Climate Change and North Carolina:
Near-term Impacts on Society and Recommended Actions

EDF
ENVIRONMENTAL DEFENSE FUND
Finding the ways that work

delivering **the promise of science** for global good

RTI INTERNATIONAL

Climate Change and North Carolina: Near-term Impacts on Society and Recommended Actions

October 2020

Authors:

George Van Houtven, Jared Woollacott, Alison Bean

RTI International,
Research Triangle Park, NC

Reviewers:

Aurora Barone, Jeremy Proville, Susanne Brooks, Suzi Kerr, Dionne Delli-Gatti, Will McDow, Hawley Truax, Danielle Arostegui, Vincent Gauthier, and Ilissa Ocko Seroka

Environmental Defense Fund,
Raleigh, NC; New York, NY

Eric Edwards

North Carolina State University,
Raleigh, NC

Acknowledgments:

Special thanks to (1) Cameron Wobus, Jim Neumann, and Claire Lay for generously providing supplementary results and data from their research, which were used and cited in this report, (2) Robert Beach, Kim Matthews, and Katie van Werkhoven for their review and helpful comments on drafts of the report, and (3) Cameron Cornwell, Kibri Everett, Hannah Hess and Nina Donaldson for their GIS and related research support.

Contents

Executive Summary

Over the last century, the Earth's climate has warmed at an unprecedented pace, and North Carolina is no exception. Evidence clearly shows that the state's climate has been changing over recent decades, and even greater changes are projected for the next 20 to 30 years and beyond. There is a high probability that sea level rise will accelerate, strong storms will continue to become more frequent and severe, and flooding will continue to worsen and become more widespread.

In the absence of concerted action, these impacts will impose significant costs on the residents of North Carolina that will be detrimental to their well-being, their economy, and their environment. To promote a better understanding of the range and size of these potential impacts, this report focuses on eight major sectors of the state's economy and summarizes available evidence on the projected costs of climate change for these sectors. Because climate change is already affecting North Carolina, this report calls specific attention to impacts in the relatively near future, that is, over the next 20 to 30 years. In addition to examining specific sectors, it also discusses cases where climate impacts are expected to disproportionately affect vulnerable communities.

Given the serious threat already posed by climate change in North Carolina, action is urgently needed to curb greenhouse gas emissions. There are many things the public and private sector can do now at the local, regional, and state levels to reduce these impacts and strengthen the state's ability to withstand these threats. This report provides several concrete recommendations for actions North Carolinians can take to counteract the hazards of climate change.

ES-1 Projected Climate Change and Climate Hazards for North Carolina

This report focuses on climate change projections for North Carolina that are based on a "no climate action" scenario. In other words, how is climate expected to change if no meaningful action is taken at a global scale to reduce emissions? These projections are based on the findings shown in the *North Carolina Climate Science Report (NCCSR)*.[1]

Based on these climate change projections, this report focuses on nine types of **climate hazards**, which are defined as climate-influenced natural processes, conditions, or events that can directly harm human health, livelihoods, or natural resources. **Table ES-1** summarizes projections for these hazards, particularly for the next 20 to 30 years.

Table ES-1. Summary of Projected Changes in Selected Climate Hazards

Climate Hazard	Projected Changes Under a No Climate Action Scenario
Air temperature increases	• In the next 20 years, average temperatures are projected to increase by about 2°F, after having increased by 1 to 2°F over the last 50 years. • It is likely (66% to 100% probability) that the number of days with extreme heat—that is, with maximums above 95°F—will increase. Over the next 20 years, they are projected to increase by 10 or more days per year across most of the Piedmont and Coastal regions of the state
Precipitation changes	• Annual precipitation is likely (66% to 100% probability) to increase on average in the coming decades, but more high and low precipitation extremes are also expected. • The frequency and intensity of extreme precipitation events (days with more than 3 inches of rainfall) is very likely (90% to 100% probability) to increase across the entire state. • Severe droughts are also likely (66% to 100% probability) to be more frequent.
Flooding	• In the Coastal region, flooding will almost certainly become more frequent and severe in the next 20 years due to the combined effects of sea level rise and more severe tropical storms and hurricanes. • The rest of the state will likely (66% to 100% probability) have more inland flooding due to more frequent and severe extreme precipitation events, including from hurricanes.
High winds	• Increases in hurricane and thunderstorm severity means higher wind hazards in North Carolina as well.
Wildfires	• Wildfire risks are likely to increase, primarily due to the likelihood of more frequent and severe droughts in the state.
Landslides	• Landslides (particularly affecting the Mountain region) are likely to increase due to more and stronger extreme precipitation events.
Water temperature & quality changes	• As the air temperature warms, so will water temperatures in the state's lakes, rivers, streams, and estuaries. These changing temperatures can alter water quality in several ways, for example by reducing the amount of oxygen it can hold and promoting the growth of algae, which can be toxic to humans and animals alike. • Stronger rainstorms will cause more soil erosion and wash more pollutants into the state's waterbodies. • In the Coastal region, continuing sea level rise will cause saltwater to intrude farther inland, affecting water quality in coastal rivers and streams, as well as in groundwater systems.
Air quality changes	• Shorter winters will lengthen the pollen season for some trees and grasses, leading to higher levels of allergy-causing pollen in the air. • More wildfires due to more intense droughts will mean more areas and days with high smoke levels in the air.

Climate Hazard	Projected Changes Under a No Climate Action Scenario
Insects, pathogens, & invasive plants	• A changing climate is likely to create conditions that favor some undesirable or invasive species. For example, warmer temperatures and wetter climates may allow for the spread of certain mosquitos and ticks, some of which carry disease-causing pathogens, like those causing Lyme disease. • Certain invasive plant species, such as kudzu, are also likely to spread more broadly with warmer temperatures.

ES-2 How Will Climate Change Impact North Carolina's Residents and Economy?

In the absence of climate action, there are many ways that the people and economy of North Carolina will be more dramatically affected by climate change in the near future. To assess the impacts of climate change, we have identified eight main sectors in North Carolina that may be affected by different climate hazards. This report not only identifies the climate hazards most likely to directly impact each sector, but it demonstrates how significant these impacts are likely to be for the sectors and how they will affect day-to-day life in the state if no action is taken to reduce emissions by the state and federal government.

Agriculture and forestry. This sector is vulnerable to almost all the climate hazard categories. Changes in average temperature and precipitation are projected to have overall negative effects on production and farm income, but the largest harmful impacts are likely be the result of intensifying extreme events, such as hurricanes, extreme heat, droughts, and floods. As a point of reference, Hurricane Florence in 2018 caused $1 billion in combined crop and livestock losses and $50 million in forestry losses. As the number of days with extreme heat rises in the coming decades, workers in the agriculture and forestry sectors will be particularly affected. In recent decades, these workers have accounted for 10 to 20% of heat-related illnesses and deaths in the United States.

Commercial fishing and aquaculture. Commercial fishing, which has long been an integral part of North Carolina's coastal culture and economy, and aquaculture, which is more of an emerging industry across the state, are both likely to be impacted by more severe hurricanes and storms. For example, in 2018, Hurricane Florence caused $13.5 million in commercial fishing and aquaculture losses. In addition, changing ocean temperatures are expected to shift habitats for commercially caught fish species. Warming estuarine waters may also lead to more fish kills, and increasing ocean acidification can harm shellfish production, which could impact many livelihoods in this industry.

Energy supply and demand. A wide range of climate hazards will increasingly impact North Carolina's ability to produce energy at a low cost for its citizens. More severe hurricanes and storms are likely to result in larger damages to energy infrastructure. For energy consumers, hotter and longer summers will drive higher demands for electricity. Growing energy bills under these conditions will be especially burdensome for low-income households across the state, and reliability may also become a major concern.

Transportation infrastructure. North Carolina currently spends roughly $1 billion per year to maintain the state-owned road network, and it is ranked 9th in the nation for average maintenance spending per

lane-mile. Climate change, particularly through its effects on sea levels and extreme events, such as floods, extreme heat, and landslides, will make it increasingly costly to maintain this system.

Water infrastructure and services. Many of the most severe climate threats facing North Carolina—from sea level rise, to stronger rainstorms and hurricanes, to changes in water quality and temperature—are related to water. Therefore, not surprisingly, climate change is already putting significant pressure on water systems and services, such as putting residents at higher risk of dam failures, and these pressures will only increase in the coming decades.

