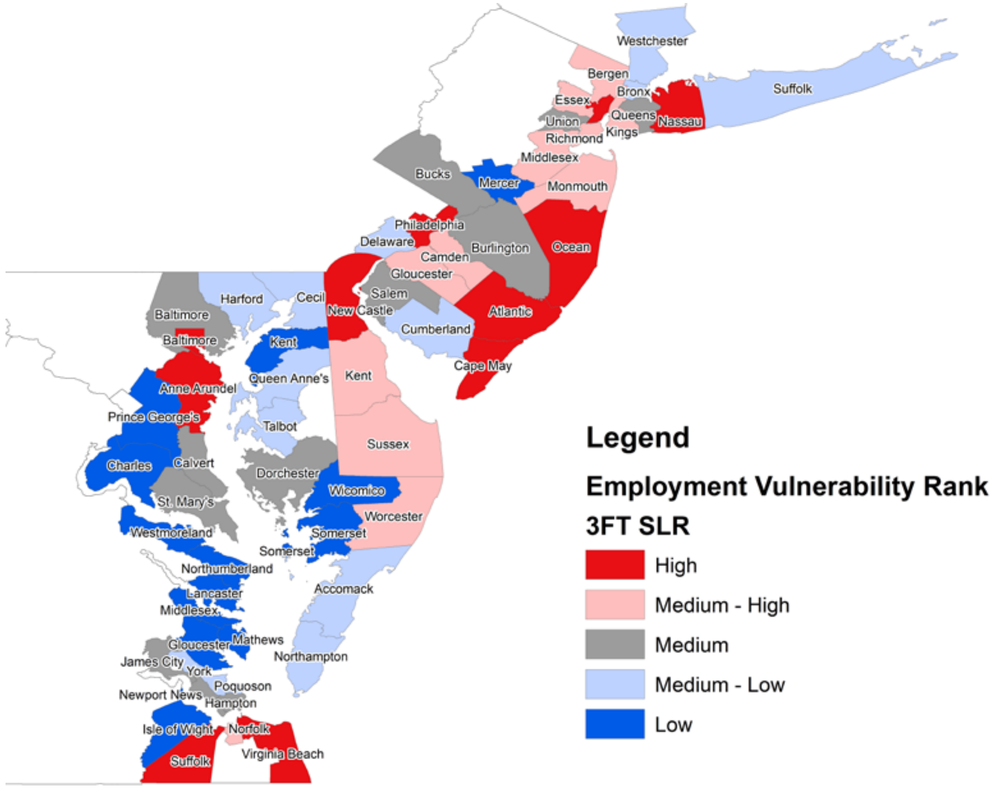
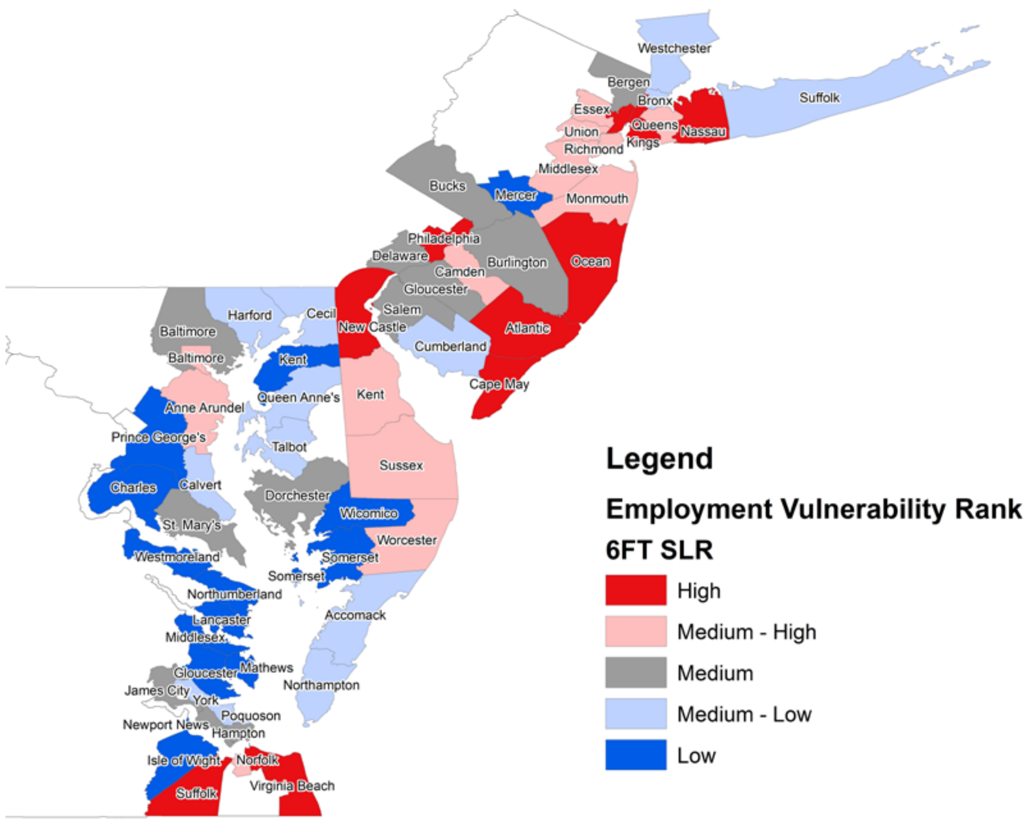


Figure 3-10 Total employment in shore adjacent zip codes.



(a)



(b)

Figure 3-11 Employment in shore adjacent zip codes weighted by (a) 3 foot SLR and (b) 6 foot SLR.

Ocean-Related Employment

The ocean economy sector is defined as comprising six sectors: (Colgan 2013)

- Marine construction
- Living Resources
- Minerals
- Ship & Boat Building
- Marine Transportation
- Tourism & Recreation

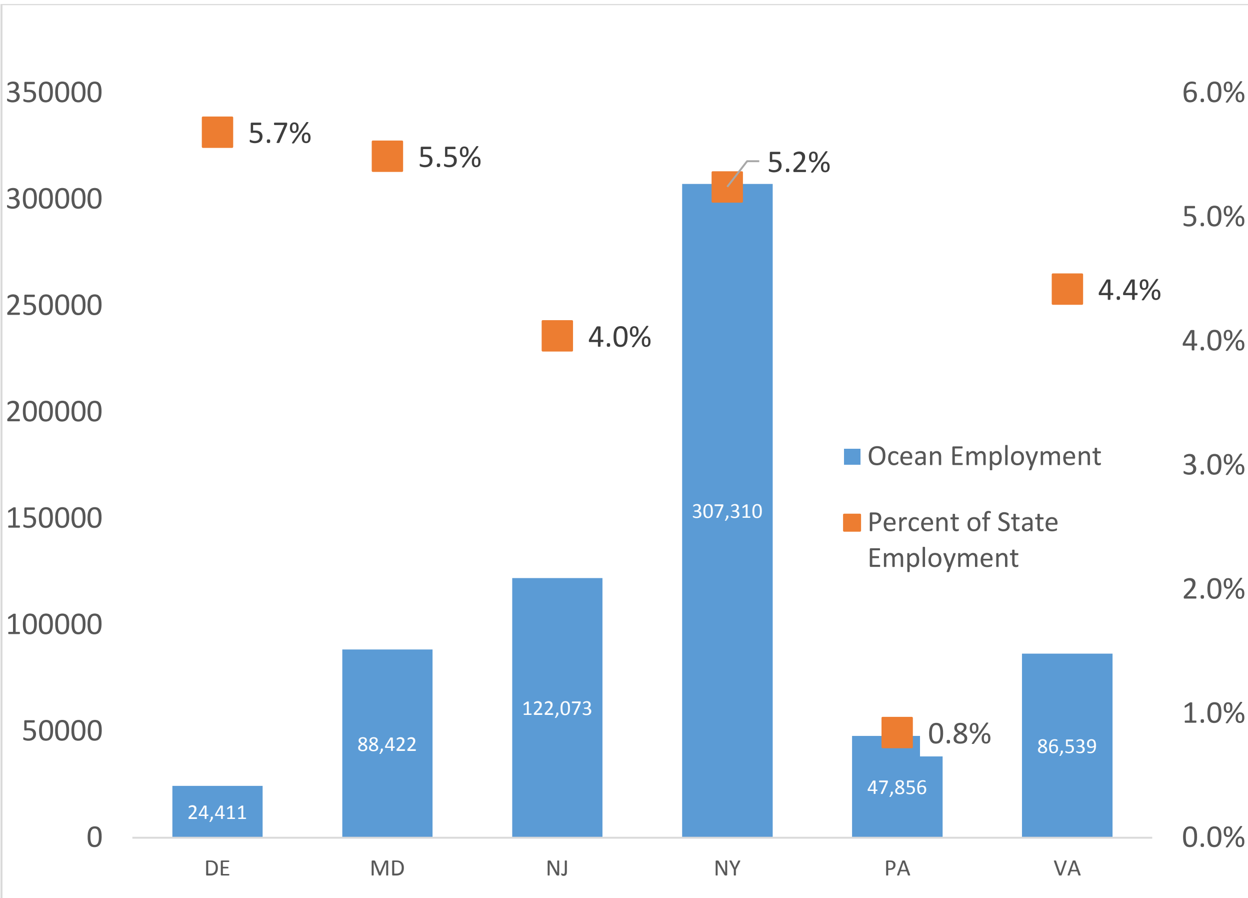


Figure 3-12 Ocean economy employment by state.

Together, these six sectors accounted for 628,755 jobs across the region, with New York having the largest ocean-related employment, in fact about half the regional ocean economy employment. This is because of the large concentration of tourism & recreation employment in Manhattan (Table 3-12). Delaware is largest in terms of the proportion of state level employment in the ocean economy. Delaware's larger share reflects its status as a small state with relatively significant employment across all ocean sectors (except minerals, in which no Mid-Atlantic state has a significant presence). Delaware's higher share at the state level is observed despite the fact none of the three Delaware Counties is in the top 10 in terms of percent of the state economy. That list (Table 3-12) shows ocean-related employment highest in the major cities, but as a percentage of the county economy, the focus is in Maryland, particularly the eastern shore, and Virginia, with Cape May, NJ.

	State	**County**	**Ocean Employment**	**State**	**County**	**Percent**
1	NY	New York	201,519	MD	Somerset	48.9%
2	PA	Philadelphia	37,545	VA	Portsmouth (city)	31.7%
3	NY	Suffolk	32,817	MD	Worcester	29.9%
4	MD	Anne Arundel	27,839	NJ	Cape May	24.1%
5	NY	Kings	26,792	VA	Northumberland	17.3%
6	VA	Virginia Beach	22,670	MD	Queen Anne's	16.6%
7	MD	Baltimore (city)	19,213	VA	York	15.9%
8	NJ	Hudson	18,485	MD	Dorchester	14.2%
9	NY	Nassau	16,097	VA	James City	12.9%
10	NJ	Monmouth	16,089	VA	Virginia Beach	12.8%

Table 3-12 Ocean employment by county and percent of state employment.

Climate change could affect the ocean economy in both negative and positive ways. Tourism and recreation employment is clearly threatened with major disruption, as, most likely, are fisheries. The changes in fisheries, although, could be both negative as species indigenous to the region shift their range and positive as formerly exotic species shift into the region (See Chapter 3). Marine transportation may be significantly affected by sea level rise, but as Chapter 4 discusses, it may be able to adapt relatively easily (though not cheaply). Marine construction may see significant growth as new infrastructure is built, wetlands are expanded, and other shoreside structures are modified to accommodate sea level rise. For these reasons, we have not intersected the ocean economy with sea level rise data in the same way as with other indicators, but have left ocean economy employment alone as an indicator of possible vulnerability to climate-related changes.

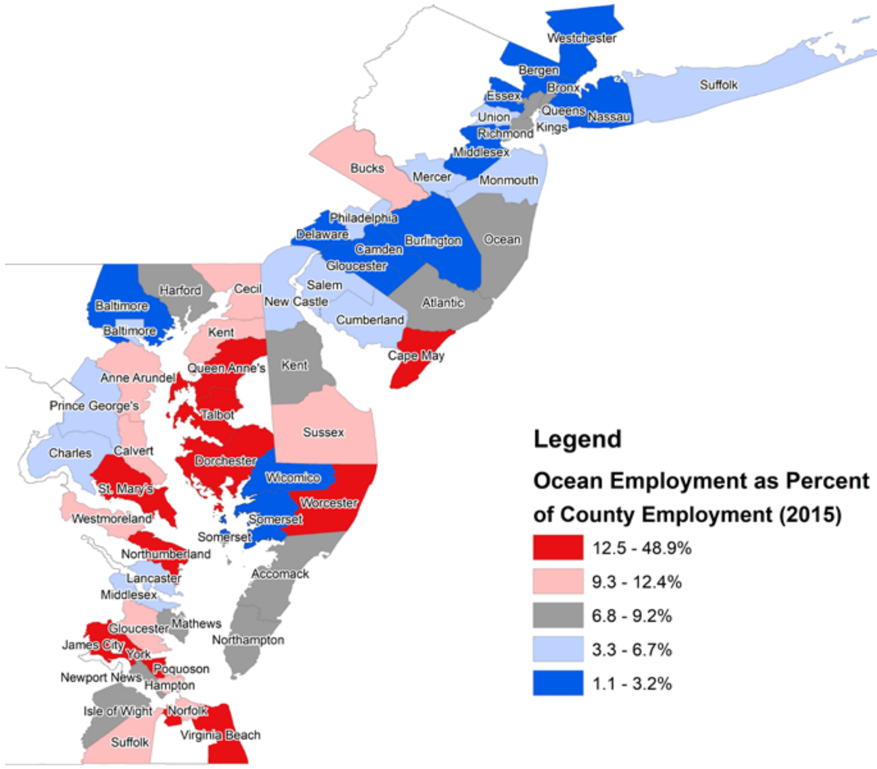


Figure 3-13 County ocean economy employment as percent of state employment.

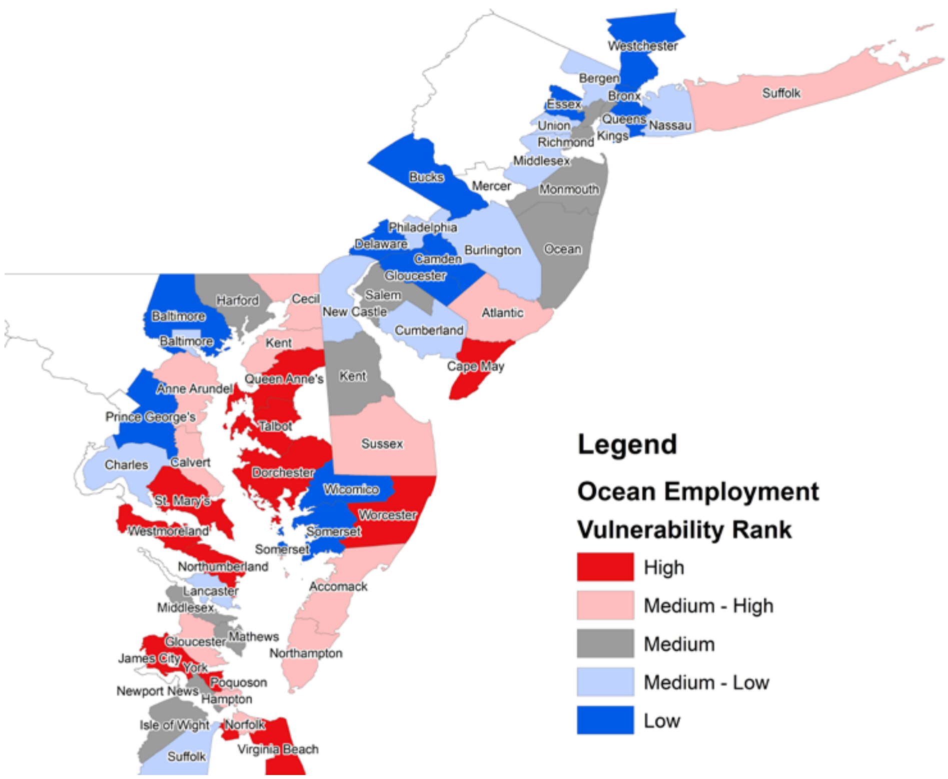


Figure 3-14 Rank of ocean-related employment (independent of SLR).

The Summer Economy

The Mid-Atlantic region is synonymous with coastal tourism and recreation. From the Hamptons to Atlantic City and the Jersey Shore to Rehoboth Beach, Ocean City, and Virginia Beach, the ocean side of the Mid-Atlantic coast is where coastal tourism in America began and grew up. The possible reshaping of the shoreline by sea level rise through the whole region must be counted as creating one of the most significant regional economic vulnerabilities. We measure that vulnerability with two indicators: seasonal housing in shore-adjacent Census tracts and the size of the summer peak employment in the leisure & hospitality sector.

State	**N Seasonal Housing**	**Pct Seasonal Housing**	**Seasonal Housing Weighted for 3ft SLR**	**Seasonal Housing Weighted for 6ft SLR**
Mid-Atlantic Region	429,804	6.7%	221,578	248,488
DE	32,806	13.6%	18,711	23,085
MD	90,398	4.5%	61,526	69,327
NJ	116,093	9.3%	92,416	102,749
NY	70,094	4.6%	35,752	38,488
PA	98,340	12.8%	1,796	2,321
VA	22,073	3.4%	11,377	12,519

Table 3-13 Seasonal housing units in shore adjacent tracts by state.

Seasonal housing is defined for the American Community Survey as "housing left vacant for seasonal use", and is measured at the tract level. Across the region, there were 439,000 seasonal units in shore-adjacent tracts in the Mid-Atlantic region. New Jersey leads the region with 116,000 units. Maryland is second and New York third. But Delaware has the highest portion of the housing stock in its shore adjacent and New Jersey is second. (Table 3-13)

Table 3-14 shows the top 10 counties in the region based on the number of seasonal housing units, the percent of total housing units and the number of seasonal housing units weighted by the proportion of the tract estimated to be flooded under the 3-foot and 6-foot sea level rise scenarios. Worcester County, MD, and Cape May County, NJ, occupy the top two places on all the indicators with Ocean County, MD and Suffolk County, NY next. As indicated in Figure 3-15 and Figure 3-16, there is very little variation in the vulnerability of seasonal housing stock across the region to sea level rise-related flooding. Essentially, all parts of the region's seasonal housing stock are equally vulnerable to the effects of sea level rise.

	State	County	N Seasonal Housing	State	County	Pct Seasonal Housing	State	County	Seasonal Housing Weighted for 3ft SLR	STATE	County	Seasonal Housing Weighted for 6ft SLR
1	MD	Worcester	53288	NJ	Cape May	50.8%	MD	Worcester	43,532	MD	Worcester	49,345.2
2	NJ	Cape May	50119	MD	Worcester	47.8%	NJ	Cape May	41,367	NJ	Cape May	47,793.3
3	NY	Suffolk	37673	DE	Sussex	43.1%	NJ	Ocean	33,273	NJ	Ocean	34,703.5
4	NJ	Ocean	37087	NY	Suffolk	35.6%	NY	Suffolk	27,761	NY	Suffolk	29,560.7
5	DE	Sussex	31116	VA	Middlesex	27.7%	DE	Sussex	18,299	DE	Sussex	22,621.3
6	NY	New York	23011	MD	Kent	25.0%	NJ	Atlantic	12,686	NJ	Atlantic	14,471.5
7	NJ	Atlantic	14936	VA	Northumberland	23.8%	NY	New York	4,523	NY	New York	4,930.9
8	NJ	Monmouth	10785	VA	Westmoreland	23.5%	NJ	Monmouth	3,874	NJ	Monmouth	4,349.1
9	MD	Anne Arundel	5940	VA	Mathews	23.0%	VA	Accomack	3,446	VA	Accomack	3,567.4
10	PA	Bucks	4978	VA	Lancaster	21.3%	MD	Talbot	2,778	MD	Talbot	3,379.3

Table 3-14 Top 10 counties for seasonal housing: current and with SLR vulnerabilities.

The other measure used for the summer economy is the peak employment ratio for the leisure & hospitality sector. Leisure & hospitality includes industries such as restaurants, hotels, and recreational services. The employment data used in the sections above is annual average employment, which does not reflect the seasonal variation in industry activity. As an indicator of the seasonality in the coastal economies of the region, we take the ratio of third quarter employment in leisure and hospitality to annual average employment in that sector. For this calculation, the Quarterly Census of Employment and Wages (QCEW) is used. QCEW data is available quarterly at the county level, so the peak ratio can be calculated for each county.

Table 3-15 shows that summer employment in leisure & hospitality is between 103% of annual average employment in New York counties and 110% in New Jersey shore counties, with Delaware right behind at 109%. But these state-level figures hide the substantially higher summer peaks to be found in a number of counties. (Table 3-16) The largest peak is in Cape May County, NJ, followed by Worcester County, MD. Other tourist hotspots with high peaks include Sussex County, DE (home to Rehoboth Beach) and Ocean County, NJ (Atlantic City). More rural counties also have high summer peaks, including Accomack, Northampton, and James City in Virginia.

State	3rd Quarter Leisure & Hospitality Employment	Annual Average Leisure & Hospitality Employment	Summer Peak Ratio
DE	53,790	49,340	109%
MD	186,551	175,736	106%
NJ	327,882	299,092	110%
NY	614,284	595,413	103%
VA	22,595	211,848	105%

Table 3-15 Summer peak ration in leisure & hospitality employment.

Adjusting the summer peak for sea level rise requires a different approach than that taken with housing or general employment. The peak ratio is used in order to focus on the size of the *difference* in seasonal employment and not just absolute size. To adjust this ratio for sea level rise vulnerability, a triple ranking process is used. The counties are ordered from high to low in terms of peak employment, and a rank score assigned. This peak ratio rank score is combined with (added to) the rank for that county in terms of potentially flooded area in each county. This combined rank score was then re-ranked to create the adjusted rank shown in Table 3-16.

	State	County	Summer Peak Ratio	State	County	Rank Adjusted for 3ft SLR	State	County	Rank Adjusted for 6ft SLR
1	NJ	Cape May	170%	NJ	Cape May	1	NJ	Cape May	1
2	MD	Worcester	140%	NJ	Ocean	2	NJ	Ocean	2
3	DE	Sussex	128%	VA	Northampton	3	VA	Accomack	3
4	NJ	Ocean	127%	DE	Sussex	4	VA	Northampton	4
5	VA	Accomack	125%	VA	Accomack	5	DE	Sussex	5
6	VA	Northampton	121%	MD	Worcester	6	MD	Worcester	6
7	VA	James City	117%	MD	Dorchester	7	MD	Dorchester	7
8	VA	Westmoreland	115%	NJ	Salem	8	NJ	Salem	8
9	NJ	Monmouth	114%	MD	Queen Anne’s	9	MD	Talbot	9
10	NY	Suffolk	114%	MD	Talbot	10	MD	Queen Anne’s	10

Table 3-16 Top 10 counties by summer peak employment ratio.

The effects of sea level rise do not alter the order of the top counties greatly. Accomack and Northampton move up the order of vulnerability, but several counties are added to the top ten list when sea level rise flooding potential is considered. These include Dorchester, Talbot, and Queen Anne’s in Maryland and Salem County in New Jersey. Overall, sea level rise does not greatly alter the ranking of the counties in terms of peak summer employment. (See Table 3-13 and Table 3-14).

Taken together these two indicators show that the potential effects of sea level rise on the summer economies of the region will be proportional to the size of those economies today. The vulnerabilities are thus relatively evenly distributed across the region.

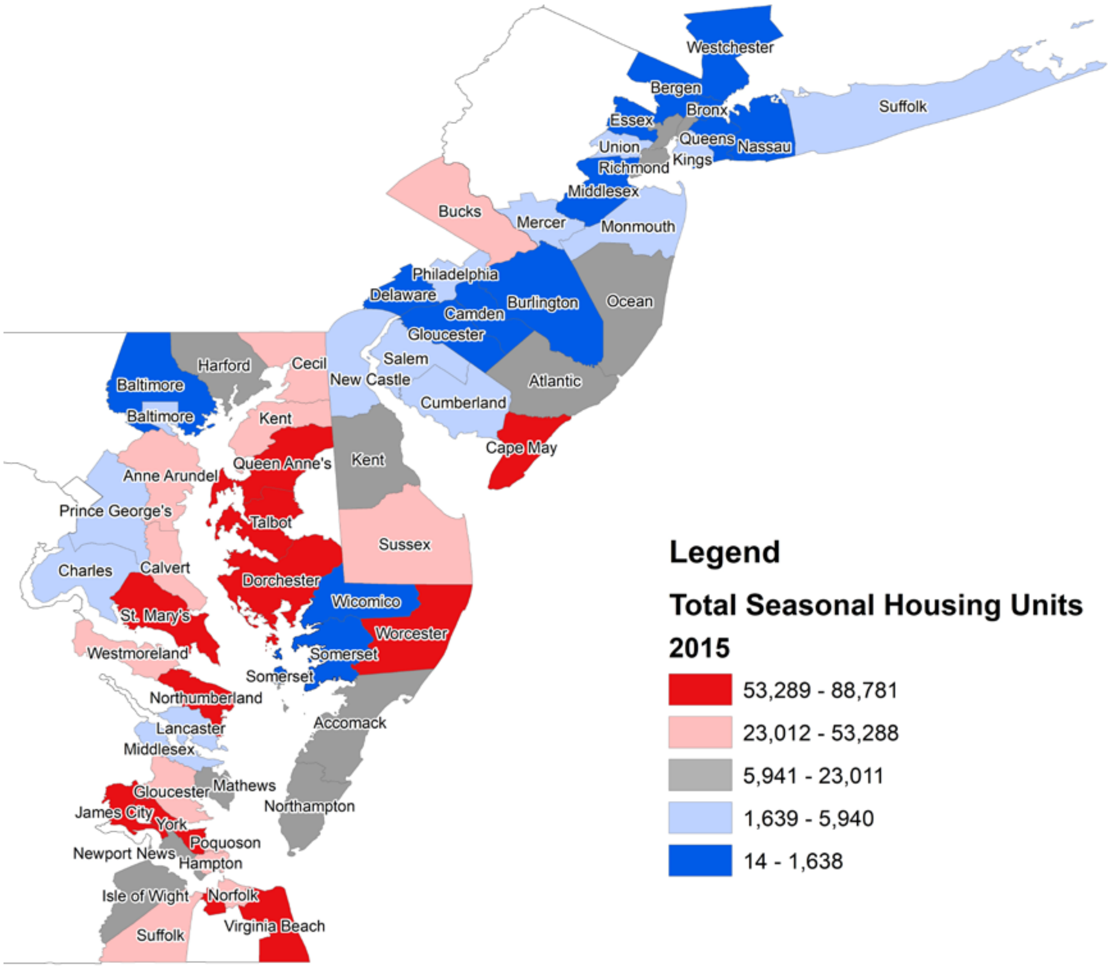
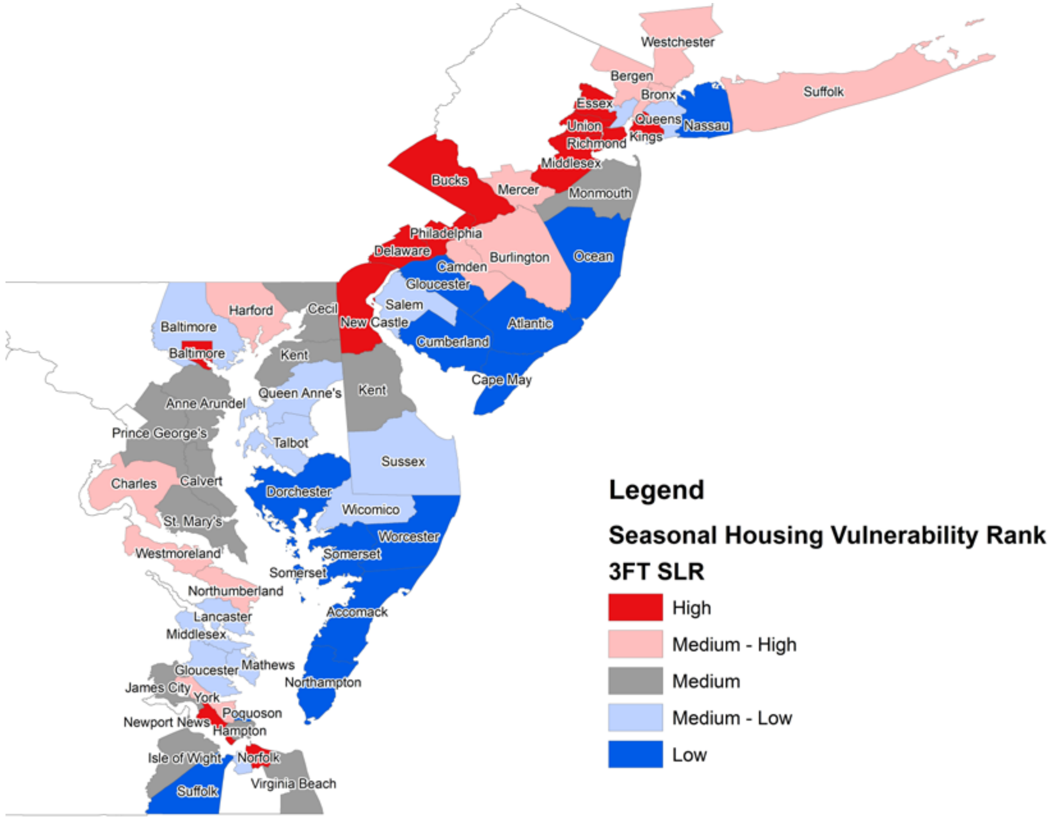
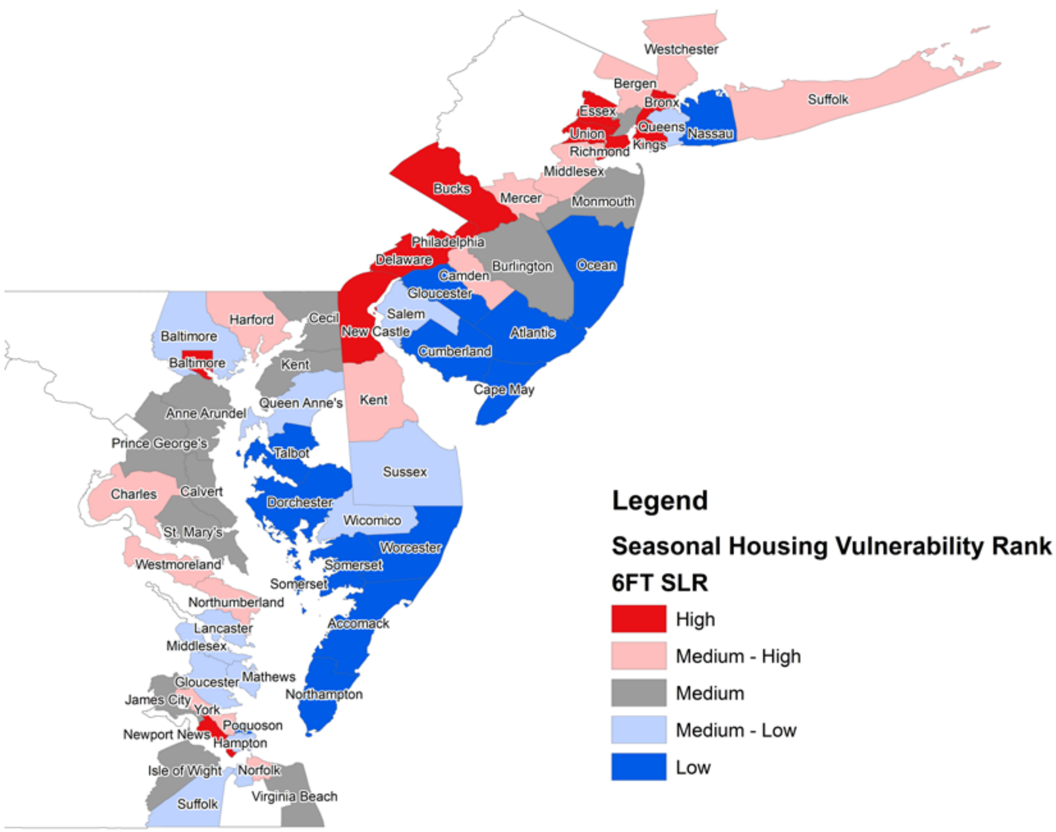


Figure 3-15 Seasonal housing in shore adjacent tracts.