Residential and commercial property. North Carolina currently has almost 5 million residential housing units and about 1.6 million commercial properties. As climate changes, both types of properties will face growing risks, particularly from sea level rise, hurricanes, floods, landslides, and wildfires. For example, more than 1,300 residential and commercial properties along the state's coast, valued at almost $340 million, are at risk of chronic flooding. By 2045, with no climate action, this estimate increases to almost 15,600 properties valued at almost $4 billion. Importantly, the growing threat of property losses from natural hazards can have cascading effects on localities across the state, especially in more vulnerable low-income communities. Rising flood and other risks tend to increase insurance rates and decrease property values, which then erodes the local tax base needed for community services, like schools and hospitals. In poorer communities that are already struggling, these changes can be devastating.

Human health and safety. Climate change is already affecting the health and safety of state residents, and these risks will continue to grow in the future. Rising temperatures, in particular, are associated directly and indirectly with a wide range of harmful health effects, from exacerbating existing chronic conditions that impact cardiovascular and respiratory health to altering the transmission of diseases. In the near-term, the most serious temperature-related impacts are likely to be those associated with extreme heat. For example, in the Raleigh, Wilmington, and Fayetteville areas, emergency room visits due to heat stroke and other hyperthermia conditions, characterized by abnormally high body temperature, are projected to increase two to threefold from 2010 to 2050 under a no climate action scenario. In many cases, these costs and impacts will be disproportionately felt by low-income and socially disadvantaged populations who have fewer resources and options for protecting themselves against climate hazards.

Recreation and tourism. Climate change is already affecting popular outdoor recreation activities in the state, ranging from higher temperatures that are limiting skiing in the Appalachian Mountains to sea level rise that is impacting beach visits along the coast, from the Outer Banks to the Crystal Coast and southern beaches. The range and size of these impacts on both residents and out-of-state visitors and the businesses that support them are likely to grow in the future.

ES-3. What Actions Can Be Taken to Address Climate Change in North Carolina?

Given that climate impacts are already occurring in North Carolina and that they are likely to accelerate in the future, what can be done?

Aggressively moving away from fossil fuels, like coal, oil, and gas, will help avert some of the most catastrophic impacts of climate change. While there is no substitute for federal action on climate, state initiatives are essential to making critical near-term reductions, helping **mitigation** of greenhouse gas (GHG) emissions and offering a roadmap for ambitious federal action, especially since North Carolina

ranks among the nation's top 15 emitters of CO_2. Not only could North Carolina set an example for other states but taking the lead on state climate action could lead to accelerated investment in the clean energy economy, promoting the growth of businesses and jobs. Though mitigation is essential for reducing harm in the future, even if we cut emissions, our climate will continue to change because of past emissions. For the climate hazards we can no longer prevent, we must embrace measures that lessen their impacts through **adaptation** and strengthen our ability to recover faster through **resilience.**

Recommended Actions for Climate Mitigation in North Carolina

To reduce or offset greenhouse gas emissions, the following actions are recommended.

- Implement a concrete, declining, and enforceable limit on climate pollution
  - Pair this limit with a price on state emissions that will incentivize meaningful and cost-effective mitigation.
- Reform state utility regulations in a way that removes barriers and creates incentives for clean energy and carbon reduction technology investment.
- Spur the adoption of electric vehicles.
- Incentivize electrification and efficiency investments.

Recommended Actions for Climate Adaptation and Resilience in North Carolina

To strengthen resilience and most effectively adapt to climate change, the following actions are recommended.

- Systematically evaluate and address climate-related risks as part of all private and public sector planning and investment decisions.
- Build partnerships and take advantage of resilience tools and lessons learned across the country.
- Continue to implement and refine state-level resilience plans.
- Incentivize resilient farming practices that have multiple benefits.
- Support data collection and research that advance understanding of resilience-building strategies.
- Take advantage of public and private programs funding resilience planning and action.
- Protect and conserve multi-benefit natural lands, including forests, wetlands, and grasslands.
- Incorporate nature-based shoreline protections in coastal planning and design.
- Incentivize voluntary relocation of homes and businesses away from high-hazard areas.
- Invest in urban green infrastructure by expanding the portion of urban lands containing natural vegetative cover. Invest in microgrid electric systems especially areas most vulnerable to hurricane and storm impacts.

Conclusions

Climate change will have wide-ranging, sometimes irreversible, impacts across the states, regions and sectors, but there is a broad array of promising actions that can be taken at the state, regional, and local level to lessen these impacts and create co-benefits, such as improved air quality and job creation. The actions listed above represent an important but relatively small sample of the many options available.

Selecting the best options will require careful consideration of their costs, but it is equally important to fully account for the multiple and diverse benefits and co-benefits that come with climate action.

- Many nature-based solutions, such as restoring forest wetlands and planting trees, have a long list of benefits. These include offsetting greenhouse gas emissions through carbon storage and strengthening resilience against climate hazards, like floods. In addition, they provide jobs, wildlife habitat and opportunities for outdoor recreation.

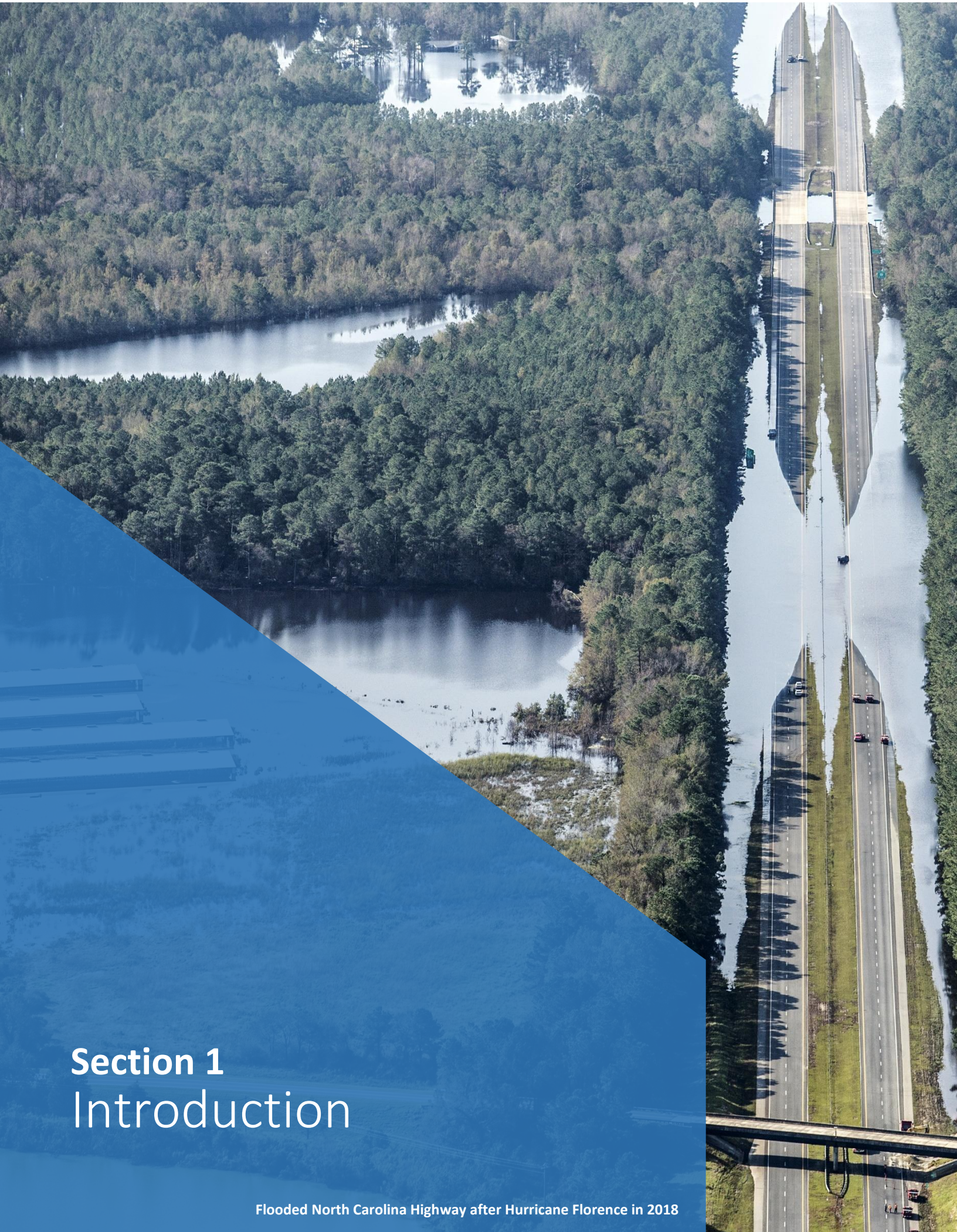
- Many clean energy programs, in addition to reducing greenhouse gas emissions, also make important contributions to the state's regional and local economies. For example, it is estimated that from 2007 to 2018, clean energy programs in North Carolina contributed almost $17 billion to the state's economy—especially in the Coastal region—and supported an average of over 14,000 jobs per year.

- Expanding the scale of and experience with clean energy alternatives is critical for bringing down their costs and making them more competitive. In many cases, zero-emissions alternatives, such as renewable energy technologies and electric vehicles, have become less expensive to own and operate than their fossil fuel-based counterparts. These trends are expected to continue.

- In addition to lowering GHG emissions, reducing fossil fuel use can reduce other pollutants like airborne particulates that cause respiratory illnesses. In some cases, the total value of these air quality co-benefits can be just as large as the main climate-related benefits of reducing fossil fuel use.

- Climate action can be an important vehicle for addressing social inequalities, particularly when socially vulnerable populations are disproportionately harmed by climate hazards. If equitably implemented, programs to protect citizens against the effects of hazards, like extreme heat and inland flooding, can be especially beneficial for people of color and low-income communities.

- Action is contagious. Evidence from observing community behaviors has repeatedly shown that healthy habits spread from person to person. With these beneficial ripple effects, actions taken by a few to reduce fossil fuel use or to adopt resilient farming practices can motivate change across an entire community. Similarly, taking leadership on climate action in North Carolina can serve as a catalyst for change across the country.



Section 1
Introduction

Flooded North Carolina Highway after Hurricane Florence in 2018

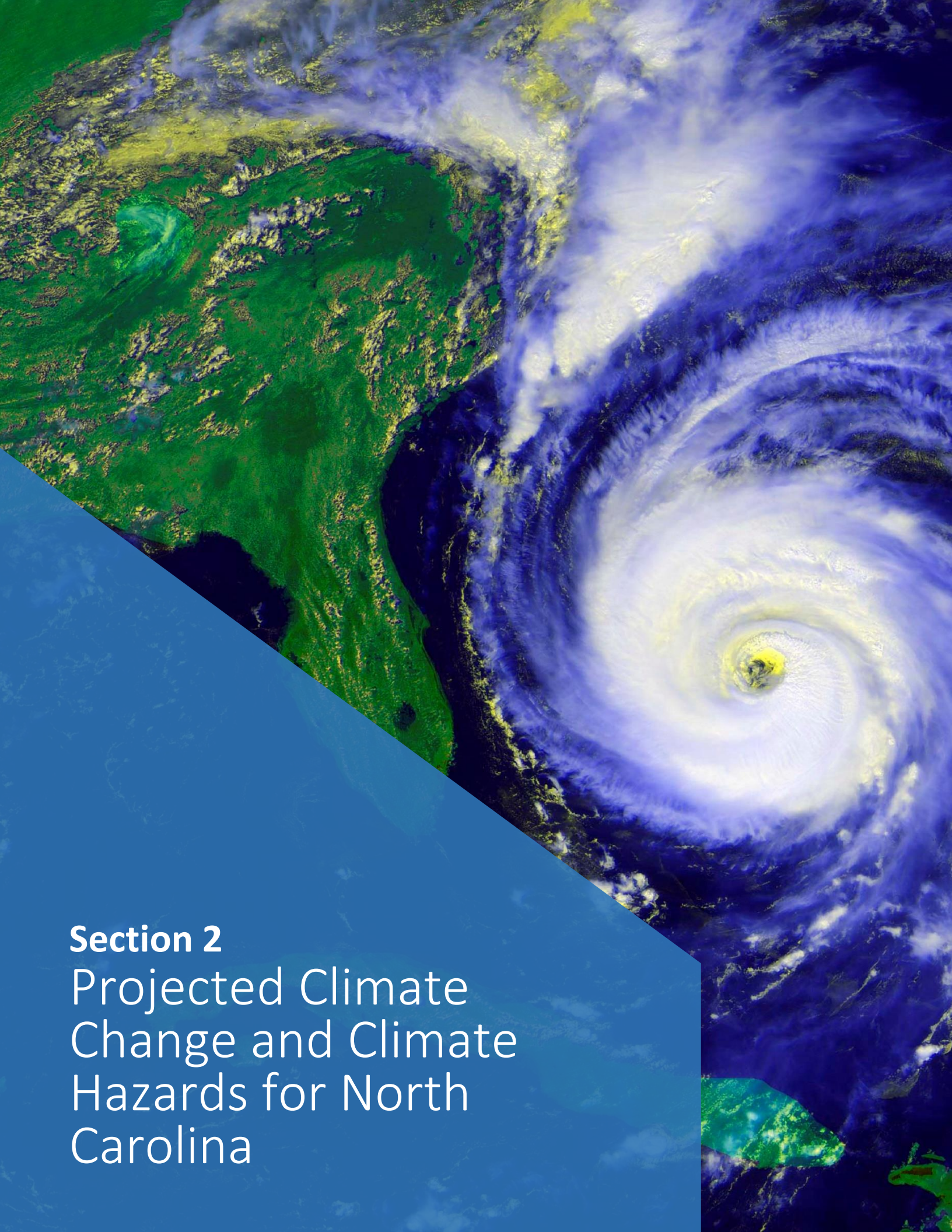
Over the last century, the Earth's climate has warmed at an unprecedented pace. Unless significant action is taken to control releases of carbon dioxide (CO_2) and other heat-trapping greenhouse gases, this warming trend will continue and is likely to accelerate over the rest of the century.

Here in North Carolina, evidence clearly shows that the climate has been changing over recent decades, and even greater changes are projected for the next 20 to 30 years. As this warming trend worsens, so will related impacts across the state. Sea levels will continue to rise. Strong storms will continue to become more frequent and severe, and flooding will continue to worsen and become more widespread.

In the absence of concerted action, these impacts will impose significant costs on the residents of North Carolina and its economy. To promote a better understanding of the range and size of these potential impacts, this report focuses on eight major sectors of the state's economy and summarizes available evidence on the projected costs of climate change for these sectors. It also describes how these impacts are expected to vary geographically across the state. In addition to examining specific sectors, it also discusses cases where climate impacts are expected to disproportionately affect low-income communities and people of color who will be more vulnerable to harm.

This report calls specific attention to impacts in the relatively near future — that is, the next 20 to 30 years. Climate change is already affecting North Carolina. Therefore, it is critical to understand the challenges facing the current and next generation of North Carolinians. This means not only taking stock of the current and near-term costs of climate change, but also identifying what *this generation* can do to address these challenges. As the health and livelihoods of North Carolinians are already being harmed and weakened by the COVID-19 pandemic, it is especially important to build resilience against the growing additional impacts of climate change

Given the serious threat already posed by climate change, action is urgently needed. Fortunately, there are many things that the public and private sector can do at the local, regional, and state levels to strengthen the state's ability to withstand the threats of climate change. The final section of this report provides several concrete recommendations for actions to counteract the hazards of climate change.