(a)



(b)

Figure 3-16 Seasonal housing in shore adjacent tracts adjusted for (a) 3 foot SLR and (b) 6 foot SLR.

Fisheries

As explained in Chapter 5, below, there are large vulnerabilities which will affect the region's commercial and recreational fishing activities. While Chapter 5 focuses attention on the ecological and biological issues with fisheries and specific issues at the community level, this chapter links the analysis of vulnerability in fishing communities to the broader context of socio-economic vulnerability. This is a subject that has been extensively examined. NOAA has undertaken an assessment of the effects of climate change and other stressors on the viability of fishing communities throughout the U.S. (Colburn et al. 2016b) This study adapts that research into the regional vulnerability framework for the Mid-Atlantic region.

The NOAA fishing community index combines multiple indicators into groups of indexes that together account for different aspects of the stresses that affect fishing communities, some of which are external factors defined by regional economic conditions, and some by the relationship to fishing activity. Four factors were selected for this analysis. Engagement and reliance indicators are calculated for both commercial and recreational fisheries. Engagement is essentially the size of the relevant fishing activity in the community and reliance is the proportion of the fishing activity in the community economy.

In its analysis, NOAA statistically combined into clusters of similar information using a process called factor analysis, which produces a score ranging from 0 to 4, where 4 indicates a high relationship of that group of indicators and fishing community stability and viability. For more information about the indicator series used, see Appendix 3-A.

The NOAA fisheries vulnerability index is scored at the community level, where communities may be municipalities or portions of municipalities. For this study, each of the communities in the Mid-Atlantic region in the NOAA database was assigned to the county in which the community is located. The average scores on the NOAA assessment ranks for each community are then calculated for the six of the composite indicator series in the NOAA data.

	Commercial		Recreational		
	Engagement	Reliance	Engagement	Reliance	Mean Score
DE	1.04	1.04	1.12	1.26	1.11
MD	0.76	0.76	1.12	1.19	0.96
NJ	1.08	1.04	1.26	1.22	1.15
NY	1.05	1.02	1.17	1.09	1.08
PA	1.00	1.00	1.00	1.00	1.00
VA	1.09	1.05	1.16	1.13	1.11

Table 3-17 Aggregate fish index scores for states.

The average ranking scores on the NOAA index across all communities in each state are shown in Table 3-17. The definition of the variables used for the ranking are contained in Appendix 3-A. Delaware and Virginia are tied for the highest fishing relationships, followed by New York and New Jersey. But when the top ten counties are examined (Table 3-18), Virginia counties account for six of the ten, including the top two (Hampton and Newport News cities). However, the mean ranking used here does not quite reflect the full picture. Hampton and Newport News both achieve top ranking because of very high scores on both commercial and recreational engagement. Though fifth-ranked overall, Cape May County, NJ, has above minimum scores (=1) on all four indicators.

Figure 3-17 shows the distribution of the mean ranking across the region. The concentration in the lower Chesapeake cities and Cape May are shown. But also noteworthy are two counties in New York City. Brooklyn scores high on recreational fishing engagement, much of which takes place along the southern shore beaches in the Rockaways. The Bronx also has a high score commercial fisheries engagement. The bulk of the counties with scores in the middle of the NOAA rankings lie in Virginia, Maryland, southern Delaware, and New Jersey.

		Commercial		**Recreational**			
State	**County**	**Engagement**	**Reliance**	**Engagement**	**Reliance**	**Mean Score**	**Rank**
VA	Newport News (city)	4.00	1.00	4.00	1.00	2.50	1
VA	Hampton (city)	3.00	1.00	4.00	1.00	2.25	2
NY	Kings	2.00	1.00	4.00	1.00	2.00	3
VA	Norfolk (city)	2.00	1.00	4.00	1.00	2.00	4
NJ	Cape May	1.38	1.25	2.31	2.00	1.73	5
NY	Bronx	3.00	1.00	1.00	1.00	1.50	6
VA	Mathews	1.00	1.00	1.50	2.50	1.50	7
VA	Virginia Beach	1.50	1.00	2.50	1.00	1.50	8
VA	Gloucester	1.00	1.00	2.00	1.67	1.42	9
VA	Northumberland	1.75	1.75	1.00	1.00	1.38	10

Table 3-18 Top 10 fisheries counties.

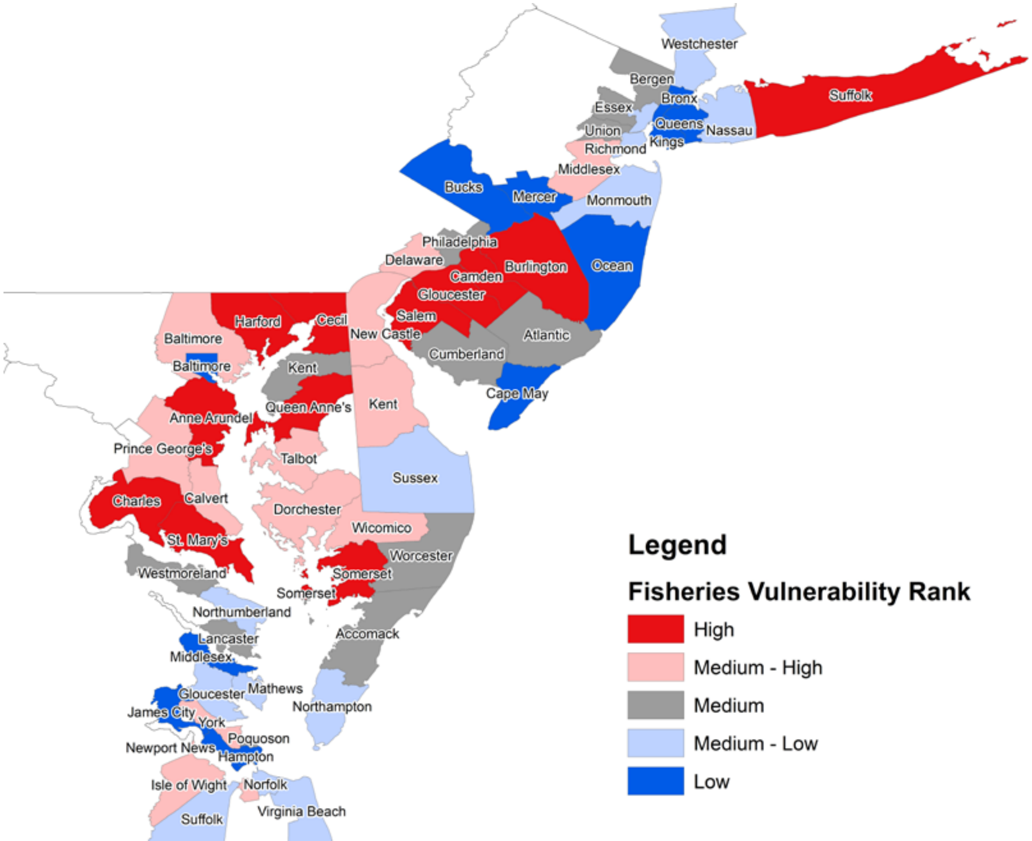


Figure 3-17 Fisheries engagement/reliance ranked (High=Most Dependent).

Social Vulnerability

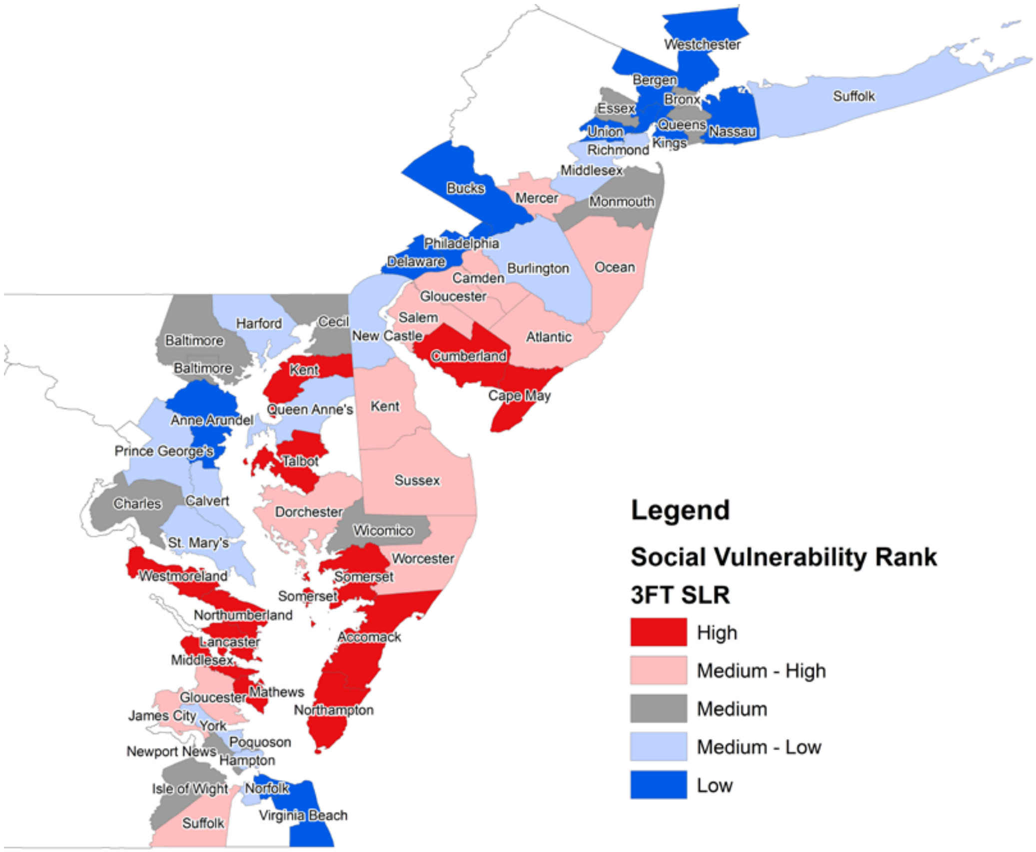
Social vulnerability is a complex mixture of conditions including language, ethnicity, income, housing costs, and age. A social vulnerability index built on data from the American Community Survey has come into widespread use for linking social vulnerability factors to other factors. (Cutter, Carolina, and Boruff 2003) The Social Vulnerability Index (SoVI) provides a convenient summary measure to link to sea level rise. The complete list of the SoVI variables used is contained in Appendix 3- B.

The SoVI index is calculated at the Census tract level, but unlike the population and housing units used earlier, the SoVI is a composite index similar to the NOAA fisheries index; its absolute value is simply an artifact of the underlying data and statistical construction method; like the NOAA index, the SoVI is compiled using factor analysis. Therefore, a process similar to the analysis of the fisheries index is used. Mean SoVI scores were calculated for all tracts within a county and then aggregated to the county level and the state level. These aggregated scores were then used to rank order the counties. These rank scores were then combined with the ranks of sea level rise flooding of tracts and the resulting combined score was re-ranked for the final score.

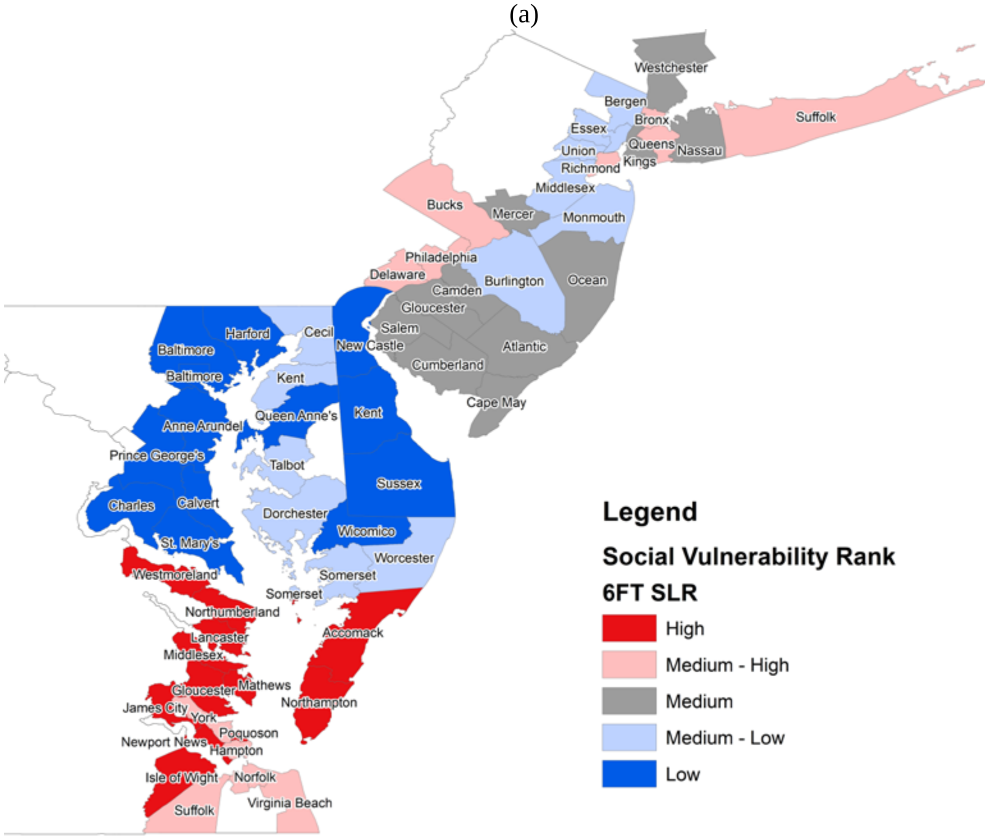
The SoVI index is best used for rank ordering among the counties, so it is of limited value in comparing the states, so that table is omitted. Table 3-19 shows the top-ranked counties adjusted for flooding and sea level rise. In this case, the same 10 counties are ranked in the same order in both SLR scenarios, meaning that the extent of SLR will have little effect in the more socially vulnerable counties.

	State	**County**	**SoVI Score Adjusted for 3ft SLR**	**State**	**County**	**SoVI Score Adjusted for 6ft SLR**
1	VA	Northampton	1	VA	Northampton	1
2	VA	Mathews	2	VA	Mathews	2
3	NJ	Cumberland	3	NJ	Cumberland	3
4	VA	Lancaster	4	VA	Lancaster	4
5	MD	Kent	5	MD	Kent	5
6	VA	Middlesex	6	VA	Middlesex	6
7	VA	Northumberland	7	VA	Northumberland	7
8	VA	Accomack	8	VA	Accomack	8
9	VA	Westmoreland	9	VA	Westmoreland	9
10	NJ	Cape May	10	NJ	Cape May	10

Table 3-19 Top 10 counties in social vulnerability under 3 foot SLR and 6 foot SLR.



(a)



(b)

Figure 3-18 Social vulnerability score adjusted for (a) 3 foot SLR and (b) 6 foot SLR.

Figure 3-18 maps the distribution of the social vulnerability index across the region. Higher scores, weighted by flooding in the 3 foot scenario. The highest scores (indicating the greatest vulnerabilities) lie in the shore adjacent tracks in the southern Chesapeake, primarily in VA, as well as, Cape May, NJ, Sussex, DE, and several of the counties in the eastern shore.

Energy and Water Infrastructure

One of the major concerns with flooding is the possible effect that it could have on infrastructure. There are two broad areas of concern: Disruptions in electricity generation, water supply, or sewer systems (including storm sewers) can spread and prolong social and economic costs. There are also disruptions to transportation infrastructure. This includes ports, which are discussed in Chapter 4, and airports, many of which in the region are just above sea level (for example: LaGuardia and Kennedy in New York, and Reagan National and Norfolk International in Virginia). The vulnerabilities of air transportation are not considered here but are addressed in assessments for individual facilities. But throughout the region the road and rail networks are vulnerable in specific places to flooding and sea level rise. This section discusses the analysis of energy and water infrastructure. The next section discusses the analysis of road and rail networks.

For energy and water facilities, the EPA maintains a database of critical infrastructure facilities which was accessed for analysis here. The focus in this analysis is on water and sewer facilities plus electricity generation. For details and sources see Appendix 3-C. Unfortunately, the ideal analysis, which is intersecting the infrastructure facility with the estimated floodplain, cannot be done with this data because it is not located at specific coordinates.

A vulnerability measure can be constructed by comparing the distribution of infrastructure with the extent of possible flooding using methods similar to those used for population, housing, and employment. Infrastructure facilities were located by county and each county's rank order in terms of the number of facilities located there and then joined with (added to) the rank order of area of flooding under each SLR scenario.

	Mean Rank of Facilities and Rank of Flood 6ft SLR	**Mean a Rank of Facilities and Rank of Flood 3ft SLR**	**Mean Rank of Facilities and Rank of Flood 6ft SLR**
DE	24.7	21.3	208
MD	20.4	22.4	1173
NJ	29.9	28.2	252
NY	16.4	16.6	211
PA	40.0	37.0	109
VA	44.8	45.5	51

Table 3-20 shows the mean ranking of the counties in each state in terms of the number of facilities in each state and the mean rank for the sea level rise scenarios. The mean facilities rank is the average ranking of all counties in that state out of the 57 MARCO counties that have either energy or water infrastructure located in them.[11] The ranking is based on the combined ranking of potential area flooded and number of facilities.

There were a total of 2004 water and energy facilities across the region, with more than half of those in Maryland, followed by New Jersey and New York. Virginia has the fewest facilities in its coastal counties, but when the vulnerabilities of sea level rise-associated flooding is added to the rank ordering, Virginia is clearly the most vulnerable. This is seen in Table 3-21.

[11] Counties without infrastructure facilities are counted as missing values in the calculation of average ranks.

	Mean Rank of Facilities and Rank of Flood 6ft SLR	Mean a Rank of Facilities and Rank of Flood 3ft SLR
DE	24.7	21.3
MD	20.4	22.4
NJ	29.9	28.2
NY	16.4	16.6
PA	40.0	37.0
VA	44.8	45.5

Table 3-20 State summary of infrastructure emplacements in coastal counties.

	State	County	Rank Number of Facilities	State	County	Rank 3ft SLR	State	County	Rank 6 foot SLR
1	MD	Anne Arundel	1	NY	Suffolk	1	NJ	Cape May	1
2	MD	Worcester	2	NJ	Cape May	2	MD	Worcester	2
3	MD	Charles	3	MD	Worcester	3	NY	Suffolk	3
4	MD	Cecil	4	MD	Somerset	4	NY	Nassau	4
5	MD	Calvert	5	MD	Queen Anne’s	5	NJ	Atlantic	5
6	NY	Suffolk	6	NY	Nassau	6	MD	Somerset	6
7	DE	Kent	7	NJ	Ocean	7	NJ	Ocean	7
8	DE	New Castle	8	NJ	Atlantic	8	NY	Queens	8
9	DE	Sussex	9	VA	Accomack	9	DE	Sussex	9
10	MD	St. Mary’s	10	DE	Sussex	10	MD	Queen Anne’s	10

Table 3-21 Top 10 counties for infrastructure.

The data on the top 10 counties suggests that the SLR-adjusted ranking of the counties in terms of infrastructure is quite different from the distribution of the facilities themselves. This is confirmed by comparing Figure 3-19 with Figure 3-20. Figure 3-19 shows the distribution of infrastructure facilities by county. Two Maryland counties (Anne Arundel, Worcester) and one Virginia County (Charles) have very high numbers of facilities compared with the other counties. Only four counties (Suffolk, NY and the three counties in Delaware comprise a middle group with between 55 and 102 facilities. The majority of counties have fewer than 54 energy or water infrastructure facilities. But when adjusted for the area of possible sea level rise related flooding, the distribution of rank orders in terms of most vulnerable shifts clearly to Suffolk, Cape May, and Worcester counties, which occupy the top three ranks in both scenarios.

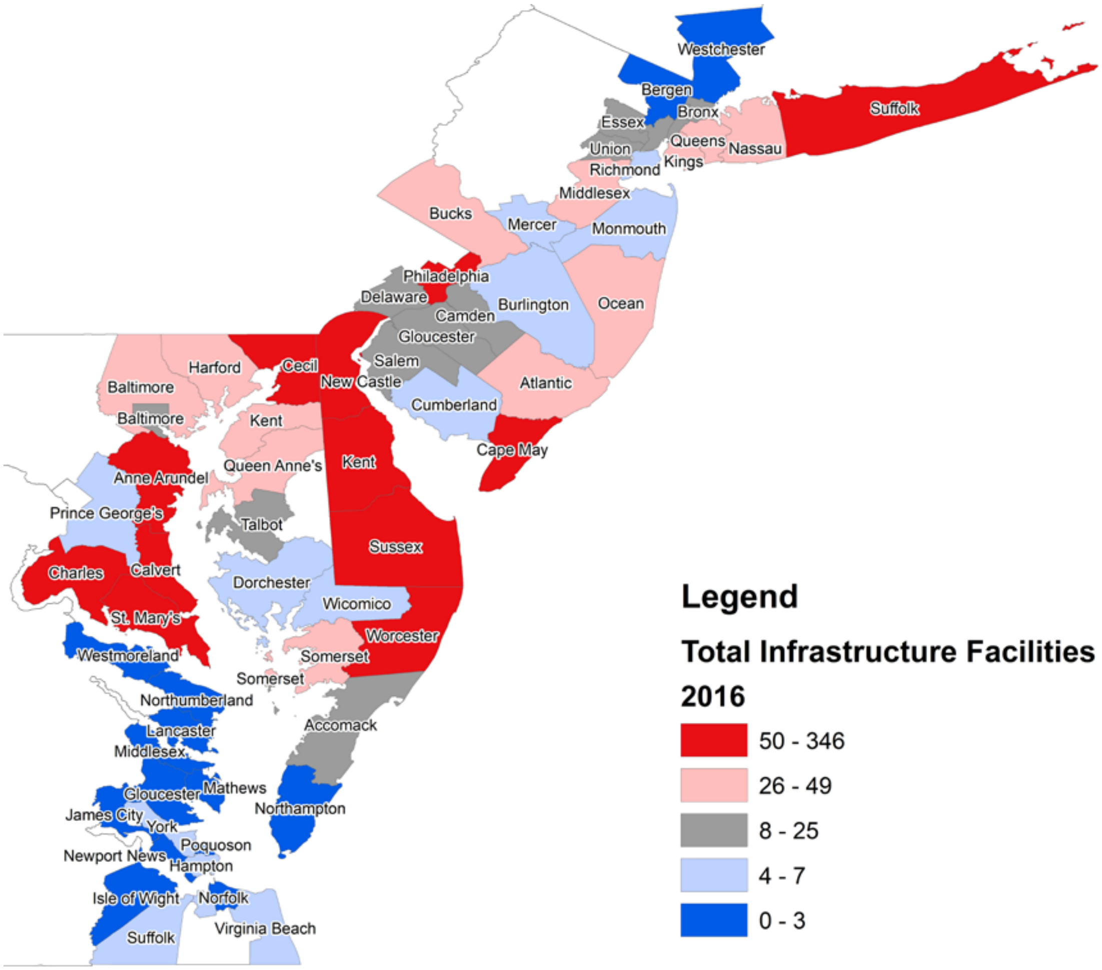
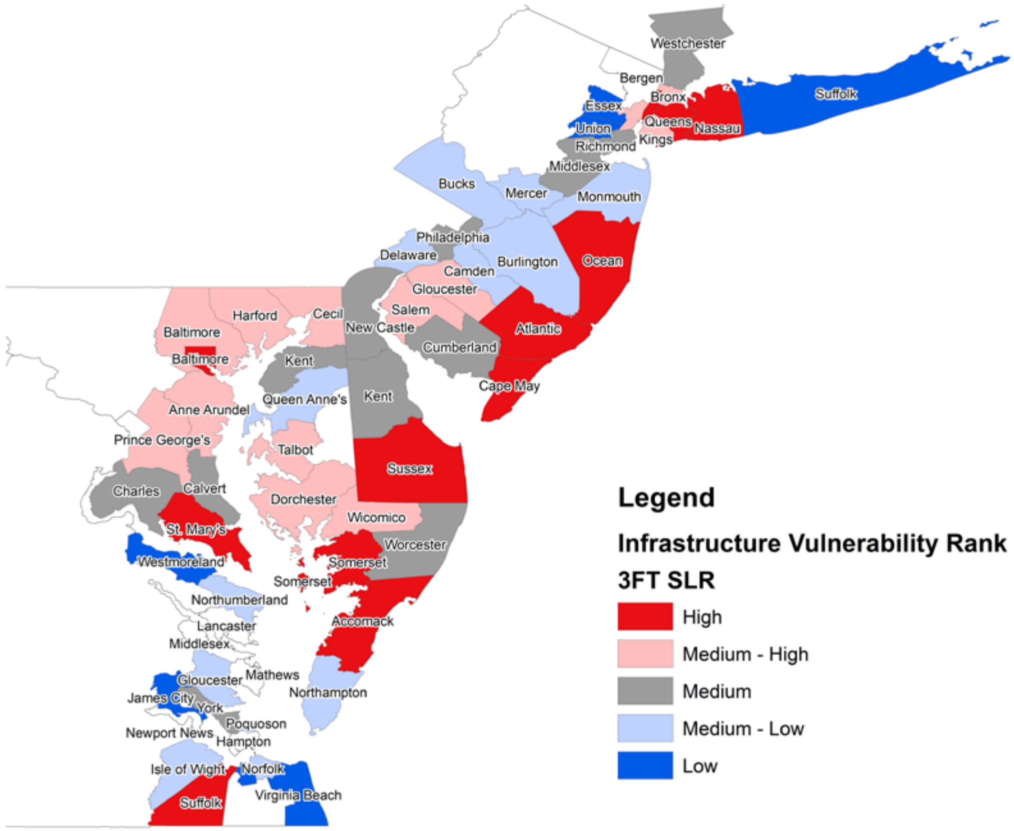
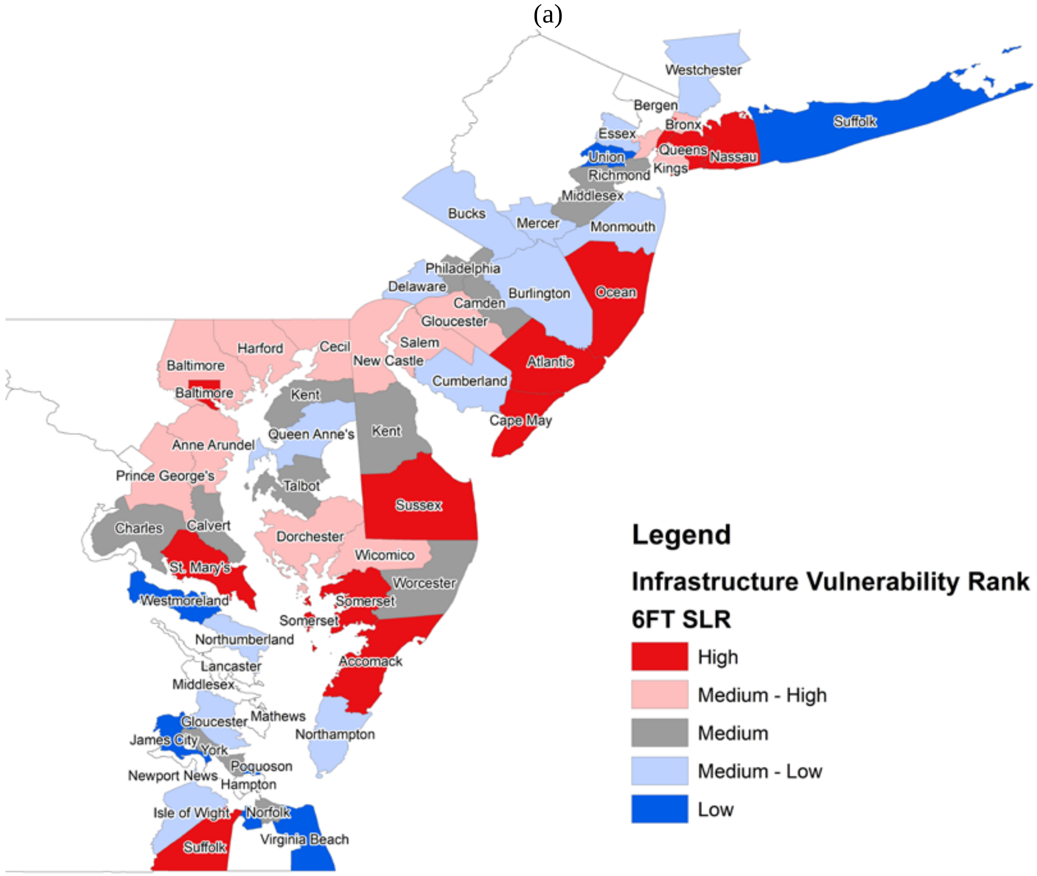


Figure 3-19 Distribution of infrastructure facilities by county.



(a)



(b)

Figure 3-20 Rank order of infrastructure facilities adjusted for (a) 3 foot SLR and (b) 6 foot SLR.

Roads and Rail

The analysis of vulnerability of the regional road and rail systems is done in a manner similar to the above analyses where specific data can be intersected with the flooding projections of the NOAA Sea Level Rise viewers. In this case, the road data is for primary regional highways. These include elements of the Interstate highways system, primary federal highways, and major state highways. It includes the major tunnels in the region, but excludes the bridges. It excludes local roads and streets. A vulnerability analysis addressing all roads would be quite complex given the size of the region and the number of urban areas. Examining vulnerability of major roads allows a focus on the major road transportation routes through the region. Rail data is for the miles of track that are vulnerable to flooding through the region. The rail data includes both passenger and freight traffic and is for total miles, not track miles.

	Miles of Vulnerable Roads		Miles of Vulnerable Railways	
	3 Foot Scenario	3 Foot Scenario	3 Foot Scenario	6 Foot Scenario
DE	3.7	6.0	10.6	21.4
MD	25.2	27.4	3.2	7.2
NJ	32.3	91.1	99.7	311.2
NY	30.4	46.4	12.3	49.1
PA	7.0	12.8	7.8	42.0
VA	24.0	30.4	4.6	29.1
MARCO Region	122.6	214.0	138.1	460.1

Table 3-22 Summary of vulnerable roads and railways by state.