Section 2

Projected Climate Change and Climate Hazards for North Carolina

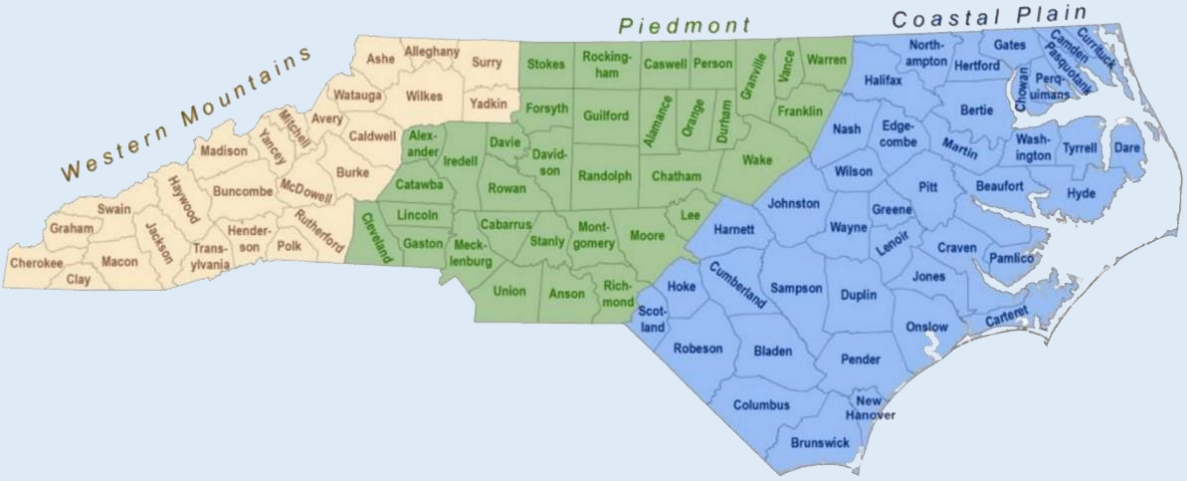
To describe how the people and economy of North Carolina will be affected by climate change, it is useful to first understand (1) how the state's climate is projected to change and (2) what types of hazards will be caused or worsened by these changes. Therefore, we begin this section by summarizing scientific predictions for the two main measures and indicators of **climate change**—temperature and precipitation—in the state over the coming decades. Then, we identify and describe how specific **climate hazards**—such as extreme heat, flooding, droughts, and landslides—are predicted to change across the state.

In Section 3, we describe how these climate hazards are projected to affect our state's citizens and economy. The section includes evidence of climate impacts for eight specific sectors of the state economy.

Three Regions of North Carolina

Because projected climate change impacts often vary geographically across the state, this report follows the approach used in the NCCSR[1] by distinguishing three main regions of the state — Mountain, Piedmont, and Coastal — as shown in the map.

Regions and Counties of North Carolina



2.1 Projected Climate Change for North Carolina

As in the rest of the world, North Carolina's climate is already changing. How temperatures and precipitation continue to change from here depends critically on the total amount of greenhouse gases released into the atmosphere in coming years. To tackle the uncertainty that comes with making predictions about global emissions, climate scientists developed a set of four scenarios of future conditions, known as Representative Concentration Pathways (RCPs). Each of the four RCP scenarios – RCP2.6, RCP4.5, RCP6.0 and RCP8.5 – relies on a different set of assumptions about factors driving emissions, such as future energy use, population and economic growth, and land use change. The scenarios range from RCP2.6, which assumes aggressive action to reduce emissions, to RCP8.5, which assumes little to no action.

For this report, we focus on how climate change is expected to impact North Carolina residents under the RCP8.5 "no climate action" scenario. In other words, what is likely to happen if no meaningful action is taken at a global scale to reduce emissions. In this report, we also focus on impacts that are projected to occur over the next 20 to 30 years.

Temperature

According to the recently released *North Carolina Climate Science Report* (NCCSR),[1] average annual temperatures in North Carolina since 1970 have increased 1 to 2°F (shown in gray in **Figure 2.1**). For comparison, the overall average observed temperature from 1970 to 2013 is shown (black line) to have been about 59°F. **Figure 2.1** highlights the fact that climate change is not just a distant future phenomenon. In the next 20 years alone, without action (RCP 8.5, shown in red shading), temperatures are projected to increase by another 2°F. The ranges shown within the red and blue shaded areas of the figure represent ranges of uncertainty, which grow as temperatures are projected farther into the future. Despite these uncertainties, there is strong evidence not only that temperatures will continue to rise without climate action, but that they will accelerate over the rest of the century.

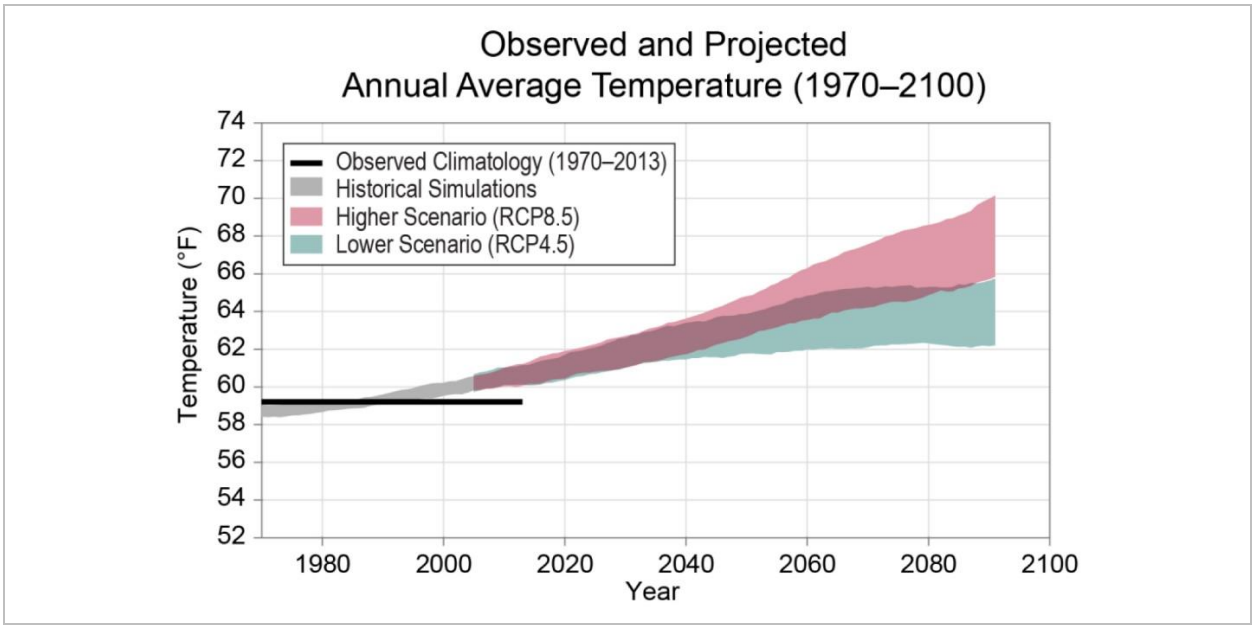


Figure 2.1. Observed and Projected Temperature Change in North Carolina[1]

Precipitation

According to the NCCSR, total annual precipitation in North Carolina is ***likely*** (66% to 100% probability) to increase in the coming decades. As shown in **Figure 2.2**, by mid-century under the no climate action scenario, annual rainfall in most of the Mountain and Piedmont regions of the state is expected to be 3 to 6% higher than current conditions.

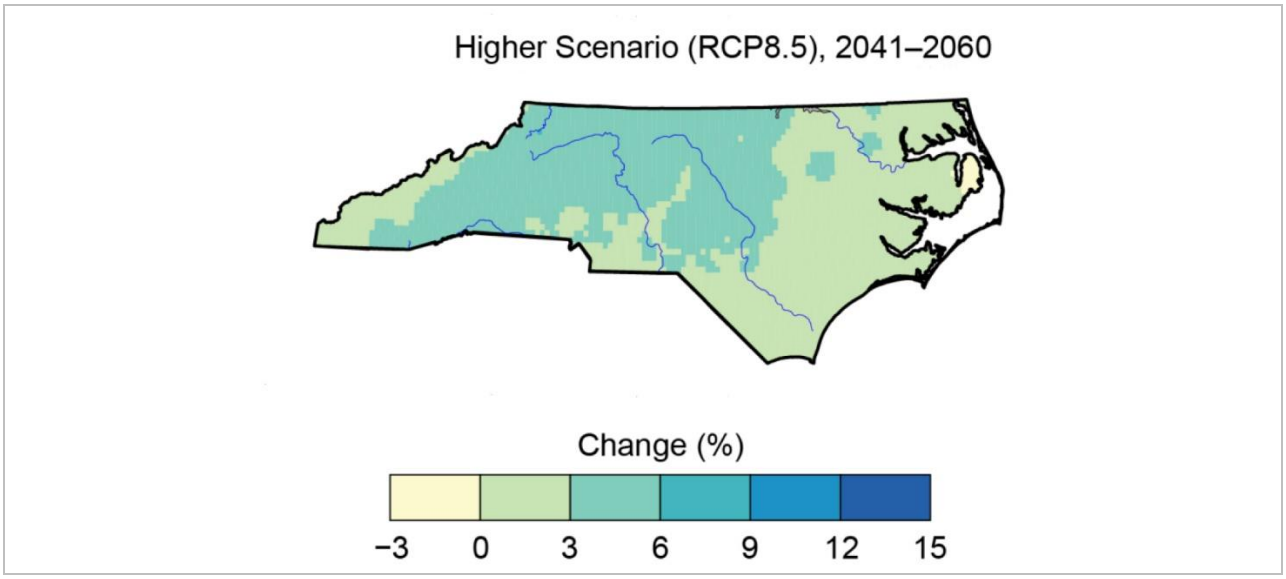


Figure 2.2. Projected Change in Annual Precipitation across North Carolina (under a no climate action scenario)[1]

2.2 Projected Climate Hazards for North Carolina

Climate hazards are climate-influenced natural processes, conditions, or events that can directly harm human health, livelihoods, or natural resources.[2] Within this report, we identify nine main types of hazards and provide a brief description of how these hazards are projected to change across North Carolina over the next 20 to 30 years.