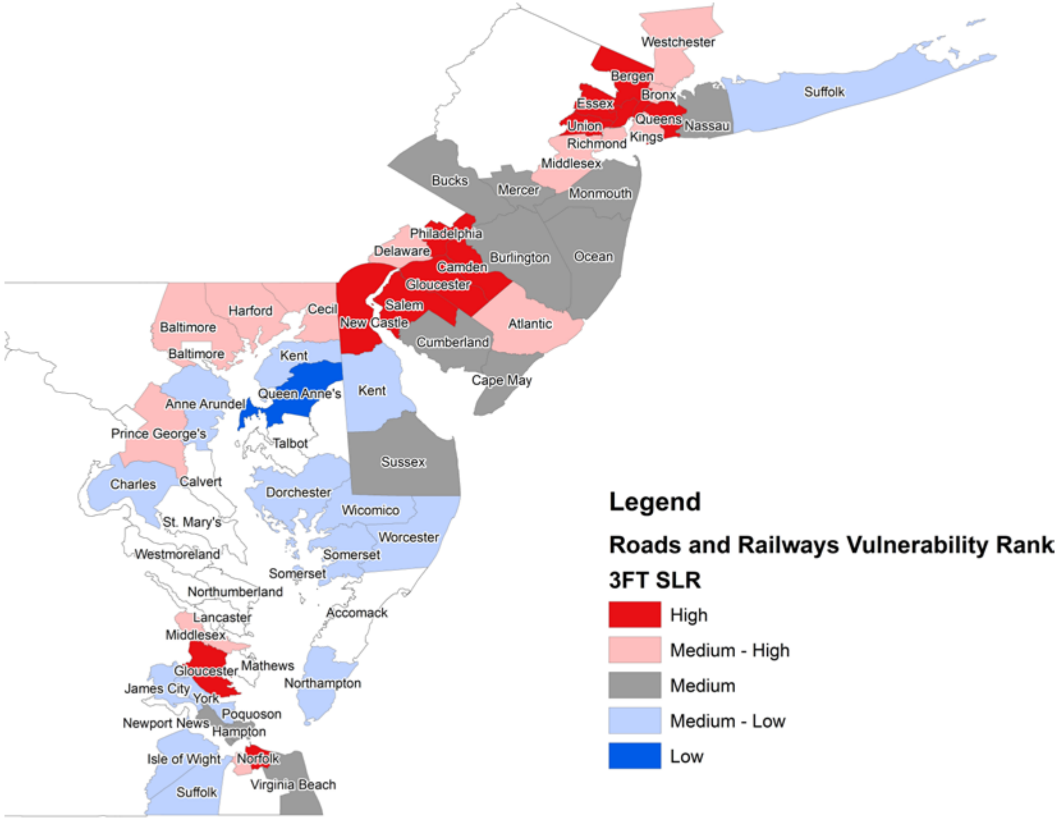
Table 3-22 summarizes the miles of road and rail determined to be vulnerable under each of the sea level rise scenarios by state. Across the region, the 3 foot scenario makes over 120 miles of major road and 138 miles of rail vulnerable to flooding. The 6 foot scenario makes 214 miles of roads and 460 miles of rail lines vulnerable. The state with the greatest vunerability for both major roads and rail under both scenarios is New Jersey.[12]

Table 3-23 shows the top ten counties by miles for each of the scenarios. Hampton City in Virginia shows up as the most vulnerable in the 3 foot scenario for major roads, but Hudson County in New Jersey is second in the 3 foot scenario and first in the 6 foot scenario. Three New York counties also appear in the top 10 list for major roads: Queens, New York (Manhattan) and Westchester. New York and New Jersey also have major vulnerabilities for the Hudson River tunnels, though the distances in the tunnels are not great. New Jersey counties comprise the top four counties for rail vulnerability under both scenarios.

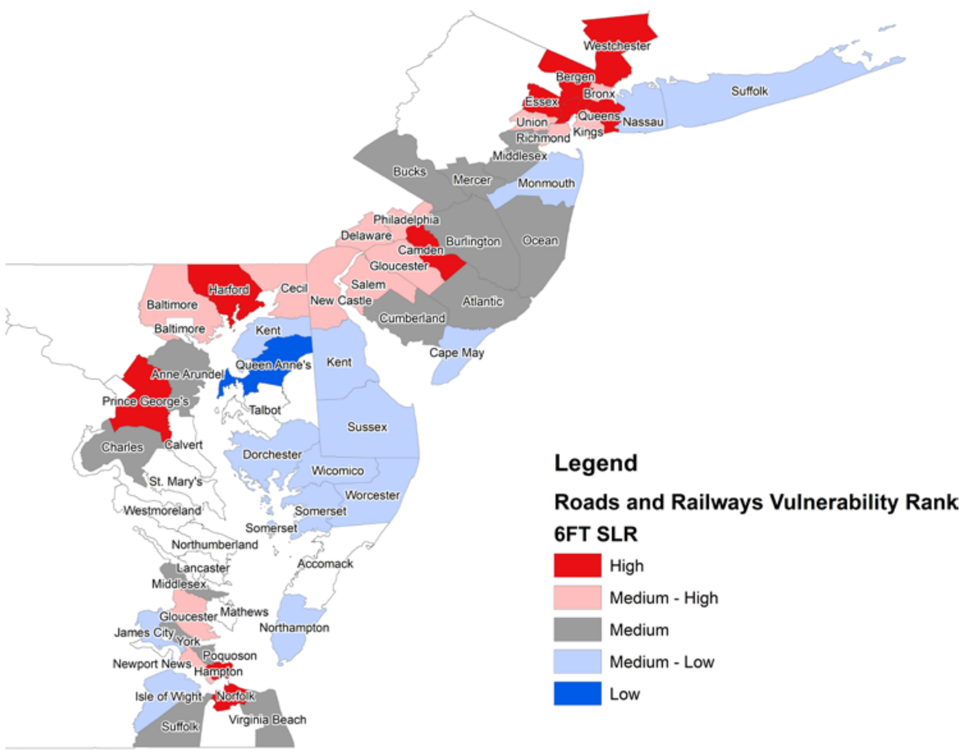
[12] There are counties that do not have either primary roads or rail mileage that is vulnerable to sea level rise. These counties are treated as missing values in the calculation of ranks.

	3 Foot			6 Foot		
	State	County	Road Miles	State	County	Road Miles
1	VA	Hampton	13.9	NJ	Hudson	27.1
2	NJ	Hudson	13.8	NJ	Bergen	24.3
3	MD	Prince Georges	10.7	NY	Queens	16.3
4	MD	Baltimore	9.9	VA	Hampton	14.6
5	NY	Westchester	9.0	NJ	Essex	12.7
6	NY	New York	8.2	MD	Baltimore	11.9
7	NY	Queens	7.0	MD	Prince Georges	10.9
8	NJ	Bergen	7.0	PA	Philadelphia	10.0
9	VA	Norfolk	5.6	NY	New York	9.7
10	PA	Philadelphia	5.0	NY	Westchester	9.0
	3 Foot			6 Foot		
	State	County	Rail Miles	State	County	Rail Miles
1	NJ	Hudson	25.4	NJ	Hudson	102.3
2	NJ	Salem	24.8	NJ	Essex	40.8
3	NJ	Gloucester	14.2	NJ	Salem	34.9
4	NJ	Bergen	11.6	NJ	Bergen	32.6
5	DE	New Castle	9.3	PA	Philadelphia	30.8
6	PA	Philadelphia	5.2	NJ	Gloucester	22.9
7	NJ	Camden	4.8	NJ	Union	19.7
8	NJ	Middlesex	4.6	DE	New Castle	19.4
9	NY	New York	4.5	NJ	Middlesex	14.6
10	NJ	Union	3.1	NJ	Camden	14.5

Table 3-23 Top 10 counties for road and railway vulnerabilities under 3 foot and 6 foot SLR scenarios.



(a)



(b)

Figure 3-21 Rank order of counties for combined road and railway vulnerability for (a) 3 foot SLR and (b) 6 foot SLR.

Conclusions

This chapter presents a region-wide analysis of some of the principal factors shaping vulnerability in the social and economic conditions of the coastal areas of the Mid-Atlantic. As a region-wide perspective, it is far less detailed than is needed for actual planning. But the analysis does point out the way that different parts of the region are affected by potential factors in different ways. By providing a sense of which factors are most likely to affect which parts of the region, it provides those concerned with each factor the areas where adaptation responses are most likely to be needed first and the chance to develop approaches that can be used throughout the region. By showing for each county which factors pose the greatest vulnerabilities it provides a starting point for adaptation planning as well as an inventory of issues to be addressed.

Appendix 3-A Definitions of Fishing Community Vulnerability in NOAA Index
Source: (Jepson and Colburn 2013b)

- **Commercial fishing engagement** measures the presence of commercial fishing through fishing activity as shown through permits and vessel landings. A high rank indicates more engagement.
- **Commercial fishing reliance** measures the presence of commercial fishing in relation to the population of a community through fishing activity. A high rank indicates more reliance.
- **Recreational fishing engagement** measures the presence of recreational fishing through fishing activity estimates. A high rank indicates more engagement.
- **Recreational fishing reliance** measures the presence of recreational fishing in relation to the population of a community. A high rank indicates increased reliance.

Appendix 3-B: Social Vulnerability Index Variables
Source: (Cutter, Carolina, and Boruff 2003)

- Median gross rent for renter-occupied housing units
- Median age
- Median dollar value of owner-occupied housing units
- Per capita income
- Average number of people per household
- % Population under 5 years or age 65 and over
- % Asian population
- % African American (Black) population
- % Civilian labor force unemployed
- % Population over 25 with less than 12 years of education
- % Population speaking English as a second language with limited English proficiency
- % Employment in extractive industries (fishing, farming, mining etc.)
- % Children living in married couple families
- % Female QFEMLBR % Female participation in the labor force
- % Families with female-headed households with no spouse present
- % Hispanic population
- % Population living in mobile homes
- % Native American population
- % Housing units with no car available
- % Population living in nursing facilities
- % Persons living in poverty
- % Renter-occupied housing units
- % Families earning more than $200,000 per year
- % Employment in service occupations
- % Households receiving Social Security benefits
- % Unoccupied housing units

Appendix 3-C: Infrastructure Facilities included in EPA Infrastructure Register

Energy
Electric Power Generator (Biomass based)
Electric Power Generator (Coal based)
Electric Power Generator (Gas based)
Electric Power Generator (Nuclear based)
Electric Power Generator (Oil based)
Electric Power Generator (Other Fossil Fuel based)
Electric Power Generator (Solar based)
Electric Power Generator (Water based)
Electric Power Generator (Wind basd)

Water
Community Water System
Transient Non-Community Water System
Water Treatment Plant

For more information

If you would like to learn more about accessing data used in the analyses online either as maps or as downloadable files, please go to http://midatlanticocean.org/.

References to Chapter 3

Colgan, Charles S. 2004. “Living near and Making a Living from the Oceans.” In *An Ocean Blueprint for the 21st Century: Report of the United States Commission on Ocean Policy*. Washington DC: U.S. Commisssion on Ocean Policy.

Colgan, Charles S. 2013. “The Ocean Economy of the United States: Measurement, Distribution, & Trends.” *Ocean and Coastal Management* 71. Elsevier Ltd: 334–43. doi:10.1016/j.ocecoaman.2012.08.018.

Cutter, Susan L, South Carolina, and Bryan J Boruff. 2003. “Social Vulnerability to Environmental Hazards.” *Social Science Quarterly* 84 (2): 2010. doi:10.1111/1540-6237.8402002.

Griggs, G, Árvai, J, Cayan, D, DeConto, R, Fox, J, Fricker, HA, Kopp, RE, Tebaldi, C, Whiteman. EA. 2017. “Rising Seas in California.” Sacramento CA. http://www.opc.ca.gov/webmaster/ftp/pdf/docs/rising-seas-in-california-an-update-on-sea-level-rise-science.pdf.

Jepson, Michael, and Lisa L Colburn. 2013a. “Development of Social Indicators of Fishing Community Vulnerability and Resilience in the U.S. Southeast and Northeast Regions.” NOAA Tech. Memo. NMFS-F/SPO-129.

———. 2013b. “Development of Social Indicators of Fishing Community Vulnerability and Resilience in the U.S. Southeast and Northeast Regions. NOAA Tech. Memo. NMFS-F/SPO-129,” no. April: 64.

Sweet, William V, Robert E Kopp, Christopher P Weaver, Jayantha Obeysekera, Radley M Horton, E Robert Thieler, and Chris E Zervas. 2017. “Global and Regional Sea Level Rise Scenarios for the United States.”

Chapter 4 : Maritime Transportation

Maritime transportation is an activity that takes place throughout the region, but by far the most economically significant is maritime freight transportation. The region is home to several of the largest ports in the United States whether for total volume of goods, total value of goods, or the transport of specific goods. Because of this national and regional significance, maritime freight transportation is the focus of this analysis. But maritime passenger transportation is an important and growing activity in the region, from cruise ships to ferry services and its vulnerabilities should be assessed in follow on research.

Economic Contribution of Maritime Freight Transportation

The maritime transportation sector includes economic activity associated with cargo vessels and the ports they visit. The sector accounted for nearly 100,000 jobs paying more than $7.1 billion in wages, and more than $14.5 billion in GDP contributions in the Mid-Atlantic region in 2014. This represents about 24% of employment and 23% of GDP contribution of the overall US maritime transportation sector. Maritime transportation contributes 14% of ocean economy employment and 31% of ocean economy GDP in the Mid-Atlantic region.

	Employment	Wages ($billion)	GDP ($billion)
New York	22,963	1.70	3.81
New Jersey	31,757	2.26	4.29
Delaware	4,846	0.21	0.35
Maryland	21,834	1.87	3.90
Virginia	15,657	1.12	2.23
MARCO Total	97,057	7.16	14.58

Table 4-1 2014 Employment, wages, and GDP contribution of the maritime transportation sector in the Mid-Atlantic region.
Source: National Ocean Economics Program

Some 274 million tons of cargo moved through the Mid-Atlantic region's ports in 2016. This included 109 million tons of Imports and 89 million tons of Exports, with a combined value of $319 billion. It also included 76 million tons of cargo moving within or between the Mid-Atlantic ports and other destinations within the United States.

The Port of New York and New Jersey (PANYNJ) alone accounted for more than half of Total maritime sector activity in the Mid-Atlantic region in 2016. Most of the Port's facilities are located in New Jersey and give New Jersey about 49% of Total cargo volume and 47% of foreign trade value for the Mid-Atlantic region. The PANYNJ handled more than 14% by value of all seaborne US trade in 2016.

Although it is not part of MARCO, Pennsylvania's ports of Philadelphia and Chester are geographically within the envelope of the region as they are located on the Delaware River and Delaware Bay. These ports handled an additional 25 million tons of cargo in 2016, including foreign trade goods valued at $25 billion.

	Imports	Exports	Internal/ Intraport	Total	% of MARCO
New York	4.83	11.73	8.89	25.45	9.3%
New Jersey	74.13	8.27	52.05	134.45	49.0%
Delaware	3.98	1.12	2.37	7.48	2.7%
Maryland	14.13	17.73	6.97	38.84	14.2%
Virginia	11.84	50.16	6.11	68.11	24.8%
MARCO Total	108.91	89.02	76.40	274.33	
*Pennsylvania	11.75	1.26	11.55	24.56	

Table 4-2 Cargo movements (million tons) through Mid-Atlantic region ports in 2016. Source: NOEP and US Army Corps of Engineers.

	Imports	Exports	Total	% of MARCO
New York	8.81	32.36	41.17	12.9%
New Jersey	138.02	10.70	148.73	46.6%
Delaware	6.91	2.42	9.33	2.9%
Maryland	35.90	14.04	49.94	15.6%
Virginia	44.12	25.91	70.03	21.9%
MARCO Total	233.77	85.43	319.20	
*Pennsylvania	19.19	5.92	25.10	

Table 4-3 Value ($ billions) of international cargo moved through Mid-Atlantic region ports (2016).
Source: NOEP

The US water transportation sector is projected to grow by 35% in GDP and by 20% in employment terms from 2016 to 2030. (Figure 4-1, source: National Ocean Economics Program) If the Mid-Atlantic region maritime transportation industry follows this projection, it should account for some 120,000 jobs and $20 billion in GDP by 2030.

<u>New York</u>

New York's maritime transportation sector is dominated by Atlantic coast facilities and traffic associated with PONYNJ, and a lesser contribution from the Port of Albany on the Hudson River. (Table 4-4 and Table 4-5 source: National Ocean Economics Program). These facilities handle predominantly containerized cargo, including imports of manufactured goods and foods, and exports of scrap, plastics, and wood.

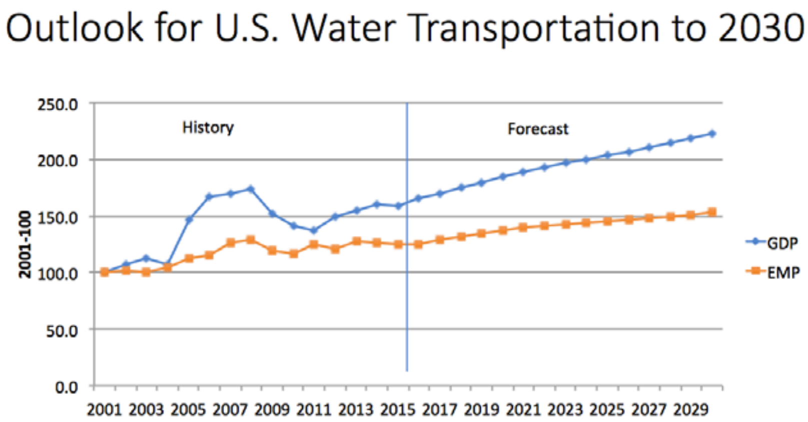


Figure 4-1 U.S. water transportation sector growth projection:

	Imports	Exports	Internal/Intraport	Total
Albany	0.44	0.35	5.86	6.66
New York	4.38	11.38	3.03	18.79

Table 4-4 Volume (million tons) of cargo moved through New York's Atlantic ports in 2016.

	Imports	Exports	Total
Albany	0.14	0.27	0.41
New York	8.68	32.09	40.77

Table 4-5 Value ($ billions) of international cargo moved through New York's Atlantic ports in 2016.

<u>New Jersey</u>

New Jersey's maritime transportation sector is even more strongly dominated by facilities associated with PANYNJ. The cargo is predominantly imports of oil and fuel products as well as containers. (Table 4-6 and Table 4-7, Source: National Ocean Economics Program)

	Imports	Exports	Internal/Intra-port	Total
Newark	58.54	5.30	40.46	104.30
Perth Amboy	6.22	0.50	4.30	11.02
Paulsboro	8.80	2.38	7.29	18.47
Camden	0.56	0.10		0.67

Table 4-6 Volume (million tons) of cargo moved through New Jersey ports in 2016

	Imports	Exports	Total
Newark	133.25	10.17	143.42
Perth Amboy	2.75	0.21	2.96
Paulsboro	1.90	0.19	2.08
Camden	0.13	0.13	0.26

Table 4-7 Value ($ billions) of international cargo moved through New Jersey ports in 2016.

A small amount of cargo also moves through the Port of Gloucester on the Delaware River.

Pennsylvania

Pennsylvania is not formally part of MARCO, but its shoreline and waterfront facilities are within the geographic envelope of the Mid-Atlantic region; data on its ports are included here for the sake of completeness. The Port of Philadelphia handles mainly imports of crude oil and petroleum products, and exports of paper products and scrap, as well as a significant amount of container traffic. (Table 4-8and Table 4-9 Source: National Ocean Economics Program)

	Imports	Exports	Internal/Intraport	Total
Philadelphia	10.83	0.93	11.22	22.97
Chester	0.92	0.33	0.33	1.58

Table 4-8 Volume (million tons) of cargo moved through Pennsylvania's Atlantic ports in 2016.

	Imports	Exports	Total
Philadelphia	13.99	3.79	17.78
Chester	5.19	2.12	7.32

Table 4-9 Value ($ billions) of international cargo moved through Pennsylvania's Atlantic ports in 2016.

Delaware

Cargo moved through the Port of Wilmington includes primarily imported crude oil, fuel products, and food products. (Table 4-10 and Table 4-11 Source: National Ocean Economics Program)

	Imports	Exports	Internal/Intraport	Total
Wilmington	3.98	1.12	2.37	7.48

Table 4-10 Volume (million tons) of cargo moved through the Port of Wilmington, DE in 2016

	Imports	Exports	Total
Wilmington	6.91	2.42	9.33

Table 4-11 Value ($ billions) of international cargo moved through the Port of Wilmington, DE in 2016.

Maryland

The Port of Baltimore handles imports of a wide range of food products and minerals, as well as imported vehicles, for which it is the nation's largest port. Exports are dominated by coal. (Table 4-12 and Table 4-13 Source: National Ocean Economics Program)

	Imports	Exports	Internal/Intraport	Total
Baltimore	14.13	17.73	6.97	38.84
Annapolis	<0.01	<0.01		<0.01

Table 4-12 Volume (million tons) of cargo moved through the Maryland ports in 2016.

	Imports	Exports	Total
Baltimore	35.88	14.04	49.91
Annapolis	0.02	<0.01	0.02

Table 4-13 Value ($ billions) of international cargo moved through Maryland ports in 2016.

Virginia

Imports via the Port of Norfolk vary widely across plastic and metal materials and manufactured goods. Coal, soybeans, wood, and paper products dominate exports. (Table 4-14 and Table 4-15 Source: National Ocean Economics Program)

	Imports	Exports	Internal/Intraport	Total
Richmond	0.06	-	0.27	0.33
Norfolk	11.44	37.24	5.36	54.05
Newport News	0.05	0.01	-	0.06

Table 4-14 Volume (million tons) of cargo moved through the Virginia ports in 2016.

	Imports	Exports	Total
Richmond	0.02	<0.01	0.02
Norfolk	44.05	25.89	69.94

Table 4-15 Value ($ billions) of international cargo moved through Virginia ports in 2016.

Climate Change Vulnerability

The primary climate change effect on the maritime transportation system is likely to be associated with sea level rise. Cargo transfer operations in ports can be disrupted when docks, roadways, railways, and other facilities are flooded during high water events. Other vulnerabilities include reduced air draft under bridges across shipping channels due to sea level rise and reduced working life of concrete port infrastructure due to higher levels of acidity.

"Coastal flooding" is defined by the National Weather Service (NWS) as water inundating normally dry coastal land. NWS distinguishes between "minor," "moderate," and "major" flooding. Minor (or "nuisance") flooding may result in standing water in parking lots or flooded impassable streets; it is associated with NWS coastal flood advisories and generally not expected to pose a risk to life or property. Moderate flooding is associated with NWS coastal flood warnings and can pose a risk to life and property. Extreme high tides can result in minor and moderate flooding; major coastal flooding is usually a consequence of a coastal storm (Spanger-Siegfried *et al.* 2014). (Major flooding is defined as that which results in extensive impact on structures and roads, significant evacuations of people and/or transfer of property to higher elevations.)

Ports in the Mid-Atlantic region may be subject to above-average rates of sea level rise because of subsidence of coastal land and because of changes in the flow of the Gulf Stream in response to climate change (Ezer *et al.* 2013; Yin et al. 2009). Using the intermediate-high sea level rise scenario of the Third National Climate Assessment, Spanger-Siegfried *et al.* (2014) estimated the increase in the rate of minor tidal flooding events at 52 tide gauge locations around the United States. Figure 4-2 shows their results for stations near Mid-Atlantic region port facilities. These suggest that tidal flooding events in the Mid-Atlantic region may increase in frequency from less than 50 per year at present to 150-400 per year by 2045.

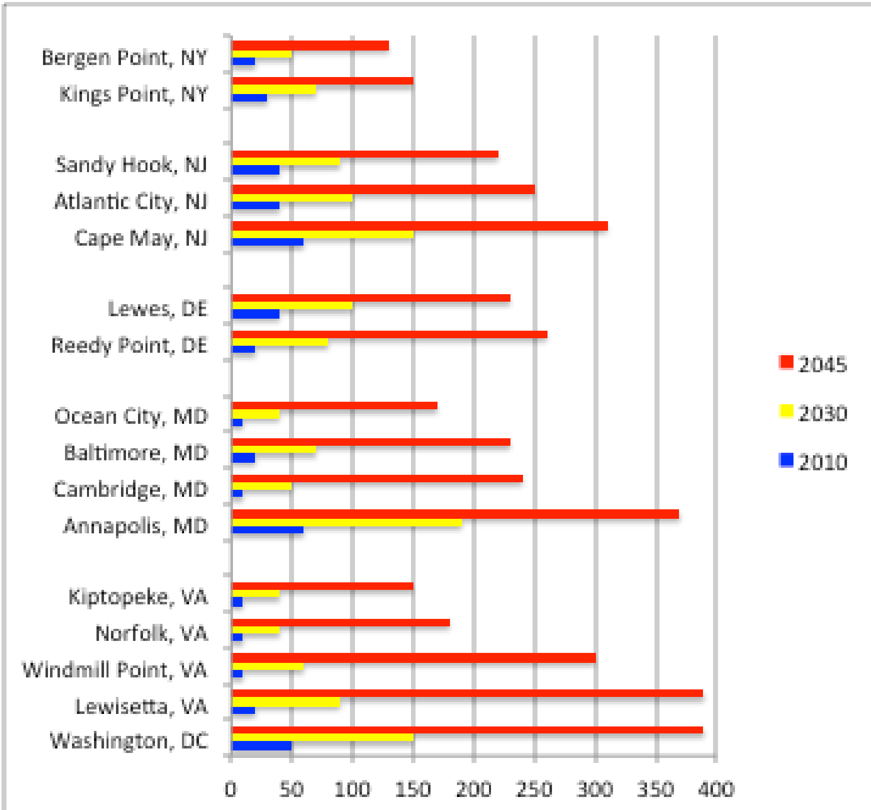


Figure 4-2 Tidal flooding events per year, 2030 and 2045.
Source: Spanger-Siegfried et al. 2014.

Figure 4-3 shows that based on the same analysis by Spanger-Siegfried *et al.* (2014) for many locations in the Mid-Atlantic region, minor or nuisance flooding events will cross the threshold to more extensive moderate flooding by 2040 (e.g. Baltimore) or 2050 (e.g. Norfolk, New York City). Figure 4-4 illustrates the particular vulnerability of the Mid-Atlantic region to increased coastal flooding in the decades ahead, relative to other areas along the US Atlantic coast (Spanger-Siegfried *et al.* [2014]).

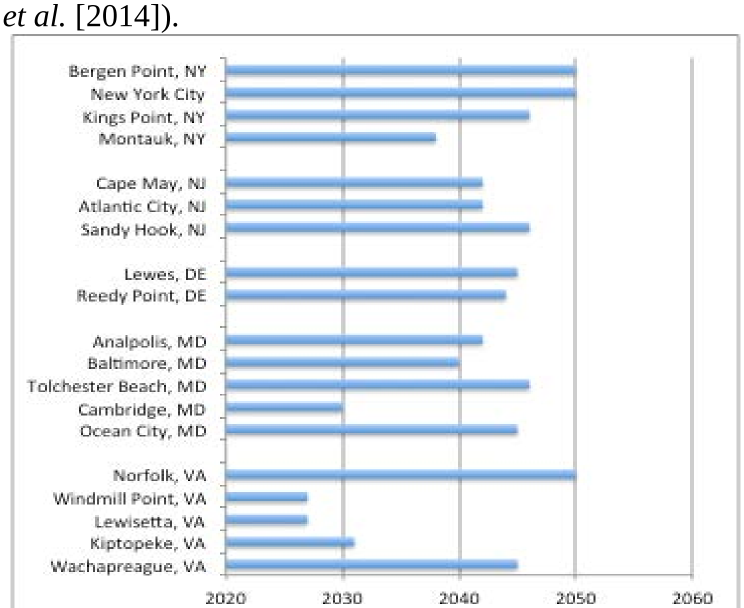


Figure 4-3 Time horizon to "extensive nuisance flooding."

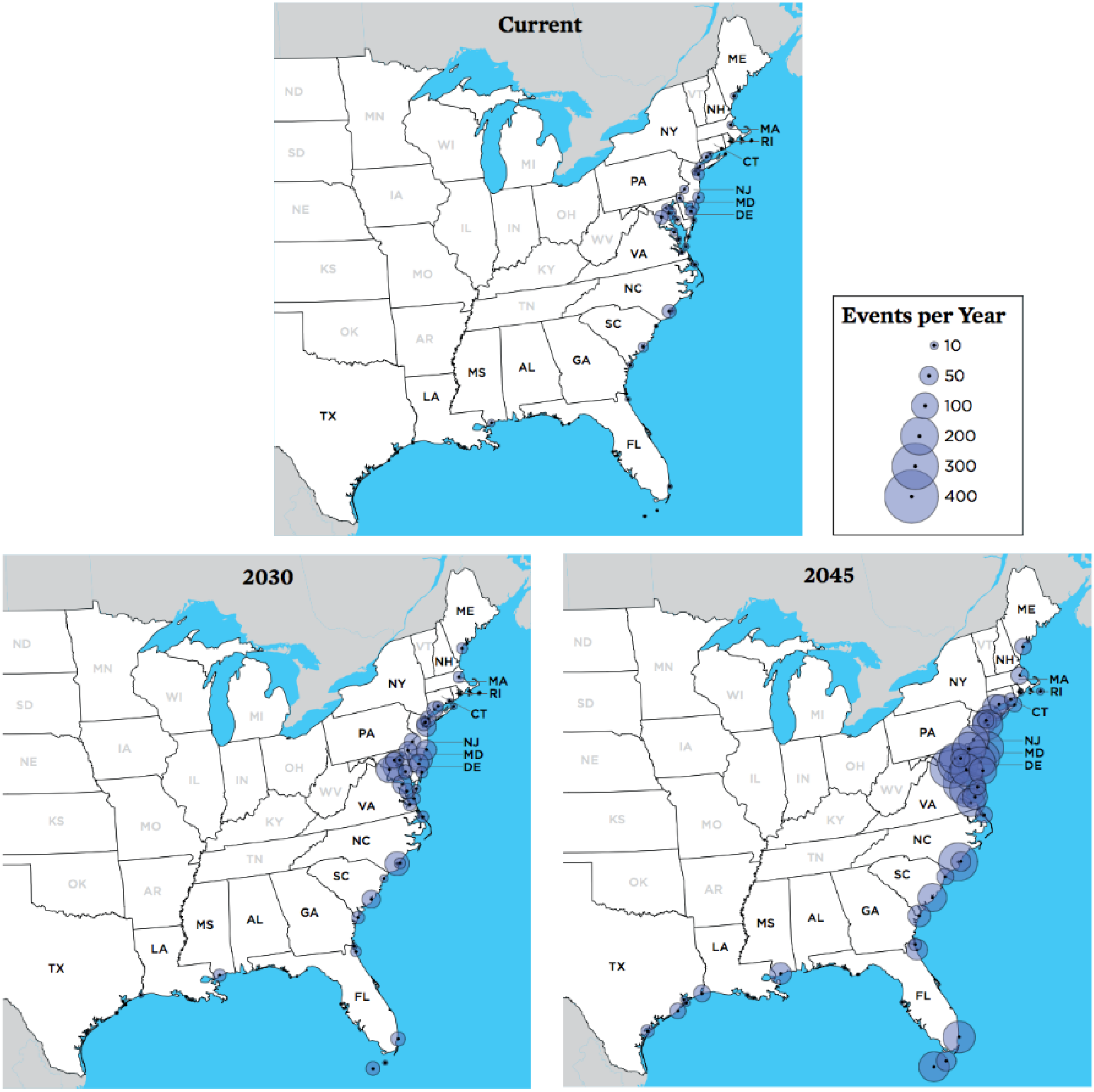


Figure 4-4 Growing frequency of tidal flooding.

About a decade ago, New York City together with PANYNJ embarked on an assessment of the possible effects of climate change on the region's infrastructure (McLaughlin *et al.* 2011). The assessment covered the full range of facilities owned and operated by PANYNJ which, in addition to marine terminals, the Port Authority maintains and operates airports, railways, tunnels, and bridges.

Figure 4-5 illustrates the range of future sea level rise that New York City's Panel on Climate Change expects the City should plan for. (New York City Panel on Climate Change, 2015) The Panel carried out flood zone mapping exercises using sea level rise of up to 75 inches to project how the flood zones associated with storms having an expected probability of occurring each year of 1% (the 100-year flood) might shift over the coming century (Figure 4-6).

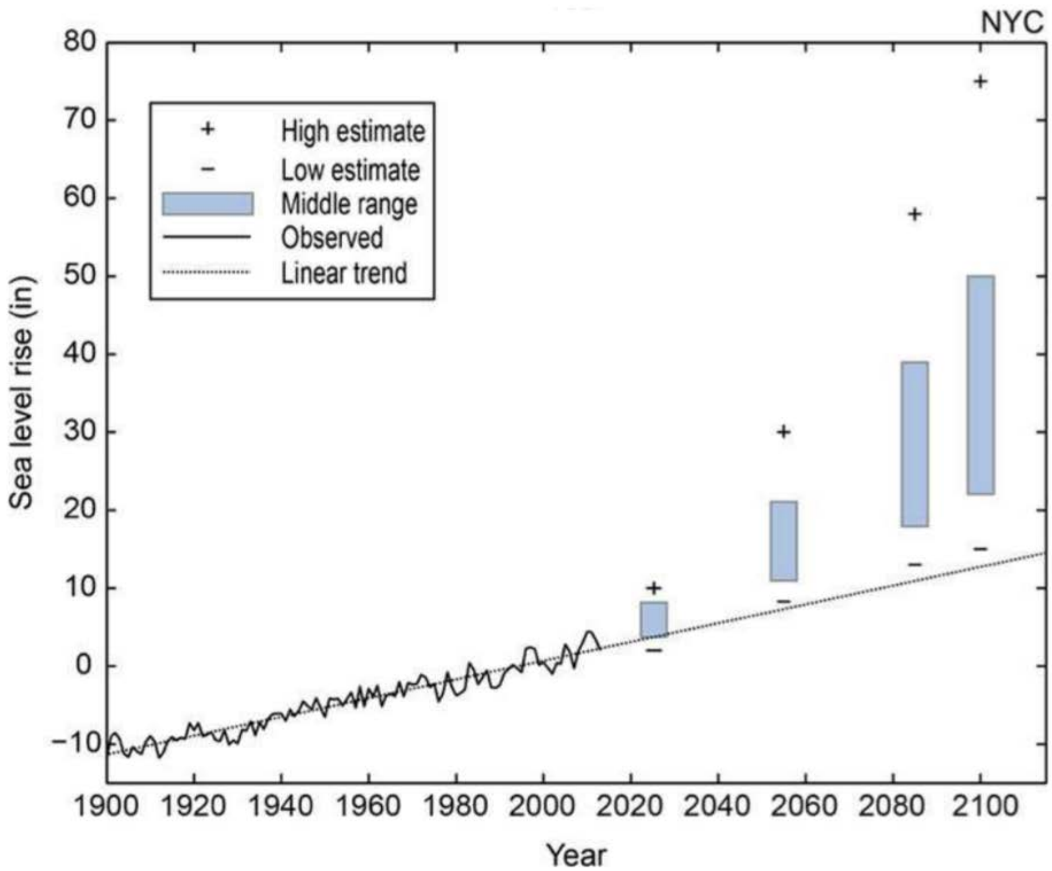


Figure 4-5 SLR projections for New York City.

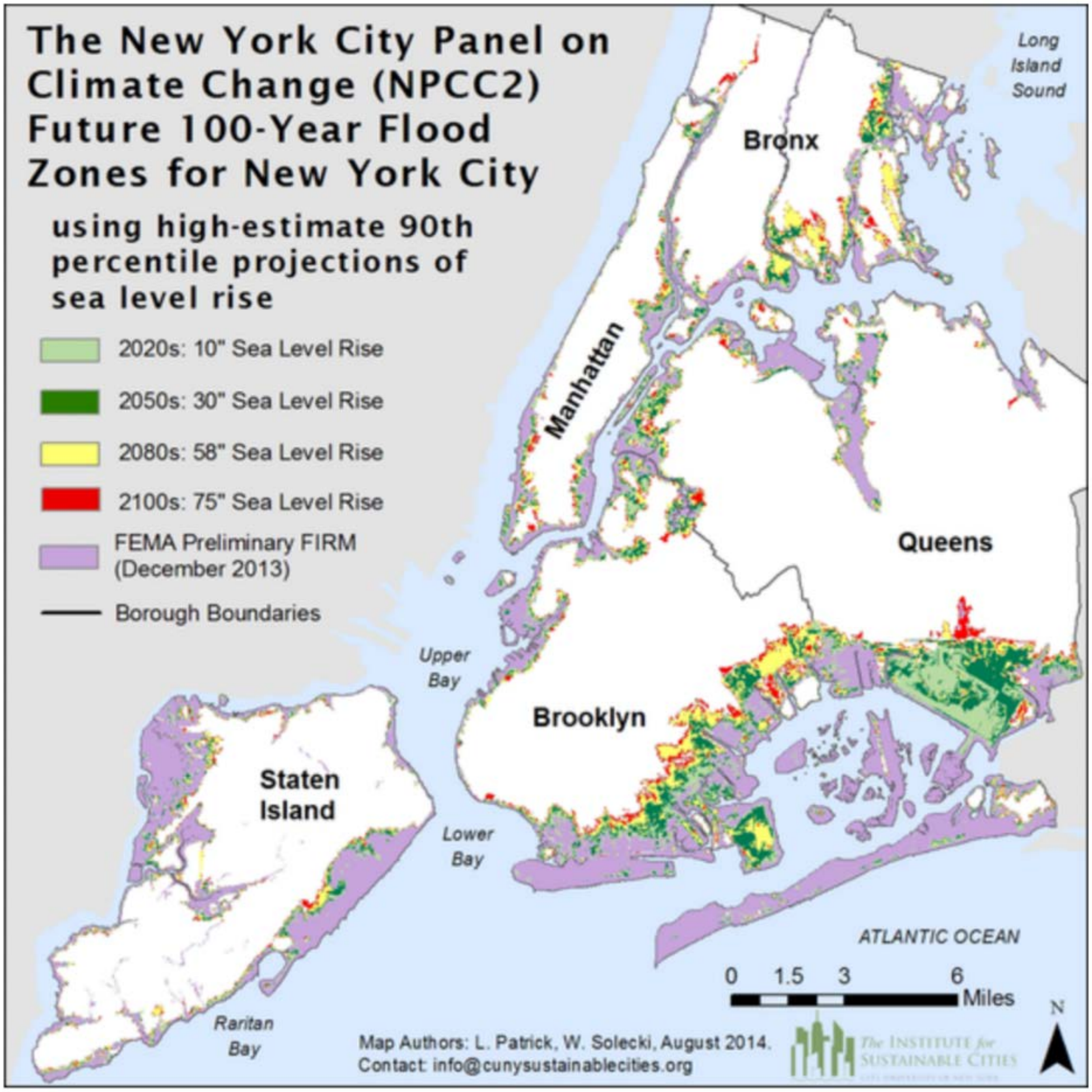


Figure 4-6 Future 100-year flood zones for New York City, based on high-estimate.

The Port Authority of New York and New Jersey has evaluated sea level rise and storm flood risk to its maritime shipping facilities. Piers, slips, and roadways identified as at risk from increased flooding risk during nor'easters and hurricanes include the Port Authority Marine Terminals at Howland Hook and Brooklyn (McLaughlin *et al.* 2011). As a result, the Port Authority has adopted interim design criteria that require new infrastructure projects to account for an increase in mean high water by the 2080s (McLaughlin *et al.* 2011). In coastal communities particularly vulnerable to flooding, such as Jamaica Bay, New York City has begun work to elevate roads, install new sewers and water mains, and improve drainage (Spanger-Siegfried *et al.* 2014).

Water levels at the Battery tide gauge near Jamaica Bay have risen by nearly a foot over the past century, as a result of sea level rise and local subsidence (NOAA 2012). The frequency of minor flooding events in the Jamaica Bay area is expected to triple by 2030 and increase by a factor of 10 by 2045 (Spanger-Siegfried *et al.* 2014).

New Jersey

Piers, slips, and roadways identified by the Port Authority of New York and New Jersey as at risk from increased flooding risk during nor'easters and hurricanes include the waterfront marine terminals of Port Newark and Hoboken, and the Port Authority Marine Terminal at Elizabeth (McLaughlin 2011).

Delaware

In a 2014 analysis of infrastructure vulnerability to sea level rise in Delaware, Strauss *et al.* conclude that, depending on the extent of sea level rise, three to six intermodal freight terminals in the state are at risk:

> …428 miles of road lie on land below 5 feet in the state; 3 intermodal freight terminals; 9 houses of worship; 2 power plants; and 87 EPA-listed sites, screened to include mostly hazardous waste sites, facilities with significant hazardous materials, and wastewater generators. At 9 feet, these numbers grow to more than 782 miles of road; 36 houses of worship; 4 power plants; 135 EPA-listed sites; and still 3 intermodal freight terminals. (Strauss *et al.* 2014)

Maryland

Annapolis, MD, is one of the most frequently flooded US East Coast cities. It has dealt with a four-fold increase in tidal flooding events since 1970, and sea level rise of more than a foot over the last century (NOAA 2012). Annapolis now sees about 50 flooding events on its City Dock waterfront each year, the worst of which submerge parking lots and force restaurants and store owners to close their premises (Spanger-Siegfried *et al.* 2014). Baltimore, which accounts for about 14% of Mid-Atlantic region shipping traffic, is expected to face a ten-fold increase in the frequency of flooding events by 2045 (Spanger-Siegfried *et al*. 2014).

Virginia

Sea level along the Hampton Roads coastline has risen by more than a foot over the past 80 years (VIMS 2013). Tidal flooding in Norfolk, which accounts for 22% of Mid-Atlantic region shipping, now occurs about once per month, three times as often as in 1970. Some Norfolk residents routinely move their cars to higher ground before streets become impassable due to floodwater around full moon tides (Kaufman 2010). By 2030, this is projected to increase to 40 flooding events per year, rising to 180 events by 2045 (Spanger-Siegfried *et al.* 2014). Strauss *et al.* (2014) estimate that:

> Floods exceeding today's historic records are likely to take place within the next 20 to 30 years at sites across Virginia under mid-range sea level rise projections. Low-range projections lead to a more than even chance of floods exceeding 5 feet above the high tide line in the same time frame for the Washington, DC and Hampton Roads areas, and by 2080 on the eastern shore and near the mouth of the Potomac. (Strauss *et al.* 2014)

The Norfolk Naval Station has begun replacing some of its piers in response to sea level rise, to make them less vulnerable to tidal and storm flooding (Fears 2011).

Summary

Maritime transportation accounted for 14% of jobs (97,000) and 31% of GDP ($14.6 billion) in the Mid-Atlantic region's ocean economy in 2014. Mid-Atlantic regional ports handled millions of tons of cargo in 2016, including 109 million tons of imports and 89 million tons of exports, with a combined value of $319 billion. Rising sea levels combined with local land subsidence is expected to increase the frequency of coastal flooding events from less than 50 per year to about 100 per year by 2030 and 200 per year by 2045. Port infrastructure and operations in the Mid-Atlantic region can expect increasingly frequent disruptions due to tidal flooding by mid-century; some ports, such as Norfolk Naval Station, are already taking steps to improve infrastructure.

References to Chapter 4

Ezer, T., L.P. Atkinson, W.B. Corlett, and J.L. Blanco. 2013. Gulf Stream's induced sea level rise and variability along the U.S. mid- Atlantic coast. *Journal of Geophysical Research: Oceans* 118:1–13.

Fears, D. 2012. Built on sinking ground, Norfolk tries to hold back tide amid sea-level rise. *Washington Post*, June 17. www.washingtonpost.com/national/health-science/built-on-sinking- ground-norfolk-tries-to-hold-back-tide-amid-sea-level-rise/2012/06/17/gJQADUsxjV_story.ht

Horton, R., D. Bader, Y. Kushnir, C. Little, R. Blake, and C. Rosenzweig. 2015. New York City Panel on Climate Change 2015 Report Chapter 1: Climate observations and projections. *Ann. N.Y. Acad. Sci*. 1336:18-35. doi:10.1111/nyas.12588

Horton, R., C. Little, V. Gornitz, D. Bader, and M. Oppenheimer. 2015. New York City Panel on Climate Change 2015 Report Chapter 2: Sea level rise and coastal storms. *Ann. N.Y. Acad. Sci*. 1336:36-44. doi:10.1111/nyas.12593

Kaufman, L. 2010. Front-line city in Virginia tackles rise in sea. *New York Times*, November 25. http://www.nytimes.com/2010/11/26/ science/earth/26norfolk.html

Kopp, R., A Broccoli, B Horton, D Kreeger, R Leichenko, J A Miller, J K Miller, et al. 2016. Assessing New Jersey's exposure to sea-level rise and coastal storms: Report of the New Jersey Climate Adaptation Alliance Science and Technical Advisory Panel. New Brunswick, NJ.

McLaughlin, B.J., S.D. Murrell, and S. DesRoches. 2011. Anticipating climate change. *Civil Engineering*, April 2011, pp. 50-55.

Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program.

Messner, S., L. Moran, G. Reub, and J. Campbell. Climate change and sea level rise impacts at ports and a consistent methodology to evaluate vulnerability and risk. 2013. *WIT Transactions on Ecology and the Environment* 169:141-53.

National Oceanic and Atmospheric Administration (NOAA) Tides & Currents. 2013. Sea level trends. http://tidesandcurrents. noaa.gov/sltrends/sltrends.shtml

New York City Panel on Climate Change. 2015. 2015 Report Executive Summary. *Ann. N.Y. Acad. Sci*. 1336:9–17. doi:10.1111/nyas.12591

Orton, P., S. Vinogradov, N. Georgas, A. Blumberg, N. Lin, V. Gornitz, C. Little, K. Jacob, and R. Horton. 2015. New York City Panel on Climate Change 2015 Report Chapter 4: Dynamic coastal flood modeling. *Ann. N.Y. Acad. Sci*. 1336:56-66. doi:10.1111/nyas.12589

Patrick, L., W. Soleki, K.H. Jacob, H. Kunreuther, and G. Nordenson. 2015. New York City Panel on Climate Change 2015 Report Chapter 3: Static coastal flood mapping. *Ann. N.Y. Acad. Sci*. 1336:45-55. doi:10.1111/nyas.12590

Rosenzweig, C. and W. Solecki. 2010. New York City Panel on Climate Change, "Climate Change Adaptation in New York City: Building a Risk Management Response," Annals of the New York Academy of Sciences 1196, (2010).

Spanger-Siegfried, E., M.F. Fitzpatrick, and K. Dahl. 2014. Encroaching tides: How sea level rise and tidal flooding threaten U.S. East and Gulf Coast communities over the next 30 years. Cambridge, MA: Union of Concerned Scientists. http://www.ucsusa.org/global_warming/impacts/effects-of-tidal-flooding-and-sea-level-rise-east-coast-gulf-of-mexico

Strauss, B., C. Tebaldi, S. Kulp, S. Cutter, C. Emrich, D. Rizza, and D. Yawitz. 2014. Delaware and the surging sea: A vulnerability assessment with projections for sea level rise and coastal flood risk. Climate Central Research Report. http://sealevel.climatecentral.org/research/reports/delaware

Strauss, B., C. Tebaldi, S. Kulp, S. Cutter, C. Emrich, D. Rizza, and D. Yawitz. 2014. Maryland and the surging sea: A vulnerability assessment with projections for sea level rise and coastal flood risk. Climate Central Research Report. http://sealevel.climatecentral.org/research/reports/maryland-and-the-surging-sea

Strauss, B., C. Tebaldi, S. Kulp, S. Cutter, C. Emrich, D. Rizza, and D. Yawitz. 2012. New Jersey and the surging sea: A vulnerability assessment with projections for sea level rise and coastal flood risk. Climate Central Research Report. http://sealevel.climatecentral.org/research/reports/new-jersey-and-the-surging-sea

Strauss, B., C. Tebaldi, S. Kulp, S. Cutter, C. Emrich, D. Rizza, and D. Yawitz. 2013. New York and the surging sea: A vulnerability assessment with projections for sea level rise and coastal flood risk. Climate Central Research Report. http://sealevel.climatecentral.org/research/reports/new-york-and-the-surging-sea

Strauss, B., C. Tebaldi, S. Kulp, S. Cutter, C. Emrich, D. Rizza, and D. Yawitz. 2014. Virginia and the surging sea: A vulnerability assessment with projections for sea level rise and coastal flood risk. Climate Central Research Report. http://sealevel.climatecentral.org/research/reports/virginia-and-the-surging-sea

Virginia Institute of Marine Science (VIMS). 2013. Recurrent flooding study for tidewater Virginia. Gloucester Point, VA. http://ccrm.vims.edu/recurrent_flooding/Recurrent_Flooding_ Study_web.pdf

Yin, J., M.E. Schlesinger, and R.J. Stouffer. 2009. Model projections of rapid sea level rise on the northeast coast of the United States. *Nature Geoscience* 2:262–266; doi:10.1038/ngeo0462.

Chapter 5 : Fisheries and Fishing Communities

Introduction

Commercial fisheries are an essential component of the Mid-Atlantic coastal economy, generating significant revenues and jobs. Concerns are now intensifying about the impacts of climate variability and change on fish stocks, fisheries, and marine ecosystems in the region. Climate phenomena may increase the risks and adversely affect the yields and returns from commercial fisheries. It is vital for fishery managers and the public to develop a deeper understanding of the effects of these phenomena, so appropriate response strategies can be developed to ensure the sustainability of the region's fisheries.

Literature Review

To provide a background for relevant policy discussions, we present a comprehensive review of the literature on climate change impacts on fisheries and fishing communities. Although most of the existing studies are not on fisheries in the Mid-Atlantic region and some are dated, their findings, in terms of directional impacts and relevant drivers, provide useful information to the present study. Climate change is expected to affect primary productivity, shift the distribution and the potential yield of marine fisheries, resulting in impacts on the economics of fisheries worldwide (Sumaila *et al*. 2011). Global warming affects the productivity of fish stocks. Some stocks will become more abundant because their food supply improves, while others may decline because their food supply will decline. All fish have a range of preferred temperatures. A change in ocean temperature will adversely affect stocks in marginal areas which become too hot and will positively affect stocks in marginal areas which become warm enough. In currently ideal habitats the conditions could be improved or worsened. These changes will, in turn, affect biomass growth potentials and, in turn, the fisheries (Hannesson 2007).

Climate change is likely to have greater effects on recruitment rates of fish populations and the survival of young fish. Recruitment variability is the dominant source of variability in the most commercially important marine fisheries (Markowski *et al*. 1999). Changes in sea temperature alter preferred habitats and, consequently, affect stock migrations and concentrations, and the distribution and mix of species (Hannesson 2007; Grafton 2010). Ocean acidification affects mollusks. Lower pH levels (higher acidity) hinder the growth of calcium carbonate shells and skeletons of many marine plants and animals (Cooley and Doney 2009). Rapid sea level rise and accompanying coastal squeeze will drive changes in marsh spatial configuration and connectivity affecting how fishes utilize the marsh. Smaller and more dispersed marshes will result in lesser potential for food and refugia. (Torio and Chmura 2015) Although the specific effects of climate change on particular marine ecosystems and fish populations are difficult to predict, on a global and regional basis there is sufficient research to indicate that many, but not all, of these impacts will be negative (Grafton 2010).

Kaje and Huppert (2007) developed a study on the value of short-run climate forecasts in managing the coastal Coho salmon fishery in Washington State. The study showed that with predictable relationships between the environment and stock abundance, fishery managers should be able to forecast variation in stock survival and recruitment. Such forecasts could present an opportunity for increasing the economic value of fisheries and for achieving other management objectives. Indeed, existing socio-economic impact assessments are typically built upon the projections of future fish stock conditions and estimate corresponding changes in fish landings and, in turn, changes in socio-economic measures (e.g., economic values) (Pendleton and

Mendelsohn 1998; Markowski *et al.* 1999; Cooley and Doney 2009; Cooley et al. 2015; Seung and Ianelli 2016).

Markowski *et al*. 1999 examined the effects of climate change on commercial fisheries in different regions in the United States and found that the effects were likely to be small given the small size of this sector in the US economy. However, the effects could be large in terms of the total value of fisheries (up to 9 percent). Because the climate effects on fisheries were highly uncertain, the study developed assessments for both damage and beneficial scenarios. For the Atlantic region, the study examined major commercial species including lobster, groundfish, sea scallops, ocean quahog, surf clam, herring, mackerel, and summer flounder. Climate change was assumed to have different effects on these stocks, some might increase or others decrease. Using demand functions for different species in the literature, the authors calculated annual economic welfare change resulting from changes in quantity landed and corresponding changes in prices. The damages were estimated between $40 million to $151 million, and the benefits $38 million to $142 million.

The effects of climate change on fisheries has been studied around the world. Arnason (2007) estimated the dynamic effects from changes in fish stocks caused by global warming on the gross domestic products (GDPs) of the Iceland and Greenland economies. Felthoven et al. (2009) found that the economic productivity of commercial fishing industry was affected by climate conditions (e.g., wind and temperature). Carter and Letson (2009) found that climate activity (e.g., ENSO) had a moderate influence on the headboat fishery for red snapper in the Gulf of Mexico. Norman-Lopez *et al*. (2011) computed the economic impacts generated by climate change on Australian marine fisheries. In a study of climate change effects on coral reef fisheries in five countries, Cinner *et al*. (2011) found that key sources of vulnerability differ considerably within and between the five countries. Seung *et al*. (2015) investigated the dynamic economic impacts of ocean acidification for Bristol Bay red king crab. Seung and Ianelli (2016) calculated the temporal and cumulative impacts of the climate change-induced changes in Pollock yields on the Alaska economy.

The long-term negative effects of ocean acidification on the U.S. shellfish fisheries were estimated to be within 10% of the values of the fisheries (Cooley and Doney 2009). Narita *et al*. (2012) also estimated the economic costs of production loss of mollusks from ocean acidification. Cooley *et al*. (2015) analyze the potential impacts of ocean acidification and warming on sea scallop landings and revenues through 2050 using an integrated assessment framework includes models of biogeochemical processes, scallop growth, and scallop harvesting.

In their study of freshwater sport fishing in the northeastern United States, Pendleton and Mendelsohn (1998) found that a doubling of atmospheric carbon dioxide could lead to between a $4.6 million loss and a $20.5 million net benefit for the region. Results of the study suggest that regional effects of climate change on anglers could be mixed depending on their target species being cold-water or warm-water fish (rainbow trout, other trout, or pan fish). The distribution of economic impacts may be uneven, some states bear the brunt of economic damages, while others benefit substantially from global warming. Since recreational fishing and boating typically occur in warm weather months, warming waters may be beneficial because of longer seasons for recreationally important species. (Mendelsohn and Markowski 1999; Loomis and Crespi 1999). Although recreational and commercial fisheries are different, certain results of these analyses on recreational fishing under climate change are likely to be shared by commercial fisheries. In many cases, climate change impacts will be uneven across geographic areas and target species.

Through both short and long-term simulations, Merino *et al*. (2010) show that the sustainability of the world’s small pelagic fish resources (anchovies, sardines, and mackerels) in the face of climate variability and change depends more on how society responds to climate impacts than on the magnitude of climate alterations. Grafton (2010) developed a risk and vulnerability assessment and management decision-making framework for adaptation. Cinner *et al*. (2011) developed a framework of policy actions to reduce different aspects of vulnerability at varying spatial and temporal scales. Adaptation requires improved regional institutional coordination, expanded spatial and temporal perspective, incorporation of climate change scenarios into all planning and action, and greater effort to address multiple threats and global change drivers simultaneously in ways that are responsive to and inclusive of human communities (Heller and Zavaleta 2009).

<u>The Northeast Region</u>

The Mid-Atlantic is located in the southern part of the larger Northeast U.S. Continental Shelf Ecosystem and thus is part of climate effects on the larger ecosystem, where water temperatures are rising, surface seawater pH is decreasing, precipitation is increasing, salinities are decreasing, and water column stratification (that prevents nutrients from being brought into the surface layer) is increasing. All of these changes have an impact on marine life (Howard *et al*. 2013). Marine fish species, such as Atlantic cod, will likely move into Canadian waters and out of the region due to warming water temperatures (Fogarty *et al*. 2008). Other species, such as Atlantic croaker, are expected to increase in biomass as well as shift their ranges northwards from the Mid-Atlantic into the southern New England (Hare and Able 2007; Hare et al. 2010). American lobster will likely see their ranges move northwards, leaving the waters of New York and Rhode Island and increasing their presence in Maine (Frumhoff *et al*. 2007). Increased acidity will affect high-value shellfish species in the region, including scallops, lobsters, and blue crab (Cooley and Doney 2009, McCay *et al*. 2011). Lobster could also suffer from sea level rise if the coastal wetlands necessary to their juvenile stages are flooded (Frumhoff *et al*. 2007).

Fishing communities' well-being is affected by marine resource conditions. To improve the sustainability of both natural resources and natural-resource dependent communities, Dyer and Poggie (2000) proposes the Natural Resource Region (NRR) as a policy tool for the management of total capital (socio-economic and biophysical) flows and interactions between fishing communities and adjacent marine ecosystems. They illustrate the NRR concept with a case study of the New England multispecies groundfish fishery, showing how ignorance by managers of total capital components significantly destabilized the fishery.

Fishing communities are also affected by several other factors including urbanization (increasing population densities and real estate development) and the growth of tourism and recreation. For example, the attraction of coastal areas for retirees and others seeking a better lifestyle has led to the "gentrification" of commercial fishing communities. The impact of “gentrification” on the commercial fishing industry often precipitates a move toward non-marine based economies that can displace local residents and their dependence on fishing as a way of life with resulting impacts to local economies and cultures (Colburn and Jepson. 2012). Gale (1991) finds that many coastal communities, particularly those experiencing rapid recreation related development, will have to take explicit steps to protect the land based infrastructure of their commercial fishing fleet. Preservation of working waterfront has become an important public policy issue in recent years. A number of working waterfronts bills have been introduced in the U.S. Congress (Ounanian 2015). Smythe (2015) presents a review of the role of five coastal management programs in the northeastern (Massachusetts, Rhode Island, Connecticut, New York and New Jersey) in managing, monitoring, and protecting water-dependent uses, and find none of the programs had a mechanism for systematically monitoring or reviewing the conversions of water-dependent uses.

Sea level rise will flood coastal infrastructure, including docks and other fishing-related structures that are on the edge of the current coastline. Many smaller ports have already lost infrastructure to gentrification, such as Barnegat Light and Cape May, NJ, and Montauk, NY (Colburn & Jepson 2012). Potential losses of key infrastructure such as boat repair facilities could have significant negative impacts on the region’s fishing fleet (Robinson *et al*. 2005).

NOAA Fisheries has developed a methodology for rapidly assessing the vulnerability of US marine stocks to climate change. The methodology uses existing information on climate and ocean conditions, species distributions, and species life history characteristics to estimate the relative vulnerabilities of fish stocks to potential changes in climate. The assessment has examined 82 species in the Northeast US Continental Shelf Ecosystem, and these species have been ranked in terms of their vulnerabilities to climate change (Hare *et al*. 2016). Results of the NOAA assessment include predictions of directional effects for the 82 species: 42 species are expected to be affected negatively by climate change (including Atlantic cod and Atlantic sea scallops), 14 positively, and 26 neutrally (including American lobster) (Figure 5-1).

Commercial fish stocks are biological assets that are potentially capable of generating flows of returns indefinitely, but climate change may affect the temporal and spatial distributions of these flows, thereby potentially impacting fishery-dependent communities adversely. Jin *et al*. (2016) developed methods for applying financial portfolio theory to multispecies fishery management. Understanding the tradeoffs between expected aggregate returns and harvest portfolio risks provides managers with information necessary to better understand historical policies and to minimize the risks of future policies.

Using the assessment results of Hare *et al*. (2016), we developed model simulations for future fishery portfolio of the Northeast US Continental Shelf Ecosystem (from Maine to North Carolina). Considering fishery revenues in 1990-2012 as a baseline, we assume that under climate change, the revenues for negatively/positively affected species would decrease/increase by 25%, and no changes in the revenues for neutrally affected species. Figure 5-3 and Figure 5-3 depict the results of the test simulation model run, showing the likely effects of changing ecosystem conditions on marine resource portfolio of the region. In the baseline years, the annual revenue was $1.6-1.8 billion. With climate change, the risk level increases rapidly when the annual revenue is above $1.1 billion (Figure 5-3). The preliminary results suggest that the potential financial effects of climate change on the regional fisheries may be significant.