Some of these hazards are directly associated with and categorized under changes in temperature and precipitation, such as extreme heat and drought. However, the list also includes hazards indirectly caused by these climate changes, such as flooding, water, and air quality changes, and increases in landslide events. Although projected changes in these indirect hazards are often less certain than projections of temperature and precipitation changes, as described in Section 3, many represent significant threats to North Carolina residents and the economy.

Temperature increases

In addition to the projected increases in average annual temperatures previously shown in **Figure 2.1**, the number of days with **extreme heat**—that is, with maximums above 95°F—will likely increase. According to the NCCSR, in the next 20 years, most of the Piedmont and Coastal regions will experience an average of 10 to 15 more days per year with maximum temperatures above 95°F (**Figure 2.3**).

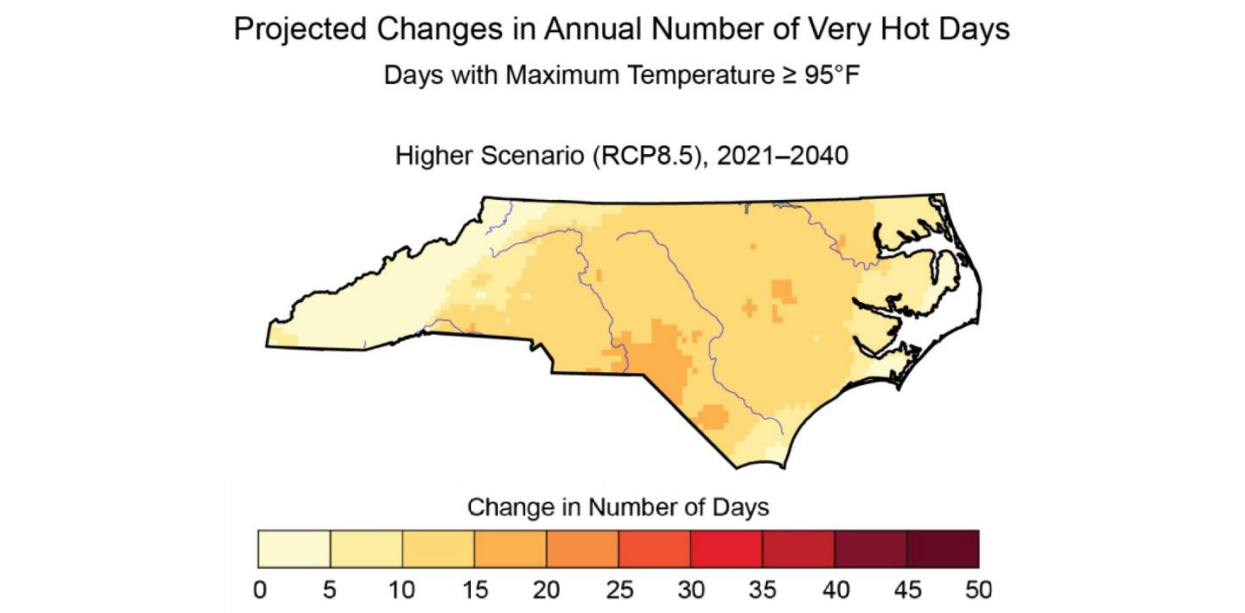


Figure 2.3. Projected Changes in Very Hot Days in North Carolina (under a no climate action scenario)[1]

Precipitation changes

In addition to the projected increases in total annual precipitation, the NCCSR projects that the frequency and intensity of **extreme precipitation** events — i.e., days with more than 3 inches of rainfall—is ***very likely*** (90% to 100% probability) to increase across the entire state. It also concludes that severe **droughts** are ***likely*** to be more frequent in the future, and they will be more intense when coupled with increased evaporation due to higher temperatures.

Flooding

In the Coastal region, flooding will continue to be more frequent and severe due to the combined effects of **sea level rise** and more severe **tropical storms and hurricanes**. Sea levels along the North Carolina coast have already risen significantly over the last century. For example, from 1940 to 2010, they rose on average by more than 1 foot, which is more than 40% above the average global rise in sea levels.[3] In some locations, like Duck on the Outer Banks, they rose by almost 1.5 feet. Sea levels are projected to rise even faster in the future under a no climate action scenario.[1] Over the next 20 years, they are projected to rise by another foot across the coast. As this happens, more areas will become permanently flooded, and others will become more vulnerable to flooding during high tides (also known as nuisance or sunny day flooding). Peak water heights during coastal storm events (storm surges) will also cause more flooding because they will occur on top of already higher sea levels. In addition, a warming planet is projected to increase the intensity of hurricanes, which will lead to larger storm surges on top of higher seas.

In all other parts of the state, climate change will likely cause more **inland flooding** due to more frequent and severe extreme precipitation events, including from hurricanes. NCCSR predicts that it is **very likely** that precipitation from hurricanes affecting North Carolina will increase in the future.[1] Even weaker storms can cause substantial flooding across the entire state, as demonstrated by Hurricane Florence in 2018, which was only a Category 1 hurricane when it made landfall in North Carolina. It is likely that climate change, through its warming effects on sea surface temperatures, contributed to the extreme amounts of rainfall that accompanied Florence.[1,4]

High winds

In addition to precipitation, climate change's effects on the intensity of hurricanes and severe thunderstorms will also bring higher wind hazards to the state. For example, as Category 4 and 5 hurricanes become more likely, average hurricane wind speeds would increase by up to 10%.[5]

Wildfires

Climate change is likely to increase wildfire risks in North Carolina, primarily due to more frequent and severe droughts in the state.[1] According to the U.S. Forest Service, the eastern part of the Coastal region and the southern part of the Piedmont region are the areas in North Carolina that currently have high or moderate wildfire potential.[6]

Landslides

Landslides are already increasing in North Carolina as a result of more extreme rainfall events.[7] They will likely continue to increase as climate change and projected growth in the frequency and intensity of extreme precipitation events. Landslides predominantly occur on the steeper slopes of the state's Mountain region, and they are often triggered by rainstorms.[8]