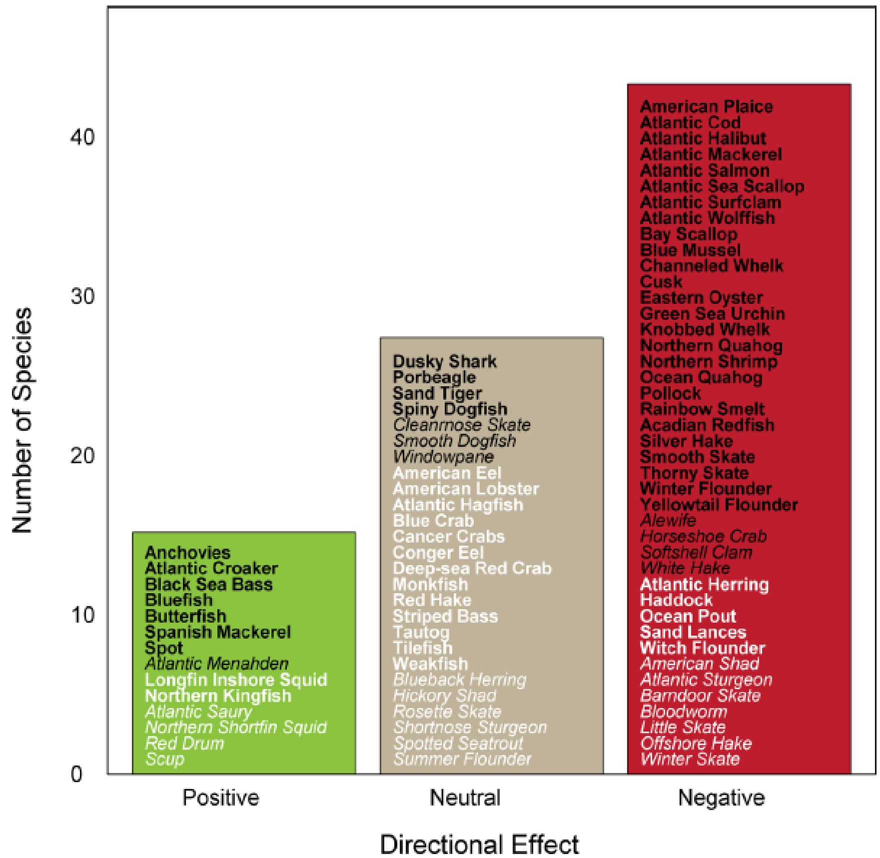


Figure 5-1 Vulnerability assessment results - directional effects.
Source: (Hare et al. 2016)

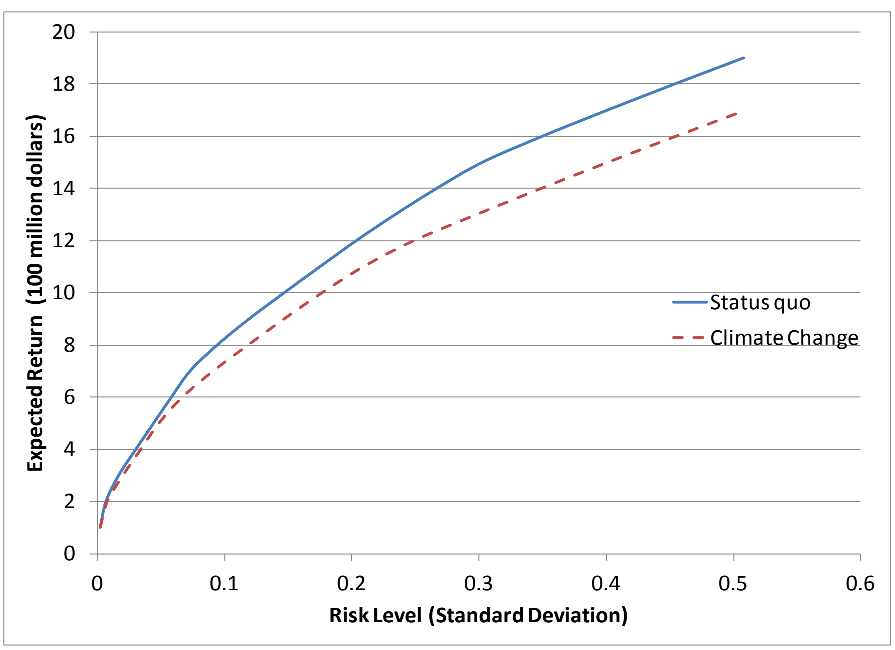
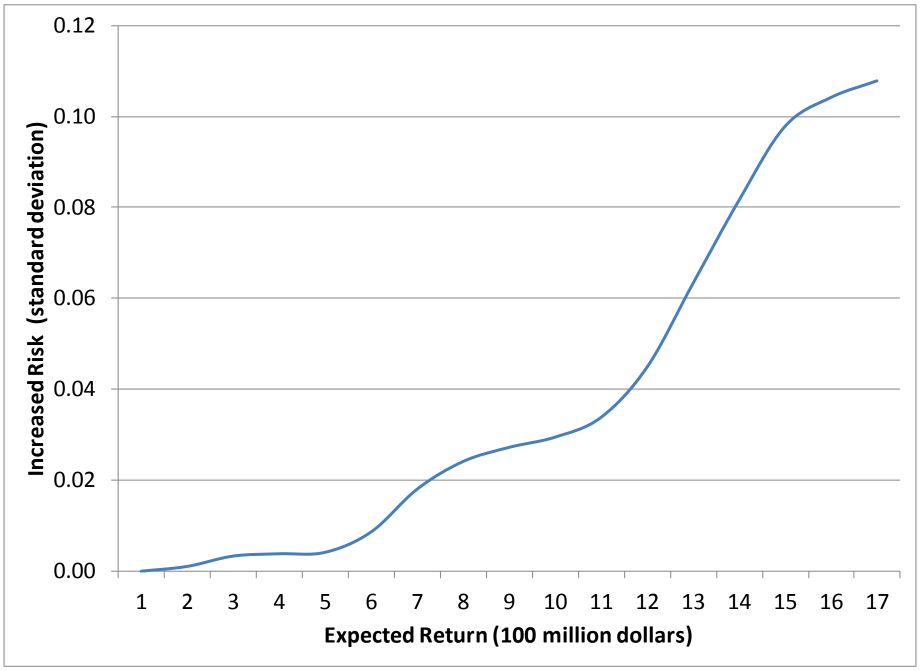


Figure 5-2 Reduction in expected revenue from simulated effects of changing ecosystem conditions on marine resource portfolio of Northeast US Continental Shelf Ecosystem.

,



(b)

Figure 5-3 Increase in financial risk from simulated effects of changing ecosystem conditions on marine resource portfolio of Northeast US Continental Shelf Ecosystem.

<u>The Mid-Atlantic Region</u>

Colburn *et al*. (2016c) classified the northeast fishing communities into four categories of climate change vulnerability (low, moderate, high and very high) based on the percent contribution of vulnerable species to total value landed in 2013 for each community. The authors found that some communities in the Northeast Ocean Ecosystem exhibited a significant dependence on species such as sea scallops that are highly vulnerable to climate change, but they also exhibit high catch diversity. For other communities that are highly dependent on the more vulnerable species but also have *low* catch diversity, the impacts of climate change could be substantial.

The Colburn study analyzed vulnerability in fishing-dependent communities by combining estimates of sea level rise with consequent flooding and land loss with a risk index is a measure of the potential impact from sea level rise of 1 through 6 feet for coastal communities based on area of community land lost. The index was constructed using factor analysis and based on a set of six indices which capture each community's social vulnerability and fishing dependence (i.e., personal disruption index, poverty index, labor force structure index, housing characteristics index, commercial fishing engagement index, and commercial fishing reliance index) (Jepson and Colburn 2013). Mid-Atlantic communities in the low lying coastal plain, especially those clustered around the Chesapeake Bay area and the New Jersey shore were ranked high with regard to expected vulnerability to sea level rise (Figure 5-4 and Appendix 5-A). This is not surprising given that the Mid-Atlantic region is experiencing sea level rise rates 3~4 times higher than the global average (Colburn *et al*. 2016).

Businesses in the seafood commerce sector include firms operating in fish hatcheries and aquaculture, commercial fishing, seafood processing, and seafood retailing. Typically, these firms are close to the shore, as proximity to fishing vessels and other infrastructure may be critical to acquiring and distributing fresh seafood and other products. Although some communities may not have a high overall risk for sea level rise (Figure 5-4) their seafood commerce businesses will be affected at the early stages of projected sea level rise in the Mid-Atlantic region (Figure 5-5 and Appendix 5-B).

Figure 5-6 depicts sea level rise impacts on business revenue using a revenue affected index which was calculated to measure the potential revenue loss at each foot of sea level rise for businesses found within the seafood commerce sector in coastal communities. Communities with high potential revenue loss in the Mid-Atlantic region are listed in Appendix 5-C.

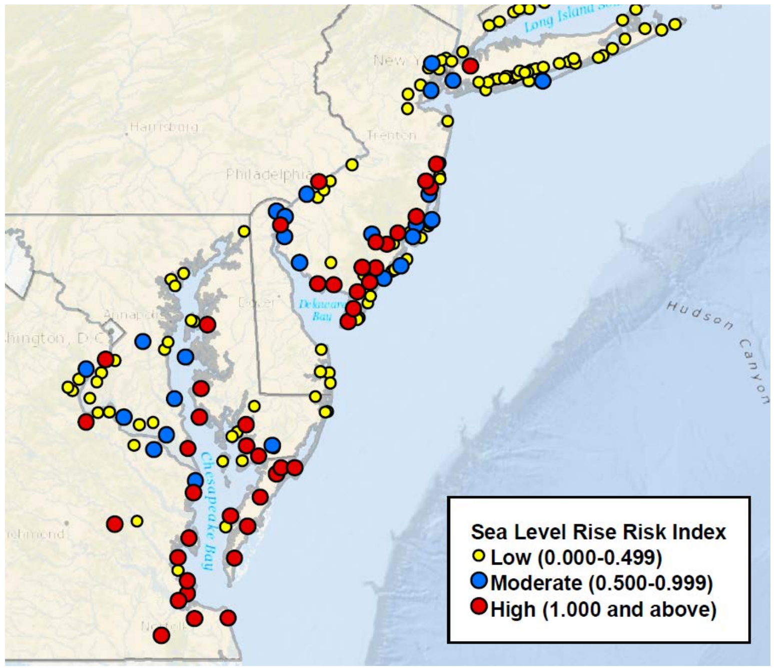
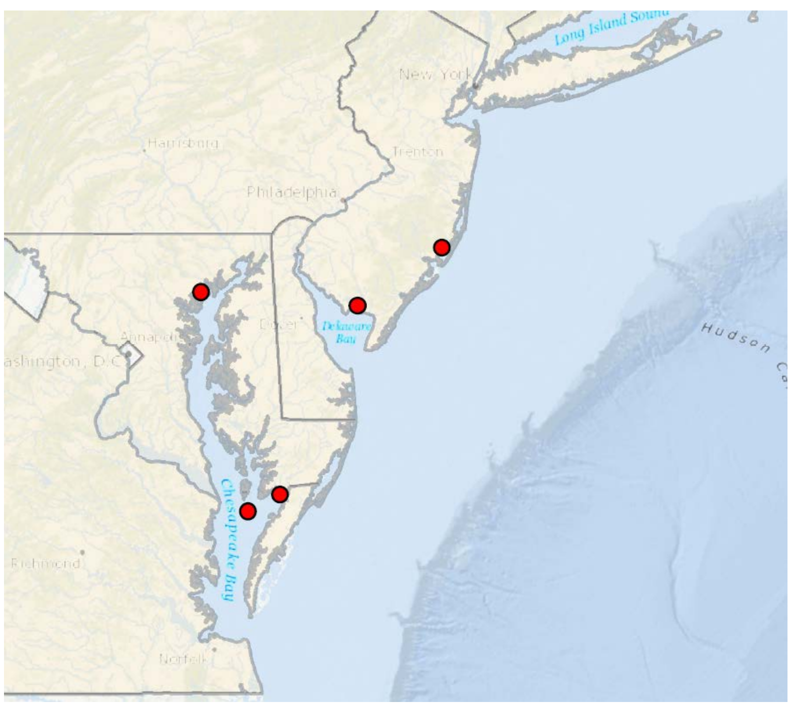
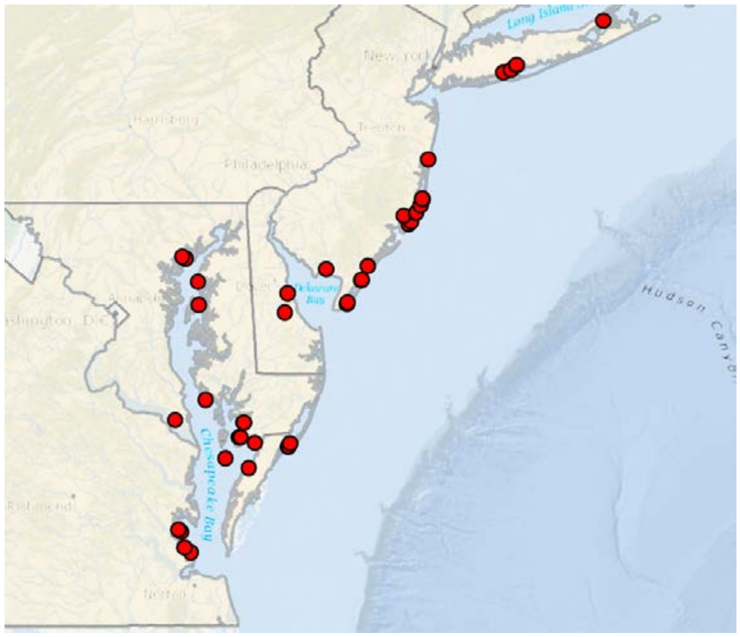


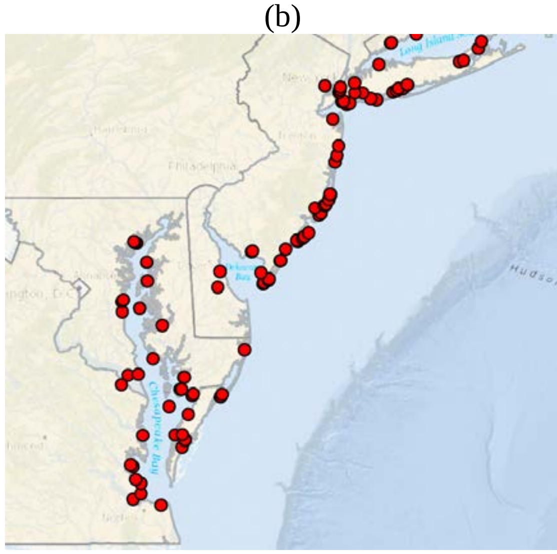
Figure 5-4 Community sea level rise risk index (Colburn et al. 2016).



(a)



(b)



(c)

Figure 5-5 Seafood commerce businesses affected by sea level rise.
Note: (a) 1 ft., (b) 3 ft. (c) 6 ft.
Source: (Colburn et al. 2016)

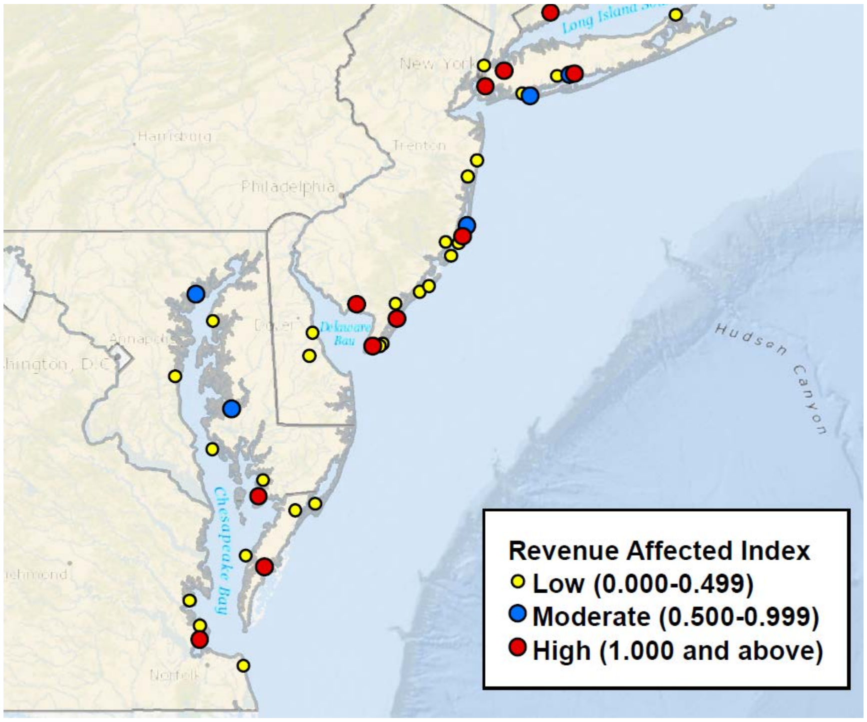


Figure 5-6 Seafood commerce revenue affected index.
Source: (Colburn et al. 2016)

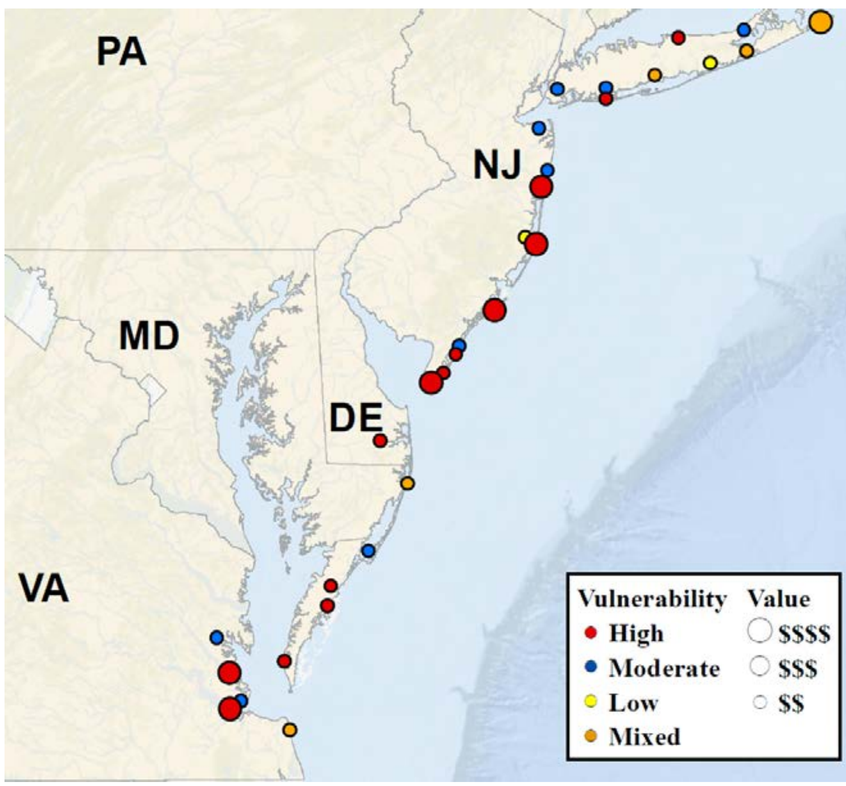
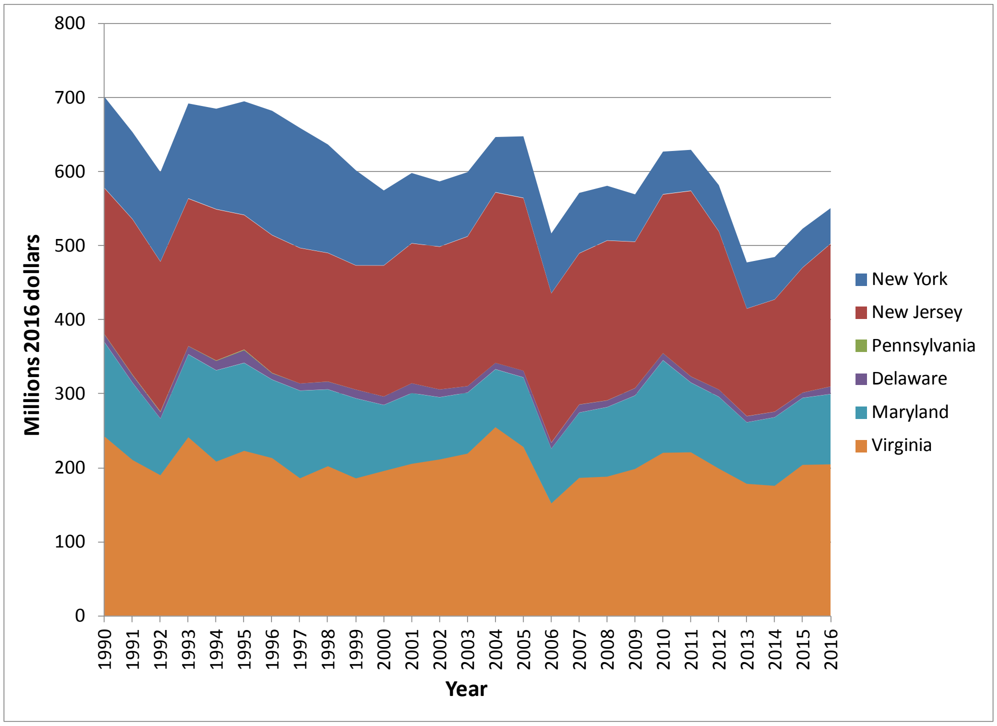


Figure 5-7 Sea level rise vulnerability due to dependence on vulnerable species.
Note: Circle size (number of dollar signs) denotes the magnitude of landings value
Source: (Colburn et al. 2016)

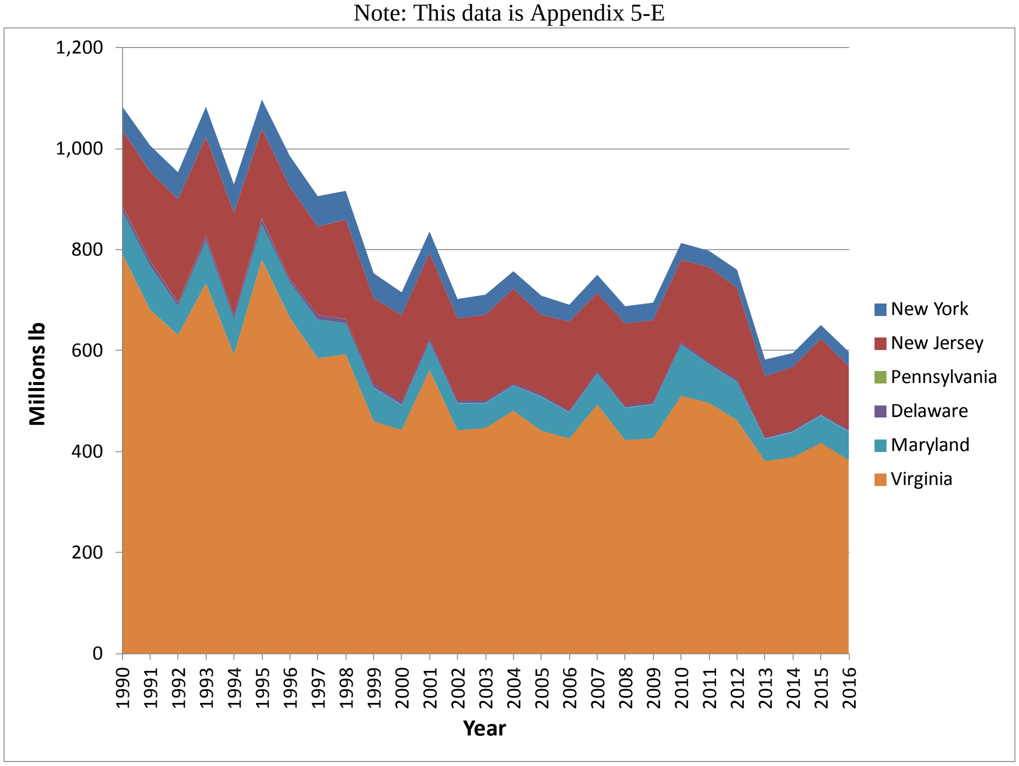
Fishing communities are also ranked by the level of dependence on species highly vulnerable to the effects of a changing climate (Hare *et al*. 2016). The fish stock vulnerability index was constructed based on historical catch composition and is mapped in Figure 5-7 and summarized in Appendix 5-D. In New Jersey, some communities are significantly dependent on species such as clams that are highly vulnerable to climate change while fish catch composition diversity in these communities is low. For those communities that are highly dependent on more vulnerable species and have low catch diversity, climate change impacts could be substantial (Colburn *et al*. 2016).

The annual revenue and quantity of commercial fishery landings in the Mid-Atlantic region are around $500 million and 600 million pounds in recent years (Figure 5-8). Although the quantity landed in Virginia is significantly larger than that in New Jersey, landings revenues in both states are about $200 million per year (Appendix 5-E and 5-F). New Jersey-based vessels land more high-valued scallops, while landings in Virginia include a large volume of relatively low-valued menhaden. Given the large number of highly vulnerable communities identified by the Colburn study, climate change impacts on these two important commercial fishing states highlight the need to develop effective adaptation policies.



(a)

Note: This data is Appendix 5-E



(b)

Figure 5-8 Value (a) and Quantity (b) of Commercial Fishery Landings.

Note: This data is Appendix 5-F

Integrating Climate Change into Fisheries Management and Community Planning

The sustainability of fisheries under climate change depends on a good understanding past, current, and projected future climate impacts, and incorporating this information into fisheries management, so that decision-makers can effectively respond to impacts on existing fisheries and take advantage of new opportunities as conditions change (Link *et al*. 2010, Sumaila *et al*. 2011). There are relatively few examples of fishery management efforts that have explicitly incorporated climate-related information (Howard *et al*. 2013). In many existing recommendations the how, by whom, and under what conditions they can be implemented are not specified. This calls for (1) more specific, operational examples of adaptation principles that are consistent with unavoidable uncertainty about the future; (2) a practical adaptation planning process to guide selection and integration of recommendations into existing policies and programs; and (3) greater integration of social science into the planning process (Heller and Zavaleta 2009).

Consideration of climate impacts on fishery resources will likely become more common as more information and tools on climate impacts and vulnerabilities become available and with the development and application of ecosystem-based fishery management, through mechanisms such as integration of changing environmental and ecological conditions into Fishery Management Plans (FPMs) (Howard *et al*. 2013). Examples of useful information for management and planning in the Northeast region include guidelines for incorporating distribution shifts into fisheries management (Link *et al*. 2011), and the identifications of vulnerable fish species and fishing communities (Hare *et al*. 2016; Colburn *et al*. 2016).

Both ecosystems and human behavioral responses are complex and dynamic, and the effects of climate change are multi-faceted and will have both direct and indirect effects on coastal communities. Coordinated and increased communication between decision-makers and science providers are essential to ensure that the most critical information needs are being met related to impacts, vulnerabilities, and adaptation of climate change. In addition, it is vital to inform the general public in their understanding of how anticipated changes might impact their communities (Howard *et al*. 2013; Colburn *et al*. 2016)

Appendix 5-A: Coastal Communities in the Mid-Atlantic Region Ranked by Sea Level Rise Risk Indices.

State	City	SLR Risk Index
MD	Brinkleys	High
MD	Fairmount	High
MD	Hoopers Island	High
MD	Madison	High
MD	Mount Vernon	High
MD	Queenstown/Grasonville	High
MD	St. Inigoes	High
NJ	Berkeley/Bayville	High
NJ	Brick	High
NJ	Cape May Court House/Middle/Rio Grande	High
NJ	Dennis	High
NJ	Egg Harbor	High
NJ	Egg Harbor City	High
NJ	Estell Manor	High
NJ	Fortescue/Newport	High
NJ	Galloway	High
NJ	Leesburg/Maurice River	High
NJ	Lower/Erma/North Cape May/Villas	High
NJ	New Gretna	High
NJ	Pennsville	High
NJ	Stafford/Manahawkin	High
NJ	Toms River	High
NJ	Upper/Beeley's Point/Seaville/Strat	High
NY	Queens	High
PA	Philadelphia	High
VA	Chincoteague	High
VA	District 2 (Accomack county)	High
VA	District 3 (Accomack county)	High
VA	District 3 (Northampton County)	High
VA	District 3/Lanexa	High
VA	District 4/Cheriton/Eastville	High
VA	District 4/Kilmarnock	High
VA	District 6/Accomac	High
VA	District 9	High
VA	Hampton	High
VA	James Madison	High
VA	Mount Vernon/Occoquan	High
VA	Newport News	High
VA	Norfolk	High
VA	Poquoson	High
VA	Suffolk	High
VA	Virginia Beach	High
VA	Westville	High
VA	York/Gloucester Point	High
DE	Wilmington	Moderate

MD	Bay Hundred/Tilghman Island	Moderate
MD	Greater Upper Marlboro	Moderate
MD	Solomons Island/Solomons/Lusby	Moderate
MD	Thompkinsville	Moderate
MD	Valley Lee	Moderate
MD	West Pocomoke	Moderate
NJ	Atlantic City	Moderate
NJ	Carneys Point	Moderate
NJ	Eagleswood	Moderate
NJ	Greenwich	Moderate
NJ	Kearny	Moderate
NJ	Lacey/Forked River/Lanoka Harbor	Moderate
NJ	Little Egg Harbor/Mystic Island	Moderate
NJ	Long Beach/North Beach Haven	Moderate
NJ	Mullica	Moderate
NJ	Ocean City	Moderate
NJ	Salem	Moderate
NY	Brooklyn/Sheepshead Bay	Moderate
NY	Fire Island	Moderate
NY	Staten Island	Moderate
PA	Tinicum Township	Moderate
VA	Cople	Moderate
VA	District 1 (Northumberland County)	Moderate
VA	Woodbridge	Moderate
DE	Bethany Beach	Low
DE	Lewes	Low
DE	Long Neck	Low
DE	Rehoboth Beach-Dewey Beach-Indian R	Low
MD	Bishopville/Ocean Pines	Low
MD	Bowleys Quarters	Low
MD	Chester	Low
MD	Crisfield	Low
MD	Dames Quarter	Low
MD	Deal Island	Low
MD	Deale	Low
MD	Dundalk	Low
MD	Edgemere	Low
MD	Elkton	Low
MD	Leonardtown	Low
MD	Marbury	Low
MD	Milestown	Low
MD	Nanjemoy	Low
MD	Ocean City	Low
MD	Piscataway	Low
MD	Pocomoke City	Low
MD	Pomonkey	Low
MD	Quantico	Low
MD	Shady Side	Low
MD	Smith Island	Low

MD	Stevensville	Low
MD	West Ocean City	Low
NJ	Avalon	Low
NJ	Beach Haven	Low
NJ	Brigantine	Low
NJ	Burlington	Low
NJ	Camden	Low
NJ	Corbin City	Low
NJ	Dover Beaches North	Low
NJ	Edison	Low
NJ	Gloucester City	Low
NJ	Jersey City	Low
NJ	Lavallette	Low
NJ	Linden	Low
NJ	Margate City	Low
NJ	Millville	Low
NJ	Newark	Low
NJ	North Bergen	Low
NJ	North Wildwood	Low
NJ	Pennsauken	Low
NJ	Point Pleasant	Low
NJ	Port Norris	Low
NJ	Port Republic	Low
NJ	Rumson	Low
NJ	Sayreville	Low
NJ	Sea Isle City	Low
NJ	Secaucus	Low
NJ	Ship Bottom	Low
NJ	Surf City	Low
NJ	Tuckerton	Low
NJ	Ventnor City	Low
NJ	West Deptford	Low
NJ	Wildwood	Low
NY	Amityville	Low
NY	Babylon	Low
NY	Bay Shore	Low
NY	Bronx/City Island	Low
NY	Brookhaven	Low
NY	Copiague	Low
NY	East Massapequa	Low
NY	East Patchogue	Low
NY	Freeport	Low
NY	Gilgo-Oak Beach-Captree	Low
NY	Great River	Low
NY	Hampton Bays/Shinnecock	Low
NY	Islip	Low
NY	Lindenhurst	Low
NY	Long Beach	Low
NY	Massapequa	Low

NY	Mastic Beach	Low
NY	Merrick	Low
NY	Montauk	Low
NY	Napeague	Low
NY	New York/Manhattan	Low
NY	North Sea	Low
NY	Northwest Harbor	Low
NY	Oakdale	Low
NY	Oceanside	Low
NY	Orient	Low
NY	Quogue	Low
NY	Seaford	Low
NY	Shirley	Low
NY	Southold	Low
NY	West Babylon	Low
NY	West Bay Shore	Low
NY	West Islip	Low
NY	Westhampton Beach	Low
NY	Woodmere	Low
VA	Aquia	Low
VA	Dahlgren	Low
VA	District 1/Grafton/Seaford/Yorktown	Low
VA	District 5	Low
VA	District 5/Belle Haven	Low
VA	Dumfries	Low
VA	Griffis-Widewater	Low
VA	James Monroe/Fairview Beach	Low
VA	Montross	Low
VA	Portsmouth	Low
VA	West Point	Low

Source: Colburn *et al*. (2016)

Appendix 5-B: Number of Seafood Businesses Affected by Sea Level Rise.

State	City	1 ft SLR	3 ft SLR	6 ft SLR
DE	Frederica		1	1
DE	Milford		1	1
MD	Cambridge			1
MD	Chesapeake Beach			1
MD	Churchton			1
MD	Crisfield		3	3
MD	Deale			1
MD	Fishing Creek		1	1
MD	Grasonville		1	1
MD	Middle River	1	2	3
MD	Ocean City			1
MD	Piney Point		1	1
MD	Ridge			1
MD	Rock Hall		1	2
MD	Sherwood			1
MD	Tilghman			1
MD	Westover		2	2
NJ	Atlantic City			2
NJ	Barnegat Light		1	2
NJ	Beach Haven		1	1
NJ	Belford			1
NJ	Belmar			1
NJ	Brick		1	1
NJ	Brigantine			1
NJ	Cape May			3
NJ	Eagleswood	1	1	1
NJ	Harvey Cedars		1	1
NJ	Long Beach		2	2
NJ	Manahawkin			1
NJ	Margate City			2
NJ	Newark			2
NJ	Point Pleasant Beach			1
NJ	Port Norris	1	1	2
NJ	Sea Isle City		2	3
NJ	Ship Bottom		2	2
NJ	Surf City			1
NJ	Upper		1	1
NJ	Villas			1
NJ	Wildwood		2	2
NY	Babylon			1
NY	Bay Shore		1	1
NY	Bayville			1
NY	Brooklyn			7
NY	Copiague			1
NY	Flushing			1
NY	Greenport			1

NY	Howard Beach			1
NY	Island Park			1
NY	Islip		1	1
NY	Jamesport			1
NY	Lindenhurst		1	1
NY	New York			3
NY	Point Lookout			1
NY	Riverhead			1
NY	Rockaway Point			1
NY	Southold		1	1
NY	West Islip		1	1
VA	Achilles		1	1
VA	Belle Haven			2
VA	Callao			1
VA	Chincoteague		3	3
VA	Deltaville			1
VA	Exmore			1
VA	Hampton			1
VA	Hayes		1	1
VA	Marionville			1
VA	Newport News			1
VA	Onancock		1	1
VA	Poquoson		2	2
VA	Saxis	1	1	2
VA	Tangier	1	1	1
VA	Virginia Beach			1
VA	Willis Wharf			1

Source: Colburn *et al*. (2016)

Appendix 5-C: Coastal Communities in the Mid-Atlantic Region Ranked by Seafood Business Revenue Affected by Sea Level Rise.

State	City	Revenue Index
MD	Crisfield	High
NJ	Long Beach/North Beach Haven	High
NJ	Lower/Erma/North Cape May/Villas	High
NJ	Port Norris	High
NJ	Sea Isle City	High
NY	Brooklyn/Sheepshead Bay	High
NY	Islip	High
NY	Queens*	High
VA	District 3 (Northampton county)	High
VA	Hampton	High
MD	Bowleys Quarters	Moderate
MD	Cambridge	Moderate
NJ	Barnegat Light	Moderate
NY	Bay Shore	Moderate
NY	Point Lookout	Moderate
DE	Bowers	Low
DE	Milford	Low
MD	Deale	Low
MD	Fairmount	Low
MD	Hoopers Island	Low
MD	Rock Hall	Low
NJ	Atlantic City	Low
NJ	Beach Haven	Low
NJ	Belmar/South Belmar	Low
NJ	Brick	Low
NJ	Eagleswood	Low
NJ	Harvey Cedars	Low
NJ	Margate City	Low
NJ	Ship Bottom	Low
NJ	Upper/Beeley's Point/Seaville/Strathmere	Low
NJ	Wildwood	Low
NJ	Wildwood Crest	Low
NY	Barnum Island	Low
NY	Greenport	Low
NY	New York/Manhattan	Low
NY	West Babylon	Low
VA	Chincoteague	Low
VA	District 2**	Low
VA	District 9	Low
VA	Poquoson	Low
VA	Virginia Beach	Low
VA	York/Gloucester Point	Low

* Including Arverne, Astoria, Bayside, Breezey Point, East Elmhurst, Flushing, Forest Hills, Fresh Meadows, Hollis, Howard Beach, Jackson Heights, Jamaica, Jamaica Bay-Rockaway, Maspeth, Queens Village, Rego Park, Rockaway Park.
** Including Assawoman, Atlantic, Greenbackville, Hallwood, Harborton, Horntown, Mappsville, Quinby, Sanford, Saxis, Tangier, Temperanceville.
Source: Colburn, et.al. (2016)

Appendix 5-D: Coastal Communities in the Mid-Atlantic Region Ranked by Fish Stock Vulnerability Index.

State	City	Vulnerability Index
NY	Montauk	3Mixed
NJ	Atlantic City	3High
NJ	Barnegat Light	3High
NJ	Cape May	3High
NJ	Point Pleasant	3High
VA	Grafton/Seaford	3High
VA	Newport News	3High
NJ	Belford	2Moderate
NJ	Belmar/South Belmar	2Moderate
NJ	Sea Isle City	2Moderate
NY	Brooklyn/Sheepshead Bay	2Moderate
NY	Freeport	2Moderate
NY	Mattituck	2Moderate
VA	Chincoteague	2Moderate
VA	Gloucester Courthouse	2Moderate
VA	Hampton	2Moderate
MD	Ocean City	2Mixed
NY	Hampton Bays/Shinnecock	2Mixed
NY	Islip	2Mixed
VA	Virginia Beach	2Mixed
NJ	Waretown	2Low
NY	Center Moriches	2Low
DE	Millsboro	2High
NJ	Avalon	2High
NJ	Brielle	2High
NJ	Wildwood	2High
NY	Mount Sinai	2High
NY	Point Lookout	2High
VA	Accomac	2High
VA	Cape Charles	2High
VA	Wachapreague	2High

Source: Colburn *et al*. (2016)

Appendix 5-E: Value of Commercial Fishery Landings (2016 dollars)

Note: These data are plotted in Figure 5-7a.

Year	New York	New Jersey	Pennsylvania	Delaware	Maryland	Virginia
1990	122,845,774	197,683,270	620,927	10,241,157	127,107,071	242,229,485
1991	117,380,134	210,270,983	707,791	10,156,978	104,294,512	210,546,552
1992	120,773,369	202,660,311	828,969	8,662,735	76,450,430	189,950,505
1993	128,217,151	199,324,140	357,953	11,061,553	111,883,047	241,244,558
1994	135,600,994	204,503,271	592,684	12,722,801	123,202,629	208,383,326
1995	153,309,086	181,965,988	951,344	17,164,009	118,695,510	222,908,231
1996	167,799,919	186,291,973	541,063	8,556,118	105,864,376	213,138,290
1997	161,949,805	183,257,869	20,710	9,607,301	118,298,444	185,832,066
1998	146,329,861	173,876,643	186,523	10,438,514	103,647,435	202,156,114
1999	128,344,978	167,930,291	73,797	11,669,816	107,987,311	185,760,073
2000	101,201,433	177,215,781	48,535	11,300,034	89,092,409	195,694,251
2001	94,752,289	189,290,848	75,547	13,152,287	95,448,454	205,381,483
2002	87,973,918	193,112,969	63,582	10,394,871	83,978,408	211,273,976
2003	86,641,404	202,414,616	65,980	8,729,438	82,257,574	219,166,438
2004	74,452,286	230,600,605	105,250	8,605,096	78,129,308	254,846,112
2005	83,030,636	233,626,158	57,489	8,995,859	93,826,247	228,178,886
2006	80,728,151	201,950,396	117,594	7,854,137	73,961,096	151,886,169
2007	81,404,957	204,424,842	171,183	10,701,059	88,145,346	186,399,092
2008	73,746,971	216,143,861	179,576	8,851,007	93,888,262	188,045,632
2009	63,832,850	197,864,398	178,080	9,848,402	99,093,366	198,488,555
2010	57,471,759	214,757,911	231,476	9,434,831	124,864,432	220,301,845
2011	55,132,014	251,027,400	227,611	8,078,846	94,050,502	220,954,457
2012	62,324,775	213,887,800	58,206	9,644,616	96,934,268	198,877,567
2013	62,297,071	145,373,793	134,623	8,120,535	83,004,823	178,382,083
2014	57,291,644	151,708,574	85,300	7,336,347	92,519,291	175,679,583
2015	52,375,226	169,071,319	118,834	6,964,971	90,383,909	203,971,998
2016	47,868,711	193,011,221	125,352	10,096,590	94,813,885	204,689,580

Source: NOAA Fisheries (https://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/annual-landings/index)

Appendix 5-F: Quantity of Commercial Fishery Landings (Pounds)

Year	New York	New Jersey	Pennsylvania	Delaware	Maryland	Virginia
1990	46,301,786	149,319,180	291,000	9,426,800	86,010,835	792,047,535
1991	51,389,491	175,765,255	315,000	9,376,162	87,981,356	681,090,387
1992	52,937,020	204,400,243	485,000	6,648,205	57,085,372	631,196,771
1993	59,511,465	196,105,456	230,000	8,309,932	84,969,391	733,212,543
1994	56,102,407	201,984,518	371,000	8,230,254	69,825,363	592,462,562
1995	57,826,760	176,730,164	506,000	10,290,894	71,236,213	779,908,258
1996	60,448,310	182,638,371	311,000	5,740,059	70,507,675	665,428,821
1997	60,050,399	174,856,553	12,639	9,084,553	76,599,482	584,895,288
1998	56,502,690	197,142,766	373,054	7,866,451	61,478,596	592,732,479
1999	49,491,223	168,644,244	32,305	8,372,220	66,419,430	460,254,105
2000	44,750,587	171,803,245	19,723	6,740,645	48,913,274	443,197,385
2001	42,459,104	168,540,752	25,000	7,140,238	55,539,093	561,792,162
2002	38,595,412	162,138,648	15,295	5,857,268	53,184,660	442,489,524
2003	39,431,047	170,132,827	21,365	5,017,922	49,349,923	446,827,713
2004	34,519,737	187,376,581	46,133	4,287,586	49,509,038	481,367,112
2005	38,193,212	156,695,414	17,696	4,851,042	67,489,329	441,526,601
2006	33,301,874	175,776,571	35,541	4,380,402	51,211,845	426,228,788
2007	35,799,298	153,848,231	46,445	5,346,208	61,585,365	493,414,618
2008	34,219,862	162,307,672	49,833	4,706,100	63,533,675	423,065,595
2009	34,331,124	162,028,868	48,671	5,010,744	66,818,699	426,797,509
2010	33,322,845	162,163,519	67,177	5,214,109	101,738,756	510,473,685
2011	32,068,377	187,538,501	63,798	4,920,702	76,257,593	496,628,643
2012	35,961,857	180,504,715	15,432	5,639,863	75,415,941	462,503,430
2013	33,446,356	119,912,104	37,190	4,048,202	43,373,891	381,606,848
2014	27,416,155	125,114,378	24,813	3,726,750	49,921,611	389,210,992
2015	27,060,549	148,418,823	34,577	3,528,647	54,247,666	417,486,725
2016	29,214,088	123,565,091	104,580	4,979,536	56,316,330	383,522,637

Source: NOAA Fisheries (https://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/annual-landings/index)

Note: This data is plotted in Figure 5-7b.

References to Chapter 5

Arnason, R. 2007. Climate change and fisheries: assessing the economic impact in Iceland and Greenland. *Natural Resource Modeling* 20:163–197.

Carter, D.W. and D. Letson. 2009. Structural Vector Error Correction Modeling of Integrated Sport Fishery Data. *Marine Resource Economics* 24(1):19-41.

Cinner, J.E., T.R. McClanahan, N.A.J. Graham, T.M. Daw, J. Maina, S.M. Stead, A. Wamukota, K. Brown, O¨ . Bodin. 2012. Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. *Global Environmental Change*, 22(1):12-20.

Colburn, L.L and M. Jepson. 2012. Social indicators of gentrification pressure in fishing communities: a context for social impact assessment. *Coastal Management* 40:289–300.

Colburn, L. L., M. Jepson, C. Weng, T. Seara, J. Weiss, and J. A. Hare. 2016. Indicators of climate change and social vulnerability in fishing dependent communities along the Eastern and Gulf Coasts of the United States. *Mar. Policy*. doi:10.1016/j.marpol.2016.04.030

Cooley, S.R and S.C. Doney. 2009. Anticipating ocean acidification's economic consequences for commercial fisheries. *Environmental Research Letters* 4 (2009) 024007 (8pp) doi:10.1088/1748-9326/4/2/024007.

Cooley, S. R., J. E. Rheuban, D. R. Hart, V. Luu, D. M. Glover, J. A. Hare, and S. C. Doney. 2015. An Integrated Assessment Model for Helping the United States Sea Scallop (Placopecten magellanicus) Fishery Plan Ahead for Ocean Acidification and Warming. *PLOS ONE* 10: e0124145. doi:10.1371/journal.pone.0124145.

Dyer, C.L. and, J. J. Poggie. 2000. The natural resource region and marine policy: a case study from the New England groundfish fishery. *Marine Policy* 24(3):245–255.

Felthoven, R.G., Paul, C. J. M. and Torres, M. 2009. Measuring Productivity and Its Components for Fisheries: The Case of the Alaskan Pollock Fishery, 1994-2003. *Natural Resource Modeling* 22(1):105-136.

Fogarty, M.J., L. Incze, K. Hayhoe, D.G. Mountain and J. Manning. 2008. Potential climate change impacts on Atlantic cod (*Gadus morhua*) off the northeastern USA. *Mitigation and Adaptation Strategies for Global Change* 13:453–466.

Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser and D.J. Wuebbles. 2007. Confronting climate change in the U.S. northeast: science, impacts, and solutions. *Synthesis report of the Northeast Climate Impacts Assessment (NECIA)*. Cambridge, MA: Union of Concerned Scientists (UCS).

Grafton, R.Q. 2010. Adaptation to climate change in marine capture fisheries. *Marine Policy* 34:606–615.

Hannesson, R. 2007. Introduction to Special Issue: Economic Effects of Climate Change on Fisheries. *Natural Resource Modeling* 20(2):157-62.

Hare, J.A. and K.W. Able. 2007. Mechanistic links between climate and fisheries along the east coast of the United States: explaining population outbursts of Atlantic croaker (*Micropogonias undulatus*). *Fisheries Oceanography* 16:31–45.

Hare, J.A., M.A. Alexander, M.J. Fogarty, E.H. Williams and J.D. Scott. 2010. Forecasting the dynamics of a coastal fishery species using a coupled climate– population model. *Ecological Applications* **20**, 452–464.

Hare J.A., W.E. Morrison, M.W. Nelson, M.M. Stachura, E.J. Teeters, R.B. Griffis, M.A. Alexander, J.D. Scott, L. Alade, R.J. Bell, A.S. Chute, K.L. Curti, T.H. Curtis, D. Kircheis, J.F. Kocik, S.M. Lucey, C.T. McCandless, L.M. Milke, D.E. Richardson, E. Robillard, H.J. Walsh, M.C. McManus, K.E Marancik and C.A. Griswold. 2016. A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf. *PLOS ONE* 11(2): e0146756. doi:10.1371/journal.pone.0146756.

Heller, N.E. and E.S. Zavaleta. 2009. Biodiversity management in the face of climate change: A review of 22 years of recommendations. *Biological Conservation* 142:14-32.

Howard, J., E. Babij, R. Griffis, B. Helmuth, A. Himes-Cornell, P. Niemier, M. Orbach, L. Petes, et al. 2013. Oceans and marine resources in a changing climate. *Oceanography and Marine Biology: An Annual Review* 51:71-192.

Jepson, Michael and Lisa L. Colburn 2013. Development of Social Indicators of Fishing Community Vulnerability and Resilience in the U.S. Southeast and Northeast Regions. U.S. Dept. of Commerce., NOAA Technical Memorandum NMFS-F/SPO-129, 64 p.

Jin, D, G. DePiper and P. Hoagland. 2016a. Applying portfolio management to implement ecosystem-based fishery management. *North American Journal of Fisheries Management* 36(3):652-669.

Kaje, J.H. and D.D. Huppert. 2007. The Value of Short-Run Climate Forecasts in Managing the Coastal Coho Salmon (Oncorhynchus Kisutch) Fishery in Washington State. *Natural Resource Modeling* 20(2):321-349.

Link, J.S., J.A. Nye and J.A. Hare. 2011. Guidelines for incorporating fish distribution shifts into a fisheries management context. *Fish and Fisheries* 12, 461–469.

Loomis, J. and J. Crespi. 1999. Estimated Effects of Climate Change on Selected Outdoor Recreation Activities in the United States. In R. Mendelsohn and J.E. Neumann Eds. *The Impact of Climate Change on the United States Economy*, pp. 289-314. New York: Cambridge University Press.

Markowski, M., A. Knapp, J.E. Neumann and J. Gates. 1999. The Economic Impact of Climate Change on the US Commercial Fishing Industry. In R. Mendelsohn and J.E. Neumann Eds. *The Impact of Climate Change on the United States Economy*, pp. 237-264. New York: Cambridge University Press.

McCay, B.J., S. Brandt and C.F. Creed. 2011. Human dimensions of climate change and fisheries in a coupled system: the Atlantic surf clam case. *ICES Journal of Marine Science* **68**,1354.

Mendelsohn, R. and M. Markowski. 1999. The Impact of Climate Change on Outdoor Recreation. In R. Mendelsohn and J.E. Neumann Eds. *The Impact of Climate Change on the United States Economy*, pp. 267-288. New York: Cambridge University Press.

Mendelsohn, R. and J.E. Neuman. 1999. *The Impact of Climate Change on the United States Econom*. New York: Cambridge University Press.

Merino, G., M. Barange, and C. Mullon. 2010. Climate variability and change scenarios for a marine commodity: Modelling small pelagic fish, fisheries and fishmeal in a globalized market. *Journal of Marine Systems* 81:196–205.

Norman-Lopez, A., S. Pascoe and A. Hobday. 2011. Potential Economic Impacts of Climate Change on Australian Fisheries and the Need for Adaptive Management. *Climate Change Economics* 2(3):209-235.

Ounanian, K. 2015. Wither the waterfront: does the United States need federal legislation to preserve working waterfronts? *Coastal Management* 43(6):668-684.

Pendleton, L.H. and R. Mendelsohn. 1998. Estimating the Economic Impact of Climate Change on the Freshwater Sportsfisheries of the Northeastern U.S. *Land Economics* 74(4):483-96.

Robinson, S. & the Gloucester Community Panel. 2005. Commercial fishing industry needs on Gloucester Harbor, now and in the future. Community Panels Project. http://seagrant.mit.edu/cmss/comm_mtgs/commmtgs.html.

Seung, C., M. Dalton, A. Punt, D. Poljak, and R. Foy. 2015. Economic Impacts of Changes in an Alaska Crab Fishery from Ocean Acidification. *Climate Change Economics* 6(4): 1550017 (35 pages). http://dx.doi.org/10.1142/S2010007815500177.

Seung, C. and J. Ianelli. 2016. Regional economic impacts of climate change: a computable general equilibrium analysis for an Alaska fishery. *Natural Resource Modeling* 29(2):289–333.

Smythe, T.C. 2015. Can coastal management programs protect and promote water-dependent uses? *Coastal Management* 38(6):665-680.

Sumaila, U.R., W. Cheung, V.W.Y. Lam, D. Pauly and S. Herrick. 2011. Climate change impacts on the biophysics and economics of world fisheries. *Nature Climate Change* 1:449–456.

Torio, D.D. and G.L. Chmura. 2015. Impacts of sea level rise on marsh as fish habitat. *Estuaries and Coasts* 38(4):1288-1303. https://doi.org/10.1007/s12237-013-9740-y.

Chapter 6 : Ecosystem Services

Summary

The importance of coastal and ocean ecosystem services (ESs) is well recognized in the Mid-Atlantic region, and, in this chapter, we characterize the solid foundation for economic valuation of these services. Prominent trends in the region's human activities include prospects for developing renewable energy areas (wind farms), accommodating larger vessels in the region's ports through channel deepening, and increases in coastal recreation, tourism, and habitation. Climate changes and other more direct human activities now pose risks to the continued realization of other services at their historic levels or to their future growth, however. These risks involve rising sea levels, flooding and erosion, warmer oceanic and estuarine waters, ongoing degradations of coastal waters due to nitrogen and phosphorous releases, and, in the longer term, decreasing oceanic acid and carbonate levels.

Fortunately, direct human uses and economic values for many of the region's coastal and ocean ecosystem services (which we refer to in this chapter as socio-economic *ecosystem endpoints*) are either not exposed or insensitive to the effects of climate change. Unfortunately, a few highly valued ecosystem endpoints are much more vulnerable. The latter include commercial and recreational fishing, wildlife viewing (birding and whale-watching), and the cultural and regulating services arising from so-called natural and nature-based features, such as salt marshes, sea grass beds, and intertidal lands, including oyster reefs. While much uncertainty exists about the geographic scales and timing of impacts to the ecosystem services of the region, it will be important for its communities to address these vulnerabilities on several fronts.

Increases in scientific research, environmental monitoring, and ecosystem service valuations are warranted and prudent. Further characterizations of the spatial distributions of services, human uses, and especially the economic values arising from those uses would be especially useful in assessing the extent of potential vulnerabilities and characterizing appropriate management responses. Primary valuation studies undertaken to evaluate explicit service tradeoffs, such as those that have already been undertaken for the Chesapeake, Delaware, and Peconic estuaries, would help inform decisions that could enhance resilience, adaptation, and sustainability.

Particular attention should be directed at maintaining or restoring the region's natural and nature-based shoreline features, especially the extensive salt marsh wetlands of the Chesapeake and Delaware estuaries. As evidenced by very large cultural ecosystem services values measured recently for the Delaware wetlands, the significant property value protections from flood and erosion afforded by natural and nature-based shoreline features, and the large—and poorly recognized—carbon sequestration capabilities of salt marshes, these environments present clear priorities for further protection and restoration. Further assessments of the relevant economic tradeoffs comprising living shoreline compression (or "coastal squeeze"), resulting from the combined effects of human coastal developments and sea-level rise, will be critical in this respect.

Introduction

All natural resources, wherever they are found, comprise physical features of the Earth that have economic value when they are in short supply. The supply status of natural resources can be the result of natural occurrences or affected by human degradation or restoration, new scientific insights or technological advances, or regulation. The economic value of natural resources can expand or contract with varying environmental conditions, such as those associated with climate change, shifting human uses and preferences, and purposeful investments, depletions, or depreciation.

It is important to characterize the physical flows of goods and services from coastal and ocean resources, referred to as "ecosystem" (or sometimes "environmental") services. Where competing uses of resources are potentially mutually exclusive in specific locations or over time, it is also helpful to be able to assess—through explicit tradeoffs—the economic values of ecosystem service flows that may be gained or lost when one or more uses are assigned or gain preferential treatment over others (such as the siting of wind generators in areas where merchant shipping traverses or where commercial fishing takes place). The values of ecosystem service flows can arise through direct, indirect, or passive uses of natural resources, in markets or as public goods, and a variety of methodologies have been developed to measure and estimate these values (Champ *et al*. 2003; Lipton et al 2014; Johnston *et al*. 2015). Often the economic values of ecosystem service flows are underestimated or even ignored, and the resulting implicit subsidies may lead to the overuse or excessive degradation of the relevant resources or even the broader environment.

In this chapter, we examine the climate-associated risks for the valued ecosystem services arising from the human use of the natural resources located on the coasts and in the ocean of the US Mid-Atlantic region. We concentrate on coastal and ocean resources from Long Island, NY to Hampton Roads, VA, representing the southern section of the Northeast Shelf Large Marine Ecosystem.[13] The Mid-Atlantic is the most densely populated region along the US East Coast, and its coastal and ocean resources are used intensively.

We present a qualitative discussion of the potential vulnerabilities of ecosystem service flows to prospective climate changes, including the consequences of increases in ocean temperatures, changes in ocean chemistry, and increases in sea-level rise. We include attention also to other pressures, including anthropogenic releases of macronutrients, such as nitrogen compounds, and growing densities of human populations in coastal environments. Although they are important influences on natural resources, even in the absence of climate change, these latter phenomena may interact with climate changes in ways that could further affect ES flows adversely.

This assessment focuses on ecosystem service "endpoints" linked to specific human uses (or non-uses) of the Mid-Atlantic's coast and ocean (Boyd and Banzhaf 2006; Lipton *et al* 2014) Here ecosystem service endpoints refer to environmental goods or services that are used or appreciated directly by humans, including ocean space (wind farms or shipping lanes), fish stocks, beaches, fauns (birds and mammals), aesthetic viewscapes, among many others. In this sense, ecosystem service endpoints are outputs of ecological processes that make an actual or a potential contribution to human welfare (Munns et al. 2016). The use of the term endpoint in this context should be distinguished from its application in ecological risk assessments, where the conventional use of the term "ecological assessment endpoint" refers to a description of environmental values (or, more generally, particular ecosystem states) to be protected from exposure to stressors, such as those that result from resource exploitation, natural hazards, or environmental changes.[14] Table 6-1 presents some of the most important endpoints, indicating the relevant resources, the existence

---

[13] We discuss ecosystem service valuation studies for the important major estuaries of the Mid-Atlantic region, including the Peconic, Long Island Sound, the New York-New Jersey harbor and estuary, Delaware Bay and River, and Chesapeake Bay. Much of the attention has focused on potential or actual changes to ecosystem services in nearshore estuarine environments.

[14] Often these environmental values are identified explicitly in environmental laws, but they may have only an indirect or uncertain contribution to human welfare. Munns et al. (2016) argue that the two uses of "endpoint" can be viewed as complementary, and they discuss distinctions and overlaps between the two.

of estimates and sources of ES values, qualitative assessments of the extent to which those estimates provide coverage of ES values for the region, and discussions of some of the gaps in valuation.

Endpoints	**Valued Resource**	**ES Values**	**Sources**	**Est. % Coverage**	**Gaps**
Navigation	Ocean area; channels; anchorages; ports	Yes	AIS data on shipping routes; avoided costs of route changes	?	Valuation is limited to specific routing change scenarios
Pipelines and cables	Seabed area	--	State submerged lands license fees	?	Largely unexplored
Coastal tourism (beach visits, boating)	Sandy beaches, ocean area	Yes	New Jersey valuation studies of WTP for beach use	?	Limited number of older use and valuation studies
Flood and erosion control	Salt marsh; dunes; physical structures	Yes	Models of value of coastal property protection with hard structures and natural and nature-based features	~100%	Effects of sea-level rise on value of natural and nature-based features; threshold effects
Recreational fishing	Fish stocks	Yes	NMFS MRIP use data; NMFS head boat data; compilations of nonmarket estimates	~100%	Spatial distribution of activity
Commercial fishing	Fish stocks	Yes	NMFS ex-vessel landings and value; VCR data and cost models	~100%	Estimate is for resource rents only; few consumer surplus estimates
Marine wildlife viewing	Birds, marine mammals	Yes	Delaware birdwatching studies	~25%	Few studies; bird-watching is important; whale-watching exists but is small in scale
Sand and gravel production	Aggregate materials	--	BOEM negotiated agreements with states to “donate” OCS materials for beach nourishment; some local dredge and fill activities	0%	Value of unpriced sand and gravel resource

Endpoints	**Valued Resource**	**ES Values**	**Sources**	**Est. % Coverage**	**Gaps**
Carbon sequestration	Salt marsh	Yes	Carbon price and sequestration potential of alternative environmental features (salt marshes, seabeds, etc.)	~25%	Sequestration estimates exist for salt marshes; sequestration potentials of other coastal and ocean areas are uncertain
Nitrogen Phosphorous Assimilation	Salt marsh, ocean and seabed	--	Valuation studies of WTP for improved water quality; avoided costs of sewer or water treatments	~50%	Some estuarine environments (e.g., Hudson, Passaic, Raritan, inland waterways) are not covered
Aquaculture	Ocean and seabed area	Yes	State estimates; NMFS commercial fishing data; USDA shellfish surveys (last in 2009); some DCF models exist	~100%	USDA surveys of nearshore shellfish growing are infrequent
Underwater cultural resources	Archaeological or historical artifacts	--	State historic preservation offices for some location data; geographic distribution data are low-resolution	0%	Few non-market values; may be incorporated into recreational boating estimates
Renewable energy	Ocean and seabed area	Yes	Lease bonuses	100%	Leasing, but no actual developments to date
Ocean science	Ocean and seabed area	--	MARACOOS; NSF; NOAA; university oceanographic laboratories	0%	no valuation estimates

Table 6-1 Mid-Atlantic region ecosystem service (ES) endpoints, sources of value estimates, percent coverage, and gaps

Following the typology developed through the United Nations' Millennium Ecosystem Assessment (Figure 6-1), we focus on provisioning, regulating, and cultural ecosystem services. In this study, we do not consider values explicitly for "supporting" services, or ecosystem "inputs," such as, for example, salt marshes, sea grass beds, or intertidal waters in their specific role as habitat for juvenile fish species. While we recognize that such values could be imputed from the economic values of the supported ecosystem service endpoints, accounting for these values could lead to double counting (*cf*., Freeman 2010). For example, a salt marsh may provide other types of services for which double counting would not occur, such as for flood protection, recreation, macronutrient assimilation, or carbon sequestration.

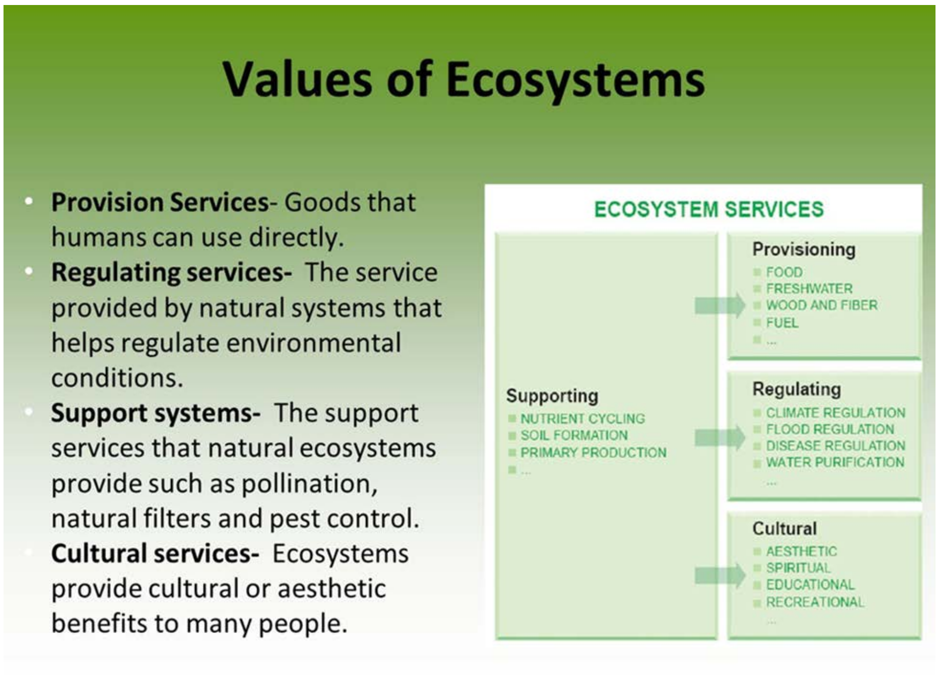


Figure 6-1 Millennium ecosystem services framework.

Table 6-2 presents a qualitative assessment of trends for ES endpoints in the Mid-Atlantic region. Salient and publicly conspicuous recent developments include the impacts and recovery from Hurricane Sandy in 2012, the dredging of ship channels to 45-50 feet, especially in the Delaware River and New York Harbor, deepening the entrances into the major ports, and the leasing of outer Continental Shelf lands for renewable energy (wind power) off New York, Delaware, Maryland, and Virginia.

In the Mid-Atlantic region, there is a long record, dating back more than 30 years, of economic valuation studies focused on ecosystem service endpoints that are not traded in markets and thus require special methods to estimate their values. These include studies of saltwater recreational fishing, beach uses, water quality improvements, wildlife viewing (bird watching), and the total economic values of estuaries and associated upland watersheds. Some of the most important of these studies are listed in the table in Appendix 6-A. In that table, valuation estimates are expressed in 2017 dollars to assure comparability in demonstrating the diversity of estimate types and to provide a sense of the magnitudes of economic values. Many of these studies comprise not only assessments of specific ES values per se but also involve analyses of tradeoffs where human uses of coastal and ocean resources overlap or conflict. ES values from these and other studies have been compiled in various online databases (e.g., de Groot et al. 2012) or other comparative studies (e.g., Pendleton 2008), including, most recently, the US Geological Survey's "Benefits Transfer Toolkit" (USGS 2017).