Water temperature and quality changes

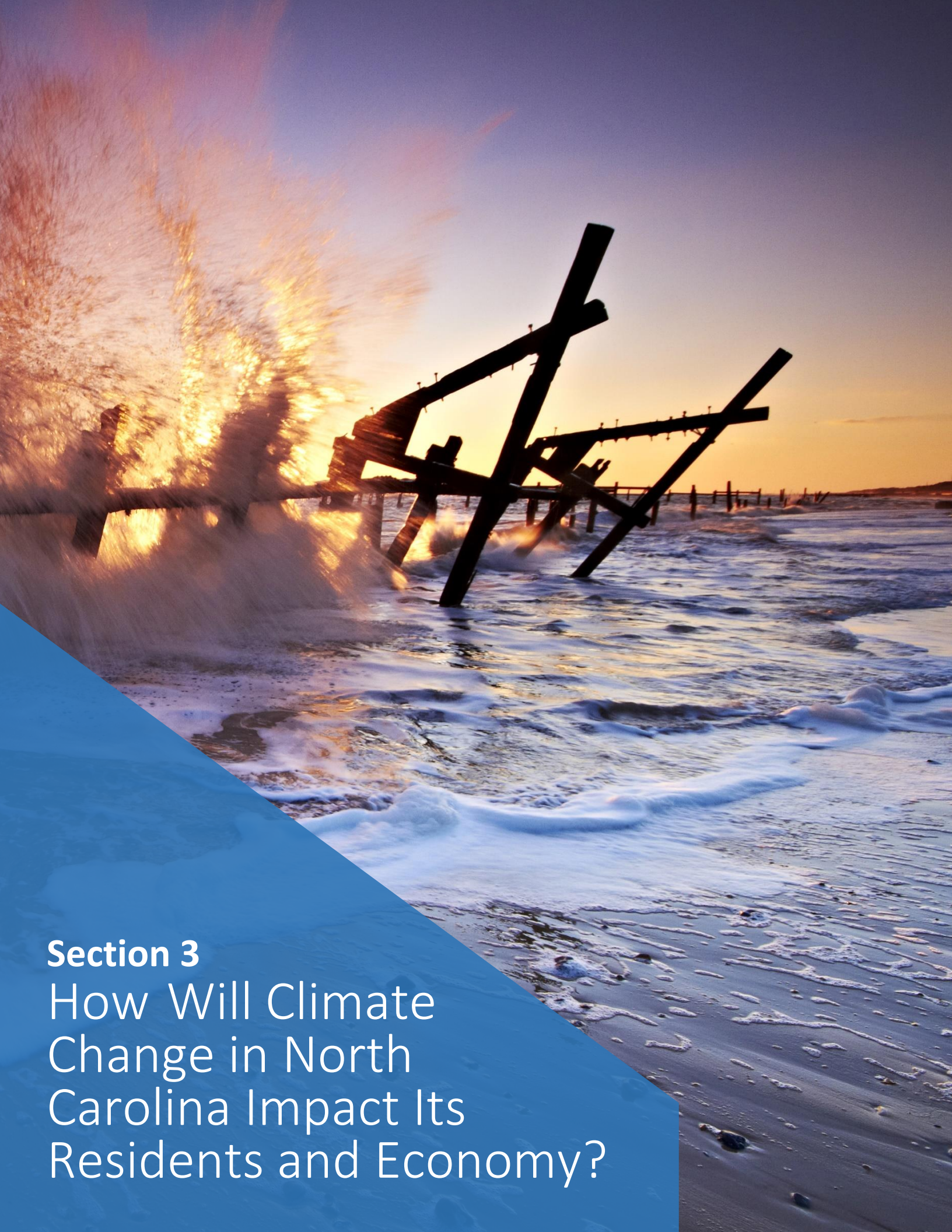
As the air warms, so will the state's lakes, rivers, streams, and estuaries. These changing temperatures can alter water quality in several ways, for example by reducing the amount of oxygen the water holds and promoting the growth of algae.[9] More generally, aquatic habitats will become less suitable for certain species, such as brook trout and other cold-water fish in the Mountain region. In some instances, they will be replaced by other non-native species, some of which will be invasive and have a deleterious effect on the local ecosystem.[10] Stronger rainstorms will also cause more soil erosion and wash more pollutants into the state's waterbodies.[11] In the Coastal region, continuing sea level rise due to climate change will also cause saltwater to intrude farther inland, affecting water quality in coastal rivers and streams, as well as groundwater systems that are used for drinking water and crop irrigation.

Air quality changes

A changing climate will also alter the environment in ways that can worsen air quality. For example, shorter winters will lengthen the pollen season for some trees and grasses, leading to higher levels of allergenic pollen in the air.[12] In addition, the increased risk of wildfires, due to more intense droughts, also means an expected increase in days with high smoke levels, making the air hazier and less healthy to breathe in more areas.

Insects, pathogens, and invasive plants

In addition to altering the existing habitat for native animal and plant species, climate change will likely create conditions that favor some undesirable or invasive species. For example, warmer temperatures and wetter climates may allow for the spread of certain mosquitos and ticks that carry disease-causing pathogens, like those that cause Lyme disease.[12] Certain invasive plant species, such as kudzu, are also likely to spread more broadly with warmer temperatures.[13]



Section 3

How Will Climate Change in North Carolina Impact Its Residents and Economy?

In this section, we explore how North Carolina's residents and economy will be affected in the near future by climate change, especially if nothing is done to counteract these changes.

Table 3.1 summarizes the impacts of the climate hazards on North Carolina. We group the affected parts of North Carolina society into eight main sectors, which are shown as column headings in the table. The **circles** in the table identify the climate hazards (in each row) most likely to have a direct impact on each sector.

There are three important notes that go along with this table:

1. Each circle represents a *direct* impact from the hazard to the sector. For example, drought has a direct impact on agriculture (by reducing water available for crops). Drought can also have *indirect* effects on agriculture, such as by causing wildfires, but this impact is shown by a circle in the wildfire hazard row.
2. The table does not include "secondary" impacts from one sector to another. For example, it shows that drought has a direct impact on the energy sector (e.g., by reducing hydropower generation). It does not show secondary impacts on other sectors, such as on the commercial property sector that purchases that energy.
3. Table cells without circles do not necessarily mean that there are no direct impacts from the hazard to the sector. Rather, either the impact is expected to be relatively small or there is currently a lack of evidence regarding the presence or size of an impact.

The remainder of this section provides a detailed sector-by-sector description of these impacts.

Table 3.1. Summary of Climate Hazards Affecting Key Sectors of North Carolina

CLIMATE HAZARDS	DIRECTLY AFFECTED SECTORS							
	Agriculture & Forestry	Commercial Fishing & Aquaculture	Energy Supply & Demand	Transportation Infrastructure	Water Infrastructure and Services	Commercial & Residential Property	Public Health & Safety	Recreation & Tourism
Air temperature increases								
Extreme heat	●		●	●			●	●
Higher average temperature	●		●	●			●	●
Precipitation changes								
Change in average precipitation	●			●				
Drought	●	●	●		●			●
Flooding								
Sea level rise	●	●	●	●	●	●	●	●
Storms	●	●	●	●	●	●	●	●
High winds	●	●	●	●		●	●	●
Wildfires	●					●	●	●
Landslides				●		●	●	
Water temperature & quality changes	●	●	●		●		●	●
Air quality changes							●	●
Insects, pathogens, & invasive plants	●						●	●

In the following subsections, we provide sector-by-sector descriptions of the impacts summarized in **Table 3.1**. Depending on the available evidence, we also describe how these impacts are likely to vary across the state (e.g., by region or county), depending on geographic, demographic, and economic characteristics. These subsections also explore cases where climate change and its associated hazards are likely to have disproportionate impacts on vulnerable communities in the state.

3.1 Impacts on Agriculture and Forestry

Together, agriculture, forestry, and agribusiness, including food and fiber systems, contribute almost $100 billion annually to North Carolina's economy.[14,15] In 2017, the agriculture and food industry accounted for over 700,000 jobs in the state and more than $77 billion in economic activity.[16] The Coastal region is where the bulk of agricultural production takes place, providing about 70% of the state's crop value and 60% of its animal production value, followed by the Piedmont and the Mountain regions. Crop and animal production serve as the cornerstone of the food and agriculture sector, generating a combined annual value of $11 billion in 2018[17,18,19] with roughly 70% from animal production. In 2017, the state was the leading national producer of poultry, hogs, and tobacco.[20]

Meanwhile, the forestry and related sectors in North Carolina (including forestry and logging operations, sawmills, furniture mills, and pulp and paper industries) directly contributed $20.8 billion to the state's economy in 2018, almost 4% of the gross statewide product.[21] Additionally, forestry was considered the top employer for positions in the manufacturing sector.[22] The largest percentage of timberland acres is located in the Coastal region, followed by the Mountain region.[23]

The agriculture and forestry sector is vulnerable to almost all of the climate hazard categories. Changes in average temperature and precipitation will continue to have a variety of effects on production and farm income, but the largest harmful impacts are likely to be the result of intensifying extreme events, such as hurricanes, droughts, and floods.