Endpoints	**Trends**
Navigation	Region's channel deepening projects now complete; larger tankers and container ships
Pipelines and cables	No apparent trend
Coastal tourism (beach visits, boating)	Increasing with increased coastal populations
Flood and erosion control	Increased need for living shorelines, hard structures due to sea-level rise, storms
Recreational fishing	Cyclical; currently in a trough
Commercial fishing	Cyclical; currently trending down
Marine wildlife viewing	Increasing with increased coastal populations
Sand and gravel production	Expect increased activity due to need for beach replenishment
Carbon sequestration	Declining with the loss of wetlands due to sea-level rise and increased development
Nitrogen & Phosphorous-assimilation	Loss of wetlands implies lower assimilation capacity
Aquaculture	Possible small upward trend in shellfish growing
Underwater cultural resources	No apparent trend
Renewable energy	Expect leased areas to begin to be developed over the next decade
Ocean science	Increased need for OOS; expansion depends upon public sponsorship

Table 6-2 Mid-Atlantic region ecosystem service endpoints and trends.

In such compilations, these values tend to be reported as or recalibrated into estimates of willingness-to-pay (WTP or consumer surpluses) per person per day. Table 6-3 presents Mid-Atlantic regional average use value estimates for some marine recreational endpoints as reported in the USGS benefits transfer database.

For purposes of coastal and ocean planning, however, it is valuable to know the spatial distributions of the underlying resources from which ecosystem services flow, the spatial patterns of human uses of the resources, and the spatial configurations of ecosystem service values that arise from these human uses. A relevant question for policy choices concerns the marginal changes in welfare at certain locations and times that could result from small changes in the patterns of human uses or activities. With the advent of geographic information system (GIS) mapping, the spatial distributions of resources and human uses have been fairly well resolved in the Mid-Atlantic region (MARCO 2017). Less clear are the scales and spatial distributions of economic values associated with the region's ecosystem services arising from those resources and uses.

	Willingness to Pay Per Person Per Day	
	Northeast*	Southeast**
Beach Use	$36	$77
Boating (motorized)	$101	$23
Boating (non-motorized)	$18	$87
Fishing (saltwater)	$63	$118
Swimming	$28	$14
Wildlife Viewing	$63	$62

Table 6-3 Estimates of values for recreational ecosystem service values.

In many cases, it is necessary to transfer benefits from other locations and contexts in order to estimate values when no other information is available. Two relevant examples from the region include the work of Costanza et al. (2006) and Liu et al. (2010) for ecosystem services in New Jersey, including coastal and estuarine services, and Kocian et al. (2016) for the ecosystem services and natural capital of Long Island Sound and its associated upland watershed. (Notably the latter study relies significantly upon the earlier work of Opaluch *et al*. (1999) and Johnston *et al*. (2002) concerning the valuation of resource services in the Peconic Estuary, located at the eastern end of Long Island.)

Benefit transfer efforts are an important initial step, but spatially identified estimates of ES values relying upon "secondary" data sometimes show widely divergent values when compared with the results of "primary" surveys, data collections, and analysis. Figure 6-2, for example, reveals very different average estimates of total economic value from the benefit transfer studies cited above when compared to a recent study of the non-market value of tidal marshes in the Delaware estuary, the latter comprising mainly cultural ES values such as the various recreational activities in or near these wetlands (Santoni *et al*. 2017 Kocian *et al*. (2016); Costanza *et al*. (2006); DNREC (2017). (Note that the two studies from New York [Kocian et al. 2016] and New Jersey [Costanza et al. 2006] are the only examples from the Mid-Atlantic region of comprehensive studies compiling secondary data on a broad variety of ES values.)

A fuller understanding of ecosystem service values in the Mid-Atlantic can help regional planners assess tradeoffs among human uses (or non-uses) that may be incompatible. Here, we characterize extant estimates with very preliminary suggestions for how such estimates eventually might be used by planners. In practice, the separation of estimates and applications may be challenging to carry out, as many planning exercises need to consider not only the identity of relevant gainers and losers but also the nature of dynamic linkages among ecosystems and these stakeholders (Johnston and Russell 2011). Thus, a central recommendation for regional ocean planning is to identify the relevant ES endpoints that may be at risk to natural phenomena or human actions, followed by focused assessments of the economic gains or losses that would result should those risks become real hazards.

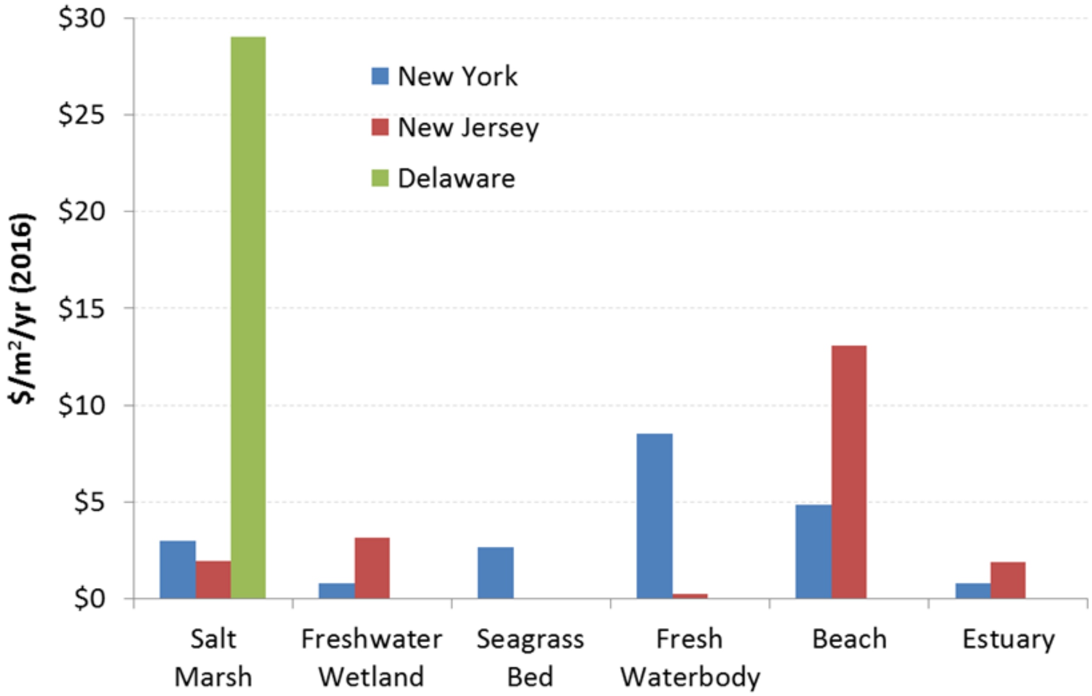


Figure 6-2 Average total economic values for coastal resource categories ($/m2/year).

<u>Climate Change Risks</u>

In the Mid-Atlantic region, fundamental environmental pressures relate to the effects of climate change, macronutrient releases, and human population increases near the coast. Specifically, increases in global atmospheric CO_2 concentrations are linked to warmer coastal water temperatures, increases in relative sea levels, retreating shorelines, probable increased tropical cyclone severities, and, in the longer term, a more acidic ocean with lower carbonate levels. Releases of nitrogen compounds from coastal runoffs, including agriculture and septic systems, municipal wastewater treatment plants and combined sewer overflows, and atmospheric deposition are causing higher levels of coastal primary production, thereby increasing the frequency of localized hypoxic or anoxic events, and degrading estuarine and ocean habitats, including seagrass beds and wetlands. Finally, the redistribution of human populations along the coast has led to an expansion of residential developments, encroachments on wetland habitats, and higher risks to public health and property from flooding and erosion, especially during extreme high tides and storm surges.

In order to begin to understand the potential risks to ecosystem service endpoints, Figure 6-3 depicts a qualitative representation of their exposures and sensitivities to climate change. This representation adapts the qualitative vulnerability assessment developed by NMFS for the fisheries of the northeast shelf (Hare *et al*. 2016), which has been used by the Mid-Atlantic Fishery Management Council in its ecosystem approach to fisheries management. Figure 6-3 characterizes the relationship between climate change effects on and the climate sensitivity of Mid-Atlantic ecosystem service endpoints. Though 2030, most of the endpoints are expected to experience low exposures, and they will be insensitive to the effects of climate change, appearing in the dark green squares in the lower left. In contrast, some endpoints, including commercial and recreational fishing and wildlife viewing (perhaps limited to only a subset of species in each case), may be more exposed and more sensitive, appearing in the dark red square in the upper right. Other endpoints fall somewhere in between.

Here we present three examples of Mid-Atlantic region ecosystem service endpoints that appear to be most at risk to climate changes, including the services that flow from active (and passive) uses of living shorelines, commercial fisheries, and recreational fisheries.

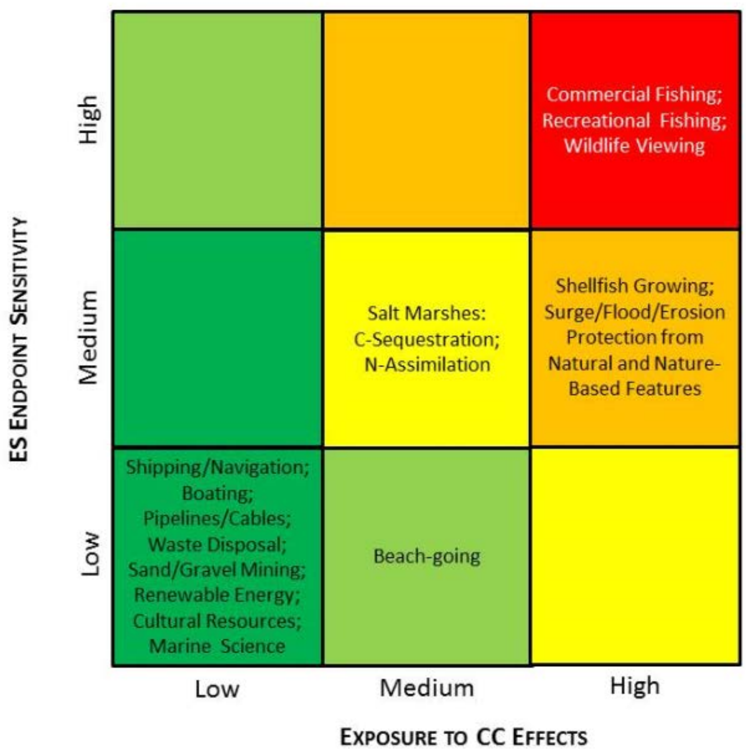


Figure 6-3 Qualitative assessment of Mid-Atlantic region ecosystem service endpoint exposures and sensitivities to climate change.

An example with high exposure to climate change effects and medium sensitivity concerns the case of the so-called natural and nature-based features, such as salt marshes, which provide protection from flooding and erosion due to extreme high tides ("king tides"), waves and overwashes and storm surges from tropical and extra-tropical cyclones, such as hurricanes and northeast storms (or nor'easters). Marshes and similar natural features face risks from both rising sea levels and encroaching human developments. In particular, the latter imply that wetlands may be unable to migrate inland with rising seas. The status of the physical natural capital is tracked at local and state levels by the relevant natural resource or conservation agencies (e.g., EPA 2012).

At the federal level, the status and trends of wetlands in coastal watersheds is assessed every five years, but the most recent assessment covers a period (2004-09) from nearly a decade in the past (Dahl and Stedman 2013). Economic assessments of wetland services historically have focused mainly on Chesapeake Bay wetlands (see the relevant references in the table in Appendix 6-A), but more recently both primary studies and benefit transfers have been undertaken for these services in the Delaware Bay (Carr *et al*. 2017; Santoni *et al*. 2017); for the New Jersey coast (Costanza *et al*. 2006; Liu *et al*. 2010); in Jamaica Bay (Meixler 2017); and in Long Island Sound (Kocian et al. 2016).

For Jamaica Bay, New York, Meixler (2017) undertook an analysis involving benefits transfers to assess the impacts of Hurricane Sandy on the bay's wetlands. The author examined before-and-after aerial photos of coastal landscapes, finding that beach erosion was the most damaging consequence of the storm and that only moderate flooding and sand deposition had occurred. To evaluate the scale of economic losses, the author transferred the ES values compiled for New Jersey by Costanza *et al.* (2006). Although almost two-thirds of the storm's damages in Jamaica Bay were expected to be reversed within five years, Meixler estimated that up to $6.5 million in economic damages occurred as a consequence mostly of the reduced storm protection service provided by beaches. This spatial quantification of ecosystem services also provided a way of prioritizing locations for potential gains as a consequence of restoration and enhanced protection.

The restoration of oyster reefs is a "living shoreline" type of response option to the sea-level rise resulting from climate change, and Grabowski *et al*. (2012) found that the economically most valuable ecosystem service provided by oyster reefs is shoreline protection. Only a small number of studies have developed quantitative estimates of the economic benefits from oyster restoration, however (Hicks *et al*. 2004; Kasperski and Wieland 2010; Grabowski *et al*. 2012; DePiper et al. 2017).

In recent work, Narayan *et al*. (2016) found reduced coastal property damages in the Mid-Atlantic region on the order of $0.6 billion due to the presence of natural and nature-based features during Hurricane Sandy. Across the entire US Northeast, the authors estimated an average of 10% reduction in losses. In Ocean County, NJ, using data on flooding from 2,000 historical storms dating back a century, the authors estimated an average of a 20% reduction in losses.[15] The potential ongoing erosion of these natural protective features implies much larger damages due to flooding and erosion from storm surges and extreme high tides.

Commercial and recreational fisheries represent two Mid-Atlantic region ES endpoints that constitute both high exposure to and high risk from climate changes. In the near term, these risks relate to increasing ocean temperatures, which have been documented already, and, in the longer term, to lower pH and carbonate levels, expected to occur before the turn of the next century. Chapter 5 of this report discusses some of the distributional impacts of climate change risks to commercial fisheries across the Mid-Atlantic region's coastal communities.

Figure 6-4 depicts the landings and ex-vessel value (gross revenues) from commercial fishing in the Mid-Atlantic region (panel a) and associated ex vessel value of landings (panel b) during 1950-2015. Values are gross revenues; the distribution shows the mean (solid red line) and one standard deviation (dashed red lines) above and below the mean. (NMFS 2017) Historically, ~$0.5 ± $0.07 billion in revenues have been realized annually from all commercial fisheries taken together, although the mix of species landed has varied. These landings have been downward trending since the mid-1990s. Using rules of thumb for estimating resource rents (gross revenues net of the costs of fishing or "producer surpluses") in the Northeast fisheries, and based upon this record, we can expect rents in the future of ~$0.2-0.3 billion annually, implying an asset value of ~$7-10 billion[16] for the Mid-Atlantic.

Commercial fish stocks of importance to the Mid-Atlantic region include sea scallops, surf clams/ocean quahogs, weakfish, black sea bass, squids, scup, and filter feeders (menhaden).

---

[15] Annual flood control values would depend upon return intervals for storms (*e.g*., the risks of Sandy-type flood recurrence). Sweet *et al*. (2012) found that return intervals for Sandy-type floods were significantly shortened by sea-level rise.

[16] The asset value is the present value of the stream of resource rents in perpetuity discounted at 3%.

Important nearshore fisheries include those for striped bass, summer flounder, and blue crab. The regional Mid-Atlantic Fishery Management Council now is debating the details of a prospective ecosystem “approach” to fisheries management in order to consider the effects of harvests on the larger ecosystem. Allocations of the pelagic filter feeders, especially menhaden, have been a central focus of implementing the Mid-Atlantic’s ecosystem approach. Ocean temperature increases are an imminent concern, as they imply a northward migration for some commercial species and habitat changes—with uncertain biomass implications—for others.

From an economic standpoint, recreational fisheries are much more important to the region than commercial fisheries, and several early, and seminal, ES valuation studies have focused on the welfare benefits of improvements to coastal water quality, much of which depended upon the economic value of recreational fishing (Kahn and Kemp 1985; Bockstael *et al*. 1990; McConnell et al. 1994). Figure 6-7 depicts participation (panel a) and total estimates of what people are willing to pay (panel b) for saltwater recreational fisheries in the Mid-Atlantic region (Pendleton (2008); MRIP 2017). Historically, ~\$1.2 ± 0.5 billion in consumer surpluses have been realized annually, which is 3-4 times larger than the estimate—reported above—of the region’s commercial fishery rents. Saltwater recreational fishing activity appears cyclical and currently is in a trough. New York and New Jersey record the highest recreational fishing activity days. The charter/party business (headboats) also is important, but its level of activity has not been shown in Figure 6-7. Saltwater anglers target striped bass, bluefish, summer flounder, weakfish, and tautog, and the higher end anglers target offshore stocks of bluefin tuna, billfish, and sharks. As is the case with commercial fishing, ocean temperature changes are an imminent concern.

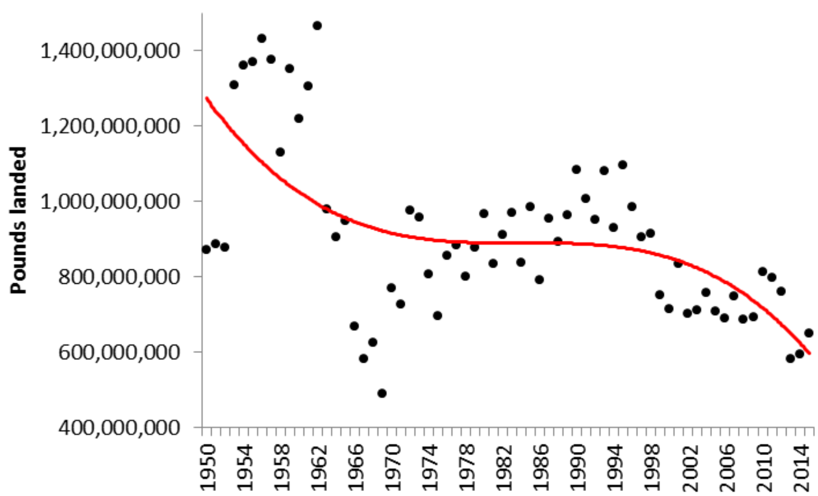


Figure 6-4 Mean and standard deviation of historical pattern of gross revenues from Mid-Atlantic region of commercial fish landings.

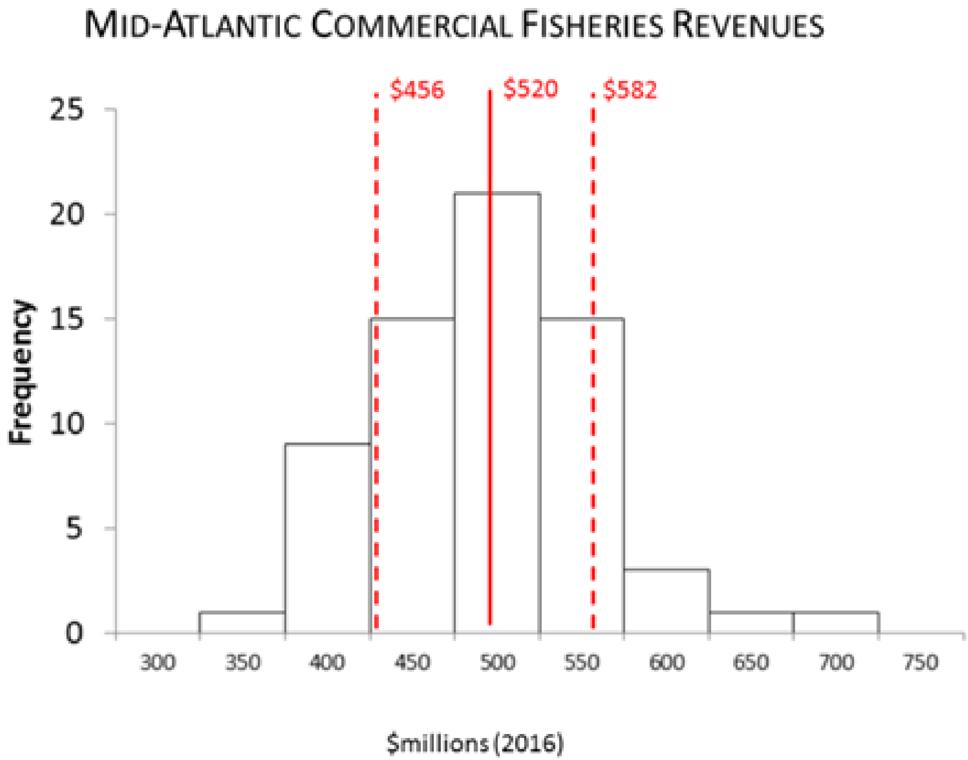


Figure 6-5 Ex-vessel value of Mid-Atlantic region commercial fish landings: 1950-2015.

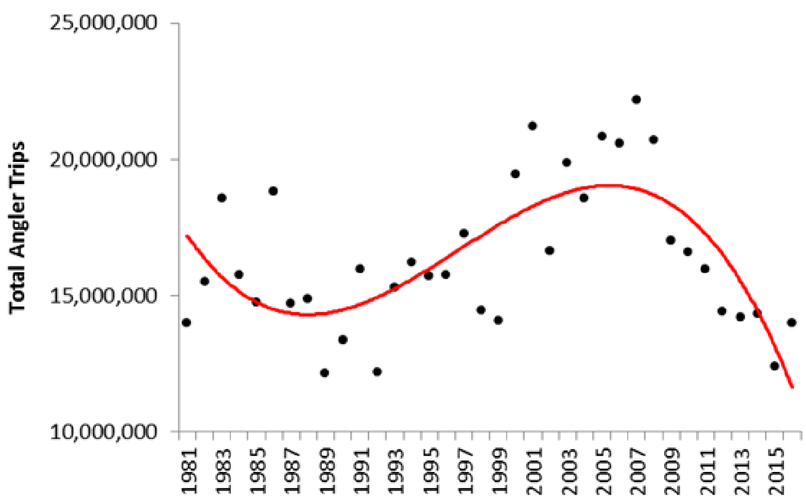


Figure 6-6 Historical pattern of participation in marine recreational fishing.
Source: MRIP (2017)

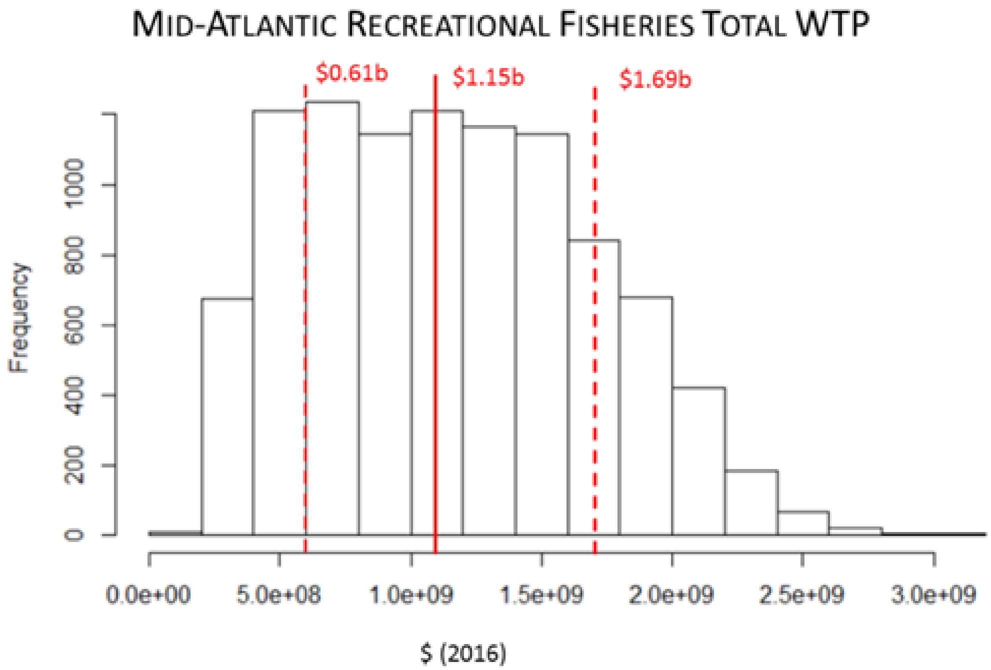


Figure 6-7 Estimated total willingness-to-pay (WTP) for recreational fisheries in the Mid-Atlantic region: 1981-2015.
Source: Pendleton (2008)

4. Sustainable Development Prospects in the Face of Climate Change

The sustainable use of the Mid-Atlantic region's coastal and ocean resources necessitates a proper pricing of the ecosystem services that flow from its valued natural resources. When the economic values of these services are ignored or where institutions for realizing or assigning prices for services are absent or flawed, then the overuse or degradation of natural resources is likely (Fenichel *et al*. 2016). A key objective for the region is to organize institutions to ensure that appropriate values have been assigned to unpriced ecosystem services.

In the near-term, the provisioning services arising from the harvest of commercial fish stocks appear to be the most sensitive of the region's ES endpoints to the effects of climate change, particularly those relating to warming ocean temperatures. As fish stocks redistribute themselves in response to environmental changes, it will become necessary for managers and fishing firms to think more broadly about mechanisms for shared management across regional management regimes. Such an approach may be easier for some institutions, such as the Atlantic States Marine Fisheries Commission, which comprises an alliance among Atlantic coastal states, than for others, such as the Mid-Atlantic and the New England fishery management councils, which must seek ways of cooperating to manage fisheries over their shifting distributions. An important model for sustainable fishery management is the surf clam/ocean quahog fishery, which utilizes a market-based approach (individual transferable quotas) that allows the emergence of prices for shellfish stocks that cover the entire Northeast Shelf.

The Mid-Atlantic is not alone in facing the pressures of climate change effects, macronutrient releases, and human developments. Three of the states in the Mid-Atlantic region (New York, Delaware, and Maryland) already participate in the Regional Greenhouse Gas Initiative (RGGI), which implements a combined allowance auction and cap-and-trade approach to carbon dioxide emissions from fossil fuel power plants. Although the RGGI cap is designed to become more constraining over time, it applies only to fossil fuel plants exceeding 25MW of capacity. Governor Phil Murphy of New Jersey announced in January 2018 that the state will rejoin the RGGI program, and Governor Terry McAuliffe of Virginia has directed state officials to establish an intrastate carbon market among the state's utilities. Further, legislation has been introduced to integrate Virginia into the RGGI program.

It may be necessary to supplement cap-and-trade institutions through the application of carbon taxes on other sources of greenhouse gases. To be consistent with the core objective of the Paris Agreement of keeping temperature rise below 2 degrees, the Carbon Pricing Leadership Coalition (CPLC) has recommended establishing a carbon price in the $40-$80 per metric ton range by 2020, which would be increased to $50-$100 by 2030.[17] For reasons of both efficiency and fairness, a carbon tax would probably need to be implemented at a national scale, although each of the Mid-Atlantic region's states have enacted gasoline taxes (NY: $0.44/gal; NJ: $0.44/gal; PA: $0.58/gal; DE: $0.23/gal; MD: $0.34/gal; VA: $0.22/gal). These taxes are not indexed to general price inflation, however. Offshore renewable energy areas have been leased already, and these could provide significant non-fossil fuel sources of electrical energy.

Progress has been made in establishing total maximum daily loads (TMDL) standards for nitrogen, phosphorous, and sediments in the Chesapeake Bay and for many of the region's other estuaries and local waters. Nutrient trading programs, involving market exchanges of pollution credits between point sources, between point and nonpoint sources, and between non-point sources, have been recommended and are under discussion for the Chesapeake. Intrastate nitrogen and phosphorous credit exchanges among wastewater treatment plants exist already in the Chesapeake's watershed states of West Virginia, Virginia, Maryland, and Pennsylvania. Nitrogen credit exchanges among publicly owned treatment works also have been established in the Connecticut portion of the Long Island Sound estuary. For the larger estuaries spanning multiple state jurisdictions, inter-basin and interstate trading in nutrient credits have been discussed and may yet emerge.

Under section 404 of the Clean Water Act, where development or infrastructure projects involve the dredging and filling of wetlands that result in unavoidable impacts, some form of compensatory mitigation is required. Compensatory mitigation can comprise the purchase of credits from wetland banks, providing funds to a sponsor of a wetland restoration project (in-lieu fee mitigation), or the restoration, establishment, enhancement, or preservation of wetlands by a developer (EPA 2008). In conjunction with EPA and other agencies, the Army Corps of Engineers has established a Regulatory In-Lieu Fee and Bank Information Tracking System (RIBITS) to account for the scale, location, and status of compensatory mitigation projects (USACE 2018). Compensatory mitigation projects have been established in each of the Mid-Atlantic states, led by Virginia (305 approved, pending or sold-out projects), Pennsylvania (30), Maryland (12), New York (11), New Jersey (8) and Delaware (2). Compensatory mitigation can help to conserve or restore coastal wetland ecosystem services, although the longer term effects of shoreline losses caused by storm-related erosion or sea-level rise are likely to impact mitigation projects adversely.

Existing institutions, such as FEMA's National Flood Insurance Program (NFIP), offer flood insurance, but many policies are subsidized at below actuarial rates. Nearly 60% of the nation's flood mapping has been found to be inaccurate, and NFIP mapping fails to account for

---

[17] CPLC. Leading Economists: A Strong Carbon Price Needed to Drive Large-Scale Climate Action (May 29, 2017) https://www.carbonpricingleadership.org/news/2017/5/25/ leading-economists-a-strong-carbon-price-needed-to-drive-large-scale-climate-action#_ftn1.

changes in flood risks due to sea-level rise. The NFIP is currently up for reauthorization and while much attention has been directed at recouping the program's current $25 billion deficit, a much bigger priority is to eliminate the hidden subsidies entrenched in the program. These subsidies encourage human encroachments in coastal areas that heighten disaster risks, thereby preventing the natural shoreward progression of natural and nature-based features. For coastal communities that can demonstrate compliance with floodplain management requirements and that take additional actions to reduce risks, flood insurance premium discounts are available through NFIP's Community Rating System. Only a small proportion of the communities in each Mid-Atlantic state, however, has been able to meet the CRS requirements (DE: 18%; NJ: 11%; VA: 7%; MD: 6%; NY: 2%; PA: 1%). Most Mid-Atlantic communities participating in the CRS program have achieved only entry-level class ratings of 9-7; a premium discount of 25% for a Class 5 rating has been achieved by only one community: Prince Georges County in Maryland.

5. Conclusions

Mid-Atlantic stakeholders and resource managers clearly recognize the importance of coastal and ocean ecosystem services to the region, and the groundwork for incorporating expanded understanding of the importance of ecosystems and their economic values has been laid already in the region. Many of the ecosystem service endpoints are either not exposed or insensitive to the effects of climate change, but several endpoints appear to be much more vulnerable. These include commercial and recreational fisheries, wildlife viewing, and living shorelines, including salt marshes, seagrass beds, and intertidal lands and resources, including oyster reefs. It will be important for the communities of the region to address these vulnerabilities on several fronts.

As evidenced by the very large cultural ES values measured recently for the Delaware wetlands (Santoni *et al*. 2017), the very significant property value protections from flood and erosion afforded by living shorelines (Narayan *et al*. 2016), and the large carbon sequestration capabilities of salt marshes (Carr *et al*. 2017), living shorelines constitute a clear priority for further protection and restoration. The double threats of retreating shorelines due to sea-level rise and encroachments from the expansion of human coastal development will need to be addressed. Further research on the scales and spatial distributions of ecosystem service values for these environments can be utilized to help understand the full scope of the costs of climate changes and the benefits of adaptation to both sea-level rise and possible increases in storm severity.