Average temperature and precipitation

Whereas changes in *extreme* heat and precipitation will have broad negative impacts on agricultural production, changes in *average* temperatures and precipitation across the state will have varying impacts. For example, even when accounting for the fertilizing effects of higher CO_2 levels in the atmosphere, corn yields will be more negatively affected by hotter summers than other crops, such as cotton, soybeans, wheat, and peanuts.[24] In addition, while small temperature increases can initially benefit some crops, eventually higher temperatures will decrease yields.[25] Given these varying effects, it is estimated that over the next 20 years, changes in average temperature and precipitation will reduce *overall* annual crop yields in the Piedmont and Mountain regions by roughly 3% under the no climate

action scenario, compared to current climate conditions. [26,27] By mid-century (2050), they are projected to be 6% to 7% lower. In contrast, overall changes in annual crop yields due specifically to changes in average temperature and precipitation (along with CO_2 fertilization) in the Coastal region are projected to be relatively small in the coming decades. However, as discussed below, these yield changes do not account for the damaging effects of changes in extreme weather, such as droughts and hurricanes.

Extreme Heat

As the number of days with extreme heat rises in the coming decades, workers in the agriculture and forestry sectors will be particularly affected. In recent decades, these workers have accounted for 10 to 20% of heat-related illnesses and deaths in the United States.[28] In North Carolina, almost half the recorded heat-related fatalities from 1977 to 2001 were among farmworkers.[29] Because they often lack adequate protections, migrant farmworkers are particularly vulnerable to heat-related illnesses. [28]

Drought

Extended periods with limited or no rainfall can have particularly detrimental impacts on crop production. The state's recent history indicates just how much damage can occur under drought conditions. The most intense period of drought occurred in 2007. At its peak, 66.2% of land was characterized as under an exceptional drought that led to crop and pasture loss as well as water shortages.[26] The 2007 drought caused over $300 million in total losses to the state's crop economy, with some of the greatest losses—roughly $160 million—experienced by soybean farmers.[30] Moving forward, the state's agricultural sector will be particularly affected if droughts become more intense as predicted by climate models.

Flooding and wind

The agriculture and forestry sectors are projected to become increasingly vulnerable to flooding and wind damage, particularly in the Coastal region. Increased flooding is expected to be caused by both sea level rise and more severe hurricanes, whereas increased wind damage would primarily be due to stronger hurricanes. Although sea level rise will permanently inundate some crop and forest lands,[31] even increases in short-term saltwater flooding from storm surges are a significant threat to forest and agricultural areas because the salinity accumulates and contaminates the soil.[32]

Predictions of future hurricane damage to the agricultural and forest sector are more complex, but past experience can provide an important perspective. For instance, over the last decade, four hurricanes in particular—Irene in 2011, Matthew in 2016, Florence in 2018, and Dorian in 2019—have together caused over $350 million in crop damages.[33] Florence, alone, caused $1 billion in combined crop and livestock losses, $50 million in forestry losses, plus almost $140 million in losses due to emergency livestock disposal and damages to agricultural building, equipment, and infrastructure.[34] In the swine industry, overflows occurred at 50 waste ponds used to collect animal manure, with two cases causing roughly 7 million gallons of waste to spill into local waterways.[35] Meanwhile, poultry farmers struggled with how to deal with the 4.2 million dead chickens and turkeys that drowned as a result of flooded poultry houses in the southeast.[36]

Wildfire

Extreme heat and more intense droughts, anticipated with further climate change, will provide the conditions needed for wildfires to occur. Wildfires can cause extreme damage to property and crops. For

example, in 2016, one wildfire burned 667 acres of timber in Brunswick County, which resulted in over $2 million of damage.[37]

Water quality changes

Sea level rise in the Coastal region is allowing saltwater to move farther inland. Below the surface, it pushes saltwater from the coast into freshwater aquifers. Above ground, higher tides and storm surge push saltwater farther into freshwater streams. The Albemarle-Pamlico Peninsula is particularly vulnerable to saltwater intrusion due to the flat terrain and extensive network of drainage canals.[38] As saltwater infiltrates these water sources, this movement affects water quality. When lower quality water encroaches on or is applied to agricultural land, soils are degraded, and yields are reduced. More evidence is needed to reliably estimate the dollar value of current and future crop losses due to saltwater intrusion.[39]

Insects, pathogens, and invasive plants

Invasive insects, pathogens, and plants are likely to have increasingly detrimental effects on agriculture and forestry operations.[40] Several different climatic hazards may play a role in increasing invasive species. For example, winter freezes play a critical role in controlling and mitigating the spread of these damaging species. However, as global and local temperatures rise, winter freezes may become less frequent. Similarly, drought conditions encourage the spread of destructive insects, like the bark beetle, which can severely harm forests.[41] Meanwhile, many pollinators, like bees are not very tolerant to high temperatures or precipitation.[4243] Several studies have been conducted, which show that invasive species, such as kudzu, privet, and cogon grass, are likely to spread across the Southeastern United States over the next century due to their ability to tolerate harsh conditions. [40,41]

Intercoastal Waterway, North Carolina

3.2 Impacts on Commercial Fishing and Aquaculture

Commercial fishing has long been an integral part of North Carolina's coastal culture, community, and economy. Over the last 5 years (2015–2019), the total value of commercial fish landings in the state—including crab, shrimp, flounder, and tuna—has averaged roughly $90 million per year. More broadly, the industry has been the source of over 7,000 jobs in the state and over $300 million per year in total economic activity.[44,45]

In contrast, aquaculture—the farming of aquatic plants and animals—is more of an emerging industry. Most recently, in 2019, the value of products sold by 107 aquaculture farms in North Carolina totaled almost $60 million.[46,47] The industry produces a range of fish and crustacean species, including trout, catfish, crayfish, and shellfish.[48]

Flooding and wind

Flooding and wind damages caused by tropical storms and hurricanes in recent years has led to costly losses in the commercial fishing and aquaculture sectors. For example, Hurricane Florence in 2018 caused $13.5 million in commercial fishing and aquaculture losses through harvest losses and damages to buildings, equipment, and gear.[49] For the state's shellfish aquaculture industry specifically, Hurricane Florence and Tropical Storm Michael caused combined damages of almost $10 million to nearly 50 aquaculture farms across eight coastal counties.[50] Flood-related losses to the commercial fishing and aquaculture industry are likely to worsen in the coming decades due to an expected increase in tropical storm intensity.

Water quality and temperature

Ocean warming will cause habitats for commercially caught fish species in the mid-Atlantic to shift, becoming more favorable for some species and less favorable for others. An analysis of fishing communities on the East Coast found that by mid-century, overall fishing opportunities will decline for five North Carolina Communities —Hatteras, Oriental, Engelhard, Lowland, Beaufort—including more than a 10% estimated decline in gillnet fishing opportunities from Hatteras.[51]

Increasing water temperatures in the state's estuaries can also harm commercial fisheries by creating conditions that result in larger and more frequent fish kills[52] (for example through more harmful algal bloom outbreaks) or bacterial contamination of shellfish (for example, *Vibrio vilnificus* in oysters).[53] However, the magnitude of these future impacts is uncertain.

In addition to increasing water temperatures, ocean acidification from additional CO_2 in the water can harm commercial shell fishing operations by directly damaging shells or by compromising early development and survival of shellfish; however, the extent of future acidification and damages in the state's estuaries is also uncertain.[52]

3.3 Impacts on Energy Supply and Demand

In the coming decades, a range of climate hazards will not only increasingly impact North Carolina's ability to produce energy at a low cost for its citizens, but hotter and longer summers will drive higher demands for electricity. Growing energy bills under these conditions will be especially burdensome for low-income communities, such as those in the Coastal region's southwestern counties, where high rates of poverty coincide with the areas with largest projected increases in extreme heat days (see Section 3.7).[54]

In 2018, North Carolina was ranked 26th in state-level **primary energy production**. Over 80% of this production was from nuclear, hydro, solar, and wind electricity production. The state is not a significant producer of fossil fuels, like coal, oil, and gas. North Carolina also currently ranks 8th in total **electricity generation**. Although the state is ranked 2nd in installed solar electricity generating capacity and nearly a tenth of all electricity comes from renewable sources, over half of North Carolina's electricity is generated using fossil fuels imported from outside the state and 36% comes from nuclear generation. With roughly 70 hydroelectric dams located across the state, hydropower is the second-largest source of renewable generation.[55]

Total spending on **energy consumption** in North Carolina was $34 billion in 2018. As shown in **Figure 3.1**, the transportation sector, which includes personal automobiles as well as other passenger and freight vehicles, accounts for almost half of the state's annual energy use. Almost 95% of this energy is derived from fossil fuels (mainly petroleum). The residential sector accounts for roughly 25% of energy use, with annual spending that averaged roughly $2,100 per household in 2018.[56] In 2017, North Carolina ranked 12th in per capita electricity consumption by the residential sector.