Increased investments in scientific research, environmental monitoring, and ecosystem service valuations are warranted. Further characterizations of the spatial distributions of services, human uses, and the values arising from those uses would be useful in assessing the extent of potential vulnerabilities and characterizing appropriate management responses. Primary valuation studies, such as those that have been undertaken for the Chesapeake, Delaware, and Peconic estuaries, will help in the development of more accurate estimates of the economic values at stake.

Several examples exist or are under development in the region of market-based institutions for realizing ES values, including auctions of allowances to fossil fueled power plants based upon a regional CO_2 cap, intrastate credit exchanges for macronutrients based upon water body discharge loadings (Total Maximum Daily Loads), compensatory mitigation for unavoidable impacts from the dredging and filling of wetlands, and an Individual Transferable Quota (ITQ) program for harvests of surf clams and ocean quahogs. These institutions provide starting points for their further expansion to all of the states of the region and to a broader array of natural resources and their associated ecosystem services. A clear priority for the region is the design and establishment of equally innovative institutions for conserving natural and nature-based features, and a strategy of investing further in ES valuations will lead to improvements in coastal sustainability and resilience.

Appendix 6-A

Key for Appendix 6-A:

[BT=benefit transfer; CB=Chesapeake Bay; CE=Choice Experiment; CVM=contingent valuation method; DB=Delaware Bay; HPM=hedonic pricing method; LISB=Long Island Sound Basin; SSV=supply-side valuation; TCM=travel cost method]

Year	Authors	Focus	Method	Results
1985	Kahn & Kemp	CB: estimated damages to commercial and recreational fisheries associated with pollution-related losses of SAV (based on juvenile striped bass in the Potomac River; data from 1970s)	SSV	☐Conservative estimate of marginal and total damages to commercial and recreational fisheries for MD striped bass ☐Extended with "multipliers" to other fisheries and entire CB ☐At baseline of 86,000ac [see Guignet *et al*. 2014], marginal damages for 5 CB fisheries are $447,000/ac and total damages are $13.5 million [2017$] ☐Unit value for SAV supporting 5 CB fisheries is $284/ac over original SAV area of 185,000ac [2017$]
1988	Silberman & Klock	NJ Coast: estimated benefits for region's beaches of beach nourishment projects (1988$)	CVM	☐Benefits for beach visitation of the nourishment of New Jersey beaches of $0.61/trip [2017$]
1990	Bockstael et al.	CB: estimated benefits from improvements in water quality for recreational uses of swimming, beach use, boating, and striped bass fishing (data from 1984)	CVM TCM	☐WTP estimated by CVM for improvement in CB water quality to make it "acceptable for swimming" ☐WTP estimated by TCM for 20% reduction in combined measure of total N and P and 20% improvement in striped bass catch rates ☐Conservative estimate of annual average range of benefits for moderate improvements in CB water quality of $24-235 million [2017$]
1991	Leeworthy & Wiley	NJ Coast: estimated demand for outdoor recreation (beach visits) at New Jersey's Island Beach State Park (data from 1988)	TCM	☐Median of consumer surplus estimates for preferred model ranged from $32-49/person/day [2017$]
1991	Parsons & Wu	CB: estimated lost "development value" due to land-use controls comprising a Critical Area Program to slow coastal development (Anne Arundel County, MD; 1983 data)	HPM	☐Estimated lost water frontage, water views, and proximity to the coast for a range of land-use control scenarios ☐From 1986-2005, the estimated present value of the displacement cost of land-use controls per county resident ranged from $113/resident in initial years to $34/resident in later years [2017$]

Year	Authors	Focus	Method	Results
1994	McConnell et al.	Mid-Atlantic: estimated asset values (WTA), values of access to fisheries (WTP), and values of increased expected catches (1988$)	CVM TCM	☐Estimated total contingent asset values based on willingness-to-sell for the Mid-Atlantic ($68 billion): NY ($11b); NJ ($20b); DE ($4b); MD ($20b); VA ($13b) [2017$] ☐Estimated aggregate values of WTP for access to fisheries, comparing CVM and TCM (RUM) models; *e.g*., RUM estimates: NY ($0.5b); NJ ($0.3b); DE ($0.02b); MD ($0.2b); VA ($0.3b) [2017$] ☐Estimated annual aggregate welfare effects of $0.6b from increase in expected catch rate of 0.5 fish/trip (due to water quality improvements) [2017$]
2000	Leggett & Bockstael	CB: estimated effects of fecal coliform pollution on waterfront home values, while controlling for effects of proximity to emission sources (Anne Arundel County, MD; 1997 data)	HPM	☐Estimated an upper bound on improvements in water quality through a reduction in fecal coliform levels to a state standard of $18.5m [2017$]
2000	Parsons et al.	MAR: random utility model of beach recreation including familiar-unfamiliar and favorite-not favorite sites	TCM	☐Estimated per person per trip welfare losses for beach closures ($0-24) or reductions in beach width ($10-16) to less than 75 feet (due to policy of no beach nourishment) [2017$]
2001	Parsons & Powell	Delaware coast: estimates of the costs of retreat from the beach for coastal properties as sea-level rises for the Delaware Atlantic coast and broken down by community (2000 data)	HPM	☐Estimated cost of beach retreat in Delaware over the next 50 years of $413 million [2017$]
2002	Johnston et al.	Peconic Estuary (Long Island, NY) resource services (1995$)	TCM CVM	☐Estimated total annual values for swimming ($19.4m), boating ($28.9m), recreational fishing ($38.0m), and birding and wildlife viewing ($43.8m) [2017$] ☐Estimated annual benefits to swimmers of 10% improvement in water quality, including Kjeldahl N, total coliform, brown tide cell counts, and Secchi disk depths ($2.1m) [2017$] ☐Estimated total values per area for protection of lands while controlling for symbolic value: farmland ($25,356/ha), eelgrass beds ($23,791/ha), wetlands ($19,280/ha), shellfish beds (18,059/ha), and undeveloped land ($4,769/ha) [2017$]
2003	Parsons & Massey	MAR: estimated lost value for region's beaches with reduced beach width (1997$)		☐Lost value for beach visitation for Mid-Atlantic beaches with widths dropping below 75 feet of $2-9/trip [2017$]

Year	Authors	Focus	Method	Results
2003	Wakefield & Parsons	DB: comparison of the costs of beach nourishment with beach retreat using two estimates of sea-level rise (2000 data)	MKT	☐50-year cost of beach nourishment at Delaware beaches is $48-60 million ☐50-year cost of retreat from the beach at Delaware beaches is $156-319 million
2004	Lipton	CB: estimated values of improvements in water quality to boaters	CVM	☐Estimated boater annual total WTP of $10.4m/yr. for improvement of one qualitative unit in water quality [2017$]
2006	Costanza et al.	New Jersey value of ecosystem services and natural capital*	BT HPM	☐Compiles land cover area and annual values per acre for coastal shelf, beach, estuary, and saltwater wetland types ☐Transferred benefits to estimate annual unit ES values for coastal shelf ($1,296/ha), beach ($171,833/ha), estuary ($47,509/ha), and saltwater wetland ($24,996/ha) types [2017$]
2007	Poor et al.	CB: effects of unit increases in DIN and TSS on waterfront home values (St. Mary's County, MD; 2003 data)	HPM	☐Estimated losses to residential homes in a small local watershed of one unit increase in either total suspended solids (TSS) (-$1,444) or dissolved inorganic nitrogen (DIN) (-$23,454) [2017$]
2010	Myers et al. Edwards et al.	DB: contingent values and travel costs to recreational birders of visiting the annual spring migration of horseshoe crabs and shorebirds (2008 data)	CVM	☐ Estimated contingent values of trips to annual spring migration in Delaware Bay are $300,000; asset values range from $6-108 million [2017$] ☐ Estimated travel cost of trips to annual spring migration in Delaware Bay are $244,000 [2017$]
2013	Parsons et al.	DB: estimated gains and losses in benefits of visits to bay beaches due to changes in beach widths, using both revealed and stated preferences	TCM	☐Estimated 49,000 trips per year by adults to all seven bay (not coastal) beaches ☐Estimated annual access value to all seven beaches of $1.8 million ☐Estimated aggregate annual estimate of consumer surplus loss for all beaches by their current width by 25% is $252,000; CS gain for doubling the width is about $139,000
2015	Kocian et al.	LISB: ecosystem service flows in the Long Island Sound Basin for 14 different ecosystem services on 9 different land cover types	BT	☐Estimated annual ecosystem service flow values of $17-37 billion/yr. for the Long Island Sound Basin
2014	Guignet et al.	CB: net ecosystem service value of submerged aquatic vegetation (SAV) in 11 Maryland counties	HPM	☐Residences on or near the waterfront and in proximity to SAV are worth 5-6% more ☐Attaining a goal of historical levels of SAV (185,000 ac from a baseline of 86,000ac) would lead to estimated property value gains of $326-398 million
2015	Walsh et al.	CB: adaptation to sea-level rise in low-lying areas	HPM	☐Tidewater property markets incorporate information about SLR

Year	Authors	Focus	Method	Results
		proximate to tidal waters (Anne Arundel County, MD)		☐Residences in 0-2ft SLR zones that are not protected by bulkheads or riprap are worth 19-23% less than those that are protected ☐Property value effects of increased flooding or erosion risks are balanced by protection benefits ☐Residences adjacent to bulkheads (regardless of SLR risk) are worth 8-13% more (due to protection from flood, storm surge, or erosion; access to recreational amenities)
2015	Moore et al.	CB and watershed lakes improved water quality value (address excess nutrients and sediment loadings)	CE	☐Representative household WTP of $87-146/hh/yr. ☐Aggregate WTP of $1.2-6.5 billion/yr. ☐46-52% of WTP relates to freshwater lakes in the CB watershed ☐80% of beneficiaries are non-users
2017	Dundas	NJ Coast: estimated value of investment in large-scale natural infrastructure (dunes) to adapt to climate change and increase coastal resilience	HPM	☐Federal dune construction increases housing process by 3.0-6.3% ☐Dune construction transfers on average $3,229 to property owners ☐Gains along NJ coast of $170 million are outweighed by construction and maintenance costs of $261 million
2017	Santoni et al.	DB: Delaware Bay tidal wetlands ecosystem services valuation	CE	☐Estimated range of WTP ~$80,000-159,000/ac/yr., comprising mainly cultural ecosystem services (recreation)

Chapter 6 List of References

Bockstael NE, Strand IE, McConnell KE, Arsanjani F. 1990. Sample selection bias in the estimation of recreation demand functions: an application to sport fishing. *Land Economics* 66:40-49.

Boyd J, Banzhaf S. 2007. What are ecosystem services? *Ecological Economics* 63: 616-626.

Carr E, Shirazi Y, Parsons G, Hoagland P, Somerfield CK. 2017. The economic value of carbon sequestration by wetlands in the Delaware Estuary: historic estimates and future projections. *Journal of Environmental Management* 206:40-50(forthcoming).

Champ PA, Boyle KJ, Brown TC, eds. 2003. *A Primer on Nonmarket Valuation*. Boston: Kluwer Academic Publishers.

Costanza R, Wilson M, Troy A, Voinov A, Liu S, D'Agostino J. 2006. *The Value of New Jersey's Ecosystem Services and Natural Capital*. Proj. Rep. for NJ Department of Environmental Protection. Burlington, VT: Gund Institute for Ecological Economics, University of Vermont, 177pp.

Dahl TE, Stedman SM. 2013. Status and trends of wetlands in the coastal watersheds of the Conterminous United States 2004 to 2009. Washington: Fish and Wildlife Service, Department of the Interior and National Marine Fisheries Service, Department of Commerce.

de Groot R, Brander L, van der Ploeg S, Costanza R, Bernard F, Braat L, Christie M, Crossman N, Ghermandi A, Hein L, Hussainj S, Kumar P, McVittie A, Portela R, Rodriguez LC, Brink, van Beukering P. 2012. Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem Services* 1:50-61.

DePiper GS, Lipton DW, Lipcius RN. 2017. Valuing ecosystem services: oysters, denitrification, and nutrient trading programs. *Marine Resource Economics* 32:1-20.

Dundas SJ. 2017. Benefits and ancillary costs of natural infrastructure: evidence from the New Jersey coast. *Journal of Environmental Economics and Management* 85:62–80.

Edwards PET, Parsons GR, KH Myers. 2011. The economic value of viewing migratory shorebirds on the Delaware Bay: an application of the single site travel cost model using on-site data. *Human Dimensions of Wildlife* 16:435–444.

Environmental Protection Agency (EPA). 2008. Wetlands compensatory mitigation factsheet (CWA 404 discharges). Washington: Office of Wetlands, Oceans, and Watersheds.

Environmental Protection Agency (EPA). 2012. Coastal wetlands initiative: Mid-Atlantic review. EPA-843-R-10-0005. Washington: Office of Wetlands, Oceans, and Watersheds.

Fenichel EP, Abbott JK, Bayham J, Boone W, Haacker EMK, Pfeiffer L. 2016. Measuring the value of groundwater and other forms of natural capital. *PNAS* 113:2382-2387.

Freeman MA. 2010. The wealth of nature: valuing ecosystem services. *Proc. 2010 EEPSEA Impact Conference*. Hanoi: Environmental Economics Program for South East Asia (February 26-27).

Grabowski JH, Brumbaugh RD, Conrad RD, Keeler AG, Opaluch JJ, Peterson CG, Piehler MF, Powers SP, Smyth AR. 2012. Economic valuation of ecosystem services provided by oyster reefs. *BioScience* 62:900-909.

Guignet D, Griffiths C, Klemick H, Walsh P. 2014. The implicit price of aquatic grasses. Wkg. Pap. No. 14-06. Washington: National Center for Environmental Economics, US Environmental Protection Agency (December).

Hare J, Morrison WE, Nelson MW, Stachura MM, Teeters EJ, Griffis RB, Alexander MA, Scott JD, Alade L, Bell RJ, Chute AS, Curti KL, Curtis TH, Kircheis D, Kocik JF, Lucey SM, McCandless CT, Milke LM, Richardon DE, Robillard E, Walsh HJ, McManus MC, Marancik KE, Griswold CA. 2016. A vulnerability assessment of fish and invertebrates to climate change on the northeast US continental shelf. *PLOS One* (Feb. 3, 2016). https://doi.org/10.1371/ journal.pone.0146756.

Hicks RL, Haab TC, Lipton D. 2004. The Economic Benefits of Oyster Reef Restoration in the Chesapeake Bay. Final Report Prepared for the Chesapeake Bay Foundation (10 May).

Johnston RJ, Grigalunas TA, Opaluch JJ, Mazzotta M, Diamantedes J. 2002. Valuing estuarine resource services using economic and ecological models: the Peconic Estuary System Study. *Coastal Management* 30:47–65.

Johnston RJ, Rolfe J, Rosenberger RS, Brouwer R, eds. 2015. *Benefit Transfer of Environmental and resource Values*. New York: Springer Science+Business Media B.V.

Johnston RJ, Russell M. 2011. An operational structure for clarity in ecosystem service values. *Ecological Economics* 70:2243–2249.

Kahn JR, Kemp WM. 1985. Economic losses associated with the degradation of an ecosystem: The case of submerged aquatic vegetation in Chesapeake Bay. *Journal of Environmental Economics and Management* 12:246-263.

Kasperski S, Wieland R. 2010. When is it optimal to delay harvesting? The role of ecological services in the Northern Chesapeake Bay oyster fishery. *Marine Resource Economics* 24:361-385.

Kocian M, Fletcher A, Schundler G, Batker D, Schwartz A, Briceno T. 2015. *The Trillion Dollar Asset: The Economic Value of the Long Island Sound Basin*. Tacoma: Earth Economics.

Leeworthy VR, Wiley PC. 1991. *Recreational Use Value for Island Beach State Park*. Rockville, MD: Strategic Environmental Assessments Division, Office of Ocean Resource Conservation and Assessment, NOAA.

Leggett CG, Bockstael NE. 2000. Evidence of the effects of water quality on residential land prices. *Journal of Environmental Economics and Management* 39:121-144.

Lipton D, Lew DK, Walmo K, Dvarskas A. 2014. The evolution of non-market valuation of US coastal and marine resources. *Journal of Ocean and Coastal Economics* 1:6.

Lipton D. 2004. The value of improved water quality to Chesapeake Bay boaters. *Marine Resource Economics* 19:265-270.

Liu S, Costanza R, Farber S, Troy A. 2010. Valuing ecosystem services: theory, practice, and the need for a transdisciplinary synthesis. *Annals of the New York Academy of Sciences* 1185:54-78.

McConnell KE, Strand IE, Valdes SK, Weninger QR. 1994. The economic value of mid and south Atlantic sportfishing. Report between the University of Maryland, EPA, NMFS, and NOAA. Coop. Agr. No. CR-811043-01-0. College Park, MD: University of Maryland.

McKenna P. 2018. New Jersey to rejoin east coast carbon market, Virginia may be next. *Inside Climate News* (January 29). https://insideclimatenews.org/news/26012018/cap-and-trade-carbon-emissions-regional-greenhouse-gas-initiative-rggi-new-jersey-virginia-climate-change.

Meixler MS. 2017. Assessment of Hurricane Sandy damage and resulting loss in ecosystem services in a coastal-urban setting. *Ecosystem Services* 24:28-46.

Mid-Atlantic Regional Ocean Council (MARCO). 2017. *Mid-Atlantic Ocean Data Portal*. Accessed on November 10, 2017 at: http://portal.midatlanticocean.org/ocean-stories/every-map-tells-a-story/.

Millennium Ecosystem Assessment Board (MEAB). 2003. *Ecosystems and Human Well-being: A Framework for Assessment*. Washington: Island Press.

Moore C, Guignet D, Maguire K, Dockins C, Simon N. 2015. A stated preference study of the Chesapeake Bay and watershed lakes. Wkg. Pap. No. 15-06. Washington: National Center for Environmental Economics, US Environmental Protection Agency (November).

Munns WR, Rea AW, Suter GW, Martin L, Blake-Hedges L, Crk T, Davis C, Ferreira G, Jordan S, Mahoney M, Barron MG. 2016. Ecosystem services as assessment endpoints for ecological risk assessment. *Integrated Environmental Assessment and Management* 12:522–528.

Myers KH, Parsons GR, Edwards PET. 2010. Measuring the recreational use value of migratory shorebirds on the Delaware Bay. *Marine Resource Economics* 25:247-264.

Narayan S, Beck MW, Wilson P, Thomas C, Guerrero A, Shepard C, Reguero BG, Franco G, Ingram CJ, Trespalacios D. 2016. *Coastal Wetlands and Flood Damage Reduction: Using Risk Industry-based Models to Assess Natural Defenses in the Northeastern USA*. London: Lloyd's Tercentenary Research Foundation.

Opaluch JJ, Grigalunas T, Diamantides J, Mazzotta M, Johnston R. 1999. *Recreational and Resource Economic Values for the Peconic Estuary System*. Peace Dale, RI: Economic Analysis Inc., 137pp.

Parsons GR, Hidrue MK, Chen Z, Standing N, Lilley J. 2013. Valuing beach width for recreational use: combining revealed and stated preference data. *Marine Resource Economics* 28:221-241.

Parsons GR, Massey DM, Tomasi T. 2000. Familiar and favorite sites in a random utility model of beach recreation. *Marine Resource Economics* 14:299–315.

Parsons GR, Massey DM. A RUM model of beach recreation. *In* Hanley N, Shaw D and R. Wright R, eds., *The New Economics of Outdoor Recreation,* New York: Edward Elgar Publishing.

Parsons GR, Powell M. 2001. Measuring the cost of beach retreat. *Coastal Management* 29: 91-103.

Parsons GR, Wu Y. The opportunity cost of coastal land-use controls: an empirical analysis. *Land Economics* 67:308-316.

Pendleton LH. 2008. *The Economic and Market Value of Coasts and Estuaries: What's at Stake?* Arlington, VA: Restore America's Estuaries.

Poor PJ, Pessagno KL, Paul RW. Exploring the hedonic value of ambient water quality: a local watershed-based study. *Ecological Economics* 60:797-806.

Santoni A, Arvay B, Scarborough R. 2017. *Delaware Tidal Wetland Ecosystem Services Valuation: Technical Report*. Dover, DE: Delaware Department of Natural Resources and Environmental Control.

Silberman J, Klock M. 1988. The recreation benefits of beach renourishment. *Ocean & Shoreline Management* 11: 73-90.

Sweet W, Zervas C, Gill S, Park J. 2013. Hurricane Sandy inundation probabilities today and tomorrow. *Bulletin of the American Meteorological Society* (September): S17-S21.

US Army Corps of Engineers (USACE). 2018. Regulatory in-lieu fee and bank information tracking system (RIBITS). https://ribits.usace.army.mil/ribits_apex/f?p=107:2:11454085658634::NO:RP:

US Geological Survey (USGS). 2017. Benefits Transfer Toolkit. USGS Sustaining Environmental Capital Initiative. https://my.usgs.gov/benefit-transfer/.

Wakefield JR, Parsons GR. 2003. A comparison of nourishment and retreat costs on Delaware's ocean beaches. *Shore & Beach* 71:23-26.

Walsh P, Griffiths C, Guignet D, Klemick H. 2015. Adaptation, sea level rise, and property prices in the Chesapeake Bay watershed. Wkg. Pap. No. 15-02. Washington: National Center for Environmental Economics, US Environmental Protection Agency (February).

Chapter 7 : Summary and Recommendations

Three themes emerge from the survey and analysis undertaken in this study:

1. Climate change will affect every part of the Mid-Atlantic region's coastal and marine environments. Every part of the region must develop responses sooner or later. But there are also important differences across the region. Effective adaptation strategies will recognize these differences to make sure multiple vulnerabilities are addressed and to find underlying connections across vulnerabilities that define synergies that can be addressed together in adaptation plans.

2. Vulnerability assessment is the first stage in what is a long and complex process. The next stage is to translate the high-level perspectives of vulnerability and to begin collecting information that will allow specific risks to be identified in specific areas in order to create effective plans.

3. Climate change poses unique challenges to the region's institutions. The stakes are enormous, but key information is lacking. Decisions are needed not just about what to do but when to do it. Take action now or wait until the picture is clearer? But the magnitude of the costs and uncertainty about whether it will be worse to take action sooner when it might turn out not to be needed; or later that might be too late could result in more paralysis than action.

We elaborate on each of these themes below, but it is worth restating an obvious but often overlooked point in adaptation discussions: it will be much easier and cheaper to reduce the need for adaptation by taking actions to reduce the extent of climate change. Large expenditures for adaptation are needed now because of a failure to effectively mitigate climate change in the past, and this imbalance will only grow in the future the longer mitigating actions are delayed. As the future costs of adaptation become more and more apparent, the benefits of mitigation will hopefully also emerge more clearly.

1. From vulnerability to risk assessment to action

Throughout this assessment, research and analysis has been discussed that makes it possible to identify the directions towards which climate change is driving resources and socio-economic systems. The picture of vulnerability that emerges points to the need for action but not what actions or when they should be taken. It does point out that vulnerability is shared, but also that different parts of the region are vulnerable to different possible changes.

Economic activity directly associated with the ocean, including fisheries, transportation, the summer economy, and the ocean economy, in general, presents one set of issues. Severe climate change impacts on key sectors of the local economy, such as will be the case with fisheries and the summer economy, can have more deeply disruptive effects in coastal communities. But the analysis indicates that virtually all of the economy of the coastal regions of the Mid-Atlantic are vulnerable to disruption. Some of the disruption will be temporary in the form of floods. Recovery from flooding is possible and has occurred many times in the past. But the future will see flooding more frequent and in much larger areas than has been experienced. It is the cumulative effect of this flooding and the disruptions it causes that will require more and more resources be devoted to disaster prevention and recovery. At some point, which cannot be foreseen, businesses will relocate away from high hazard areas.

The next steps, therefore, should focus on using the information generated here to add to already ongoing planning process in order to accomplish several things:

- Incorporate more specific, geographically precise information into planning.
    - Census tract data can be further localized to Census block groups and blocks using decennial census data for more precise measurement of possible flood risks.
    - Forecasts of local growth done for transportation planning purposes can be adapted to better defining future risks that may be substantially different than the most recent data used here can provide.
    - Employment establishments are located by latitude and longitude in the state Quarterly Census of Employment and Wages data sets; with special permission and rigorous protection for confidentiality, this data can yield very precise estimates of employment and economic impacts. If not available from the state government, such estimates are available from commercial firms.
    - State data sets can be used to refine the infrastructure analysis done here to more precise geographies.
    - Shift sea level rise planning to the latest generation of models that rely less on linear extrapolations to specific time periods and more on distinguishing the more likely and the less likely scenarios at any given time. Start the process by asking not "what will sea level be in 2070?" but by asking "what are the probabilities that sea level will exceed some minimum threshold needed for action within the next N years"? Use discussions of this question, based on the best available information, to form the foundation for planning processes.
    - Use the findings of this report as a checklist for adaptation planning. The focus may be on the issues of the summer economy or fisheries, but what are the social vulnerability issues that exist alongside?

<u>2. Recognize differences in vulnerabilities but look for common causes and responses.</u>

Though vulnerabilities may be different in extent and intensity within a given region, it may also be that there are many synergies in the underlying ecological and social systems that would make it possible to address many risks at once.

- Coastal wetlands, including beaches, serve as foundations for some economic activity but may also serve as natural infrastructure reducing potential damages from the flood vulnerabilities identified.
- A capital plan for a maintaining a port may also require updating of road, rail, and land use plans in the area to be effective. Those multiple asset plans address different vulnerabilities through common actions.

3. The challenge of dealing with climate change will stress institutions.

Over the past 50 years, American governments have built significant capacity at all levels to manage complex systems. That capacity comprises laws and implementing regulations, administrative and policy planning procedures, processes for stakeholder engagement, and professional staff, often working with citizen decision makers. That capacity continually evolves and seeks to improve, but it does so primarily in small increments of change, which is the style best suited to the ecology of these systems (Lindblom 1959). These systems have several features in common:

- *Silos* Organizational structures are built on the principle of specialized organizations to accomplish specialized tasks. Expertise is concentrated. Cross-specialization problems are managed largely by ad hoc arrangements.
- *Linearity of the Future* The future is assumed to be largely foreseeable from some linear or quasi-linear projections of past trends.
- *One problem at a time* The system works best on one problem at a time, largely divided by specialization. Funding cycles, staff resources, and external demands on the organization require focusing limited resources on as small a number of problems as possible. This is particularly the case with issues affecting long-term issues.
- *Ceterus Paribus* In order to use linear views of the future and focus on a small number of problems, it is necessary to identify a set of factors which will be "held equal" or kept constant so as not to try to manage too many factors at once.
- *Speed of change* Another key assumption is that the systems being addressed will change at a speed roughly coincident with the speed of the administrative processes necessary to deal with them.

It is easy to see how these essential characteristics are rendered largely moot by climate change. Linear futures are useless because climate change fundamentally means the future will *not* be like the past. As the report makes clear, climate change creates problems across a wide front, not at all the province of any one or even a few agencies. Ceterus is no longer paribus; it is no longer possible to hold some assumptions constant any more. The speed of change is unknown but, as indicated in the fisheries chapter, can come at a speed far faster than the institutions are capable of handling on top of all the other requirements that must be met

Formulating adaptation strategies is a planning problem unlike others that organizations are set up to confront. Adaptation is mostly an information problem so continuous investment in information is essential. This report presents the base layer of information needed to understand how climate change may affect the Mid-Atlantic region, but as discussed above, much more is needed. Moreover, the information must be continually updated and refined. We already know much more about climate change and its effects than we knew a decade ago, and we will know more a decade hence and a decade after that. Information gathering must be ongoing and continually improved. Every increment of new information reduces uncertainty, better defines options, and increases confidence in the choices to be made.

Adaptation is about building defense in depth, not simply coming up with a strategy sufficiently acceptable to be implemented today. Every adaptation action considered should be accompanied by backup plans in the event that the situation turns out to be much different than anticipated. The backup plan should be ready for implementation as soon as evidence is available that the risks of inaction are exceeding the risks of action. And the backup should have a backup to that. And each plan and its backups should be updated, and action should taken as soon as needed, rather than restarting the process every time.

A good example of this approach is to adopt the principle that disasters create opportunities and thus preparations should be made to seize those opportunities. Natural infrastructure (using natural features such as salt marshes as buffers against sea level rise-exacerbated flooding) has not been a widely used choice in disaster recovery. The default response to many flooding events has been to build sea walls or other engineered structures in large part because a history of such responses has created a familiarity that makes them seem the easy choice. The defects in the use of such engineered structures are well known, but still, they persist. Natural infrastructure is a relatively new concept who's technical and economic details are only recently becoming more widely understood. The time to plan for the use of natural infrastructure, and, where appropriate, engineered structures is before the next Sandy hits, not in the chaotic aftermath when merely getting basic functions monopolizes attention.

The institutional stress comes from the fact that it is proving difficult enough to gather resources and muster support simply to take the first steps to address climate change. Some states in the region have been able to take advantage of the influx of funds following Hurricane Sandy to take significant steps (another example of the opportunities in disasters), but this is not the case everywhere. We are asking not only that the steps to be taken include planning for actions that may not be needed for decades (but may be needed next year if the probabilities break the wrong way). And we are asking this process be continually repeated for an unknown amount of time into the future. But that is the nature of wicked problems; they can be managed but not avoided.

Money for adaptation is an underappreciated vulnerability, but it can be addressed. The costs of effective adaptation actions will likely far exceed the money needed for the planning. Fear of those costs and of making the wrong choices can make it all too easy to avoid the whole subject, to kick the can down the road. This problem of financing has not been part of the scope of this study, but it is of such significance that it should be considered one more vulnerability created by climate change.

But climate change is also occurring at the same time as a number of innovations that make it much easier to deal with the issues of funding. New financial instruments such as catastrophe bonds, impact investing products such as climate bonds, the creation of new local financial institutions such as hazard districts and infrastructure banks open up a whole new set of possibilities to find new ways of combining public and private resources to fund adaptation. (Colgan, Beck, and Narayan 2017)

If adaptation is left to the standard practice of coming up with a plan and then waiting for the state or federal government to find the funding, then money will become as big a barrier to action as any of the uncertainties and knowledge gaps discussed here. Many governments in the region, particularly some of the larger cities, are already exploring these new options for resources, but they are not for larger cities alone. Even small communities can join together to access some of the new resources. Financial planning should be as integral a part of adaptation planning as any other.

Adaptation is now… and in the future. Climate change has taken more than a century to reach the current levels of threat but most indicators point to a significant acceleration in the pace and severity of climate change and its effects. We just do not know how big that acceleration is. It is clear that action is needed now. Climate change is not something that will occur in a remote future. It will be a dominant fact of life for children born in this decade throughout their lifetimes. When we project a 3- or 6-foot sea level rise in 2100, that is something that will be experienced by an 82-year-old version of a child born in 2018. Many of those children will not know the Jersey

Shore, or Ocean City, or Fire Island as adults. These features that have defined the Mid-Atlantic for a century or more will simply not be there.

But adaptation cannot be the steps taken over the next decade as important as those will be. Adaptation is a three-dimensional chess game where the rules are subject to revision without notice. It is a game about which we know enough to get started, but not enough to know when or even if the game will be finished. The region is vulnerable to drastic change in multiple and complex ways. Reducing that vulnerability is possible, even likely. Eliminating it is much more difficult.

References to Chapter 7

Colgan, Charles S., Michael W. Beck, and Siddharth Narayan. 2017. “Financing Natural Infrastructure.” Santa Cruz, CA: The Nature Conservancy. www.coastalresilience.org.

Lindblom, Charles E. 1959. “The Science of Muddling Through.” *Public Adminstration Review* 19: 79–88.