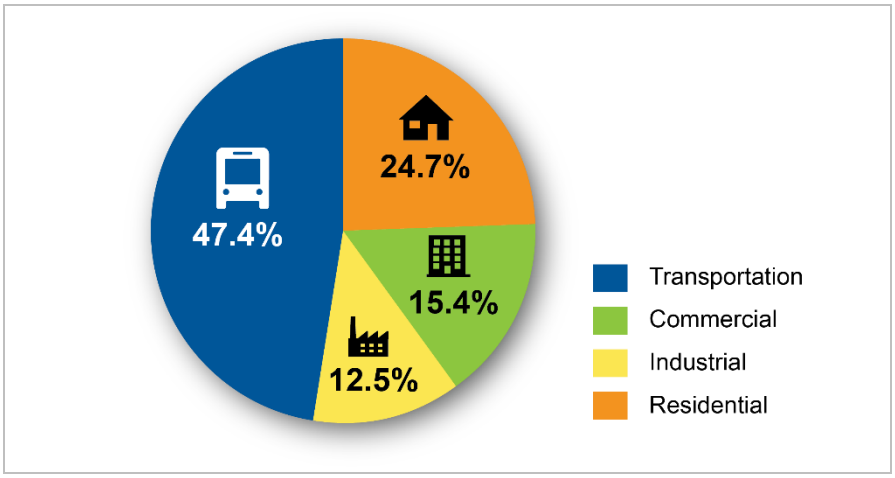


Figure 3.1. Share of North Carolina Energy Consumption by Sector in 2018

Temperature changes

Rising average temperatures across the state in all seasons will affect households' spending on energy, both by increasing spending on air conditioning and decreasing spending on heating. Overall, however, the increasing yearly costs are expected to outweigh the yearly savings. Over the next 20 years, in the Coastal and Piedmont regions, residential energy spending is projected to be 2 to 3% higher each year under the no action scenario. By mid-century, it is projected to be 6 to 7% higher each year. Increases are also projected for the Mountain region, with residential energy spending expected to be 1 to 2% higher over the next 20 years, and roughly 4% higher by mid-century.[26,57]

Commercial energy spending is also projected to increase but at a somewhat slower pace than residential. In the Coastal and Piedmont regions, annual commercial spending is projected to be 2 to 3% higher over the next 20 years and over 4% higher by mid-century under the no action scenario. In the Mountain region, the projected increases for those same periods are 1% and 2%, respectively.

Drought

The ability of the state's roughly 70 hydroelectric dams to generate power is vulnerable to extreme drought because they depend on adequate rainfall in the Mountain and Piedmont regions. Over the last 20 years, hydroelectric plants have generated roughly 4% of North Carolina's total electricity generation, except for during drought years (2001–2002, 2007–2008), when their contribution was closer to 2%.[56] In extreme cases, drought can also cause shutdowns at thermoelectric plants by causing water levels to fall below the intakes used for cooling water.

One study looking at the potential impacts of drought for Duke Energy's electricity generating operations in North Carolina and South Carolina (including thermoelectric, hydropower, solar systems) concludes that extreme drought would cause over $100 million in losses for the company.[58]

Flooding and wind

As storms and hurricanes increase in severity, the state's energy infrastructure will be at increased risk of flood and wind damage. This infrastructure includes powerlines and pipelines for distributing electricity and gas, as well facilities for storing fuels and generating electricity. The extent of these future damages is uncertain, but a useful point of comparison is the impact of Hurricane Florence in 2018, which caused almost $700 million in damages to the electrical and gas infrastructure.[59] Additionally, Hurricane Florence left at least 759,000 customers without power in the state.[60]

Water temperature increases

In North Carolina, 80 to 85% of electricity comes from thermoelectric power plants—coal, nuclear, natural gas—that need water to cool their systems. Warmer water due to climate change can greatly reduce the efficiency of these cooling systems, which reduces generating capacity and increase the costs of providing electricity.[61] These higher costs will translate to higher energy bills for consumers.

Blue Ridge Parkway, North Carolina

3.4 Impacts on Transportation Infrastructure

North Carolina's transportation infrastructure includes over 200,000 miles of roads and over 18,000 bridges, which provide essential support for the state's people and economy.[62,63] Additionally, 19 interstate highways run through the state, playing a critical role in transportation, travel, and the national and state economy.[64,65] North Carolina has also been among the top-20 ranked states in terms of total railroad miles for passenger and freight trains.[66]

North Carolina currently spends roughly $1 billion per year to maintain the state-owned road network, and is ranked 9th in the nation for average maintenance spending per lane-mile.[67] Climate change, particularly through its effects on sea level and extreme events, such as floods, extreme heat, and landslides, will make it increasingly costly to maintain this system.

Temperature and precipitation change

Roads are vulnerable to changing temperatures and precipitation. Higher temperatures lead to increased cracking and rutting damages, resulting in higher costs of repair and maintenance. For the Southeastern United States as a whole, higher average temperatures by 2050 are projected to increase average annual per-mile road repair and maintenance costs. However, the increased costs from these temperature changes–roughly $2 per lane-mile or about $0.5 million per year in North Carolina[68]—are fairly small compared to the potential damages from other climate hazards discussed below.

Flooding and wind

By 2050, it is estimated that 1,400 (1%)[69] of bridges in the Southeast United States will be vulnerable to more frequent flooding due to climate change, resulting in $430 million in additional maintenance costs per year. [68] Assuming these rates of vulnerability and maintenance costs also occur here, the increase in annual bridge maintenance costs are estimated to be almost $50 million in 2050 for the state.[70]

In the Coastal region, one result of continuing sea level rise will be more cases of high-tide flooding of roadways. In North Carolina, over 2,000 miles of roadways (over 1%) are estimated to already be at risk of high-tide flooding, and the total number of hours that motorists spend in roadway delays because of high-tide flooding will increase more than 4-fold between now and 2060, even under an intermediate sea level rise scenario.[71]

Estimates of increases in future road and bridge damages due specifically to the expected increase in severity of hurricanes are uncertain. However, as a point of reference, Hurricane Florence is estimated to have caused roughly $260 million in damages to roads and bridges in 2018.[59]

Landslides

More severe rainfall events in the Mountain region are expected to increase the frequency and severity of landslides. Since 1990, 57 landslides have caused serious damages to 32 roads. The costs of road repair due to landslides vary widely; however, previous examples include a total of $15 million to repair damages from two separate rockslides on I-40 in 1997 and 2009.[72]


Fontana Dam, North Carolina

3.5 Impacts on Water Infrastructure and Services

Our state's water infrastructure includes a wide variety of public and private systems and structures designed to store, transport, and treat water for households, industry, and government. Over 80% of the state's 10.5 million residents receive treated drinking water from more than 2,000 community water systems.[73] These systems are served in part by a network of roughly 200 water supply reservoirs.[74] In addition, the state has over 200 municipal wastewater treatment plants,[75] nearly 2 million septic systems,[76] and over 100 municipal stormwater sewer systems.[76]

Many of the most severe climate threats facing North Carolina—from sea level rise, to stronger rainstorms and hurricanes, to changes in water quality and temperature—are related to water. Therefore, not surprisingly, climate change is already putting significant pressure on the state's water systems, and these pressures will only increase in the coming decades.

Drought

Although North Carolina's system of water supply reservoirs is designed to ensure adequate supplies during dry periods, during severe droughts, additional measures, such as customer water use restrictions, are also needed to conserve water. For example, during the 2007-2008 drought, about half of the state's water systems implemented some type of mandatory or voluntary conservation measures, including limits on yard watering, car washing, and swimming pool filling.[77,78] As droughts become more likely, water customers will increasingly be faced with these types of restrictions.

Flooding

As sea levels continue to rise, an increasing number of underground septic systems in the Coastal region will become inoperable. These systems require over a foot of dry soil beneath them to properly drain and treat human waste; however, groundwater levels are rising due to higher sea levels and heavy rainstorms. As water levels rise, septic systems must be pumped more regularly or retired and replaced with a connection to community sewer lines, which can cost over $5,000, and may not always be available in rural communities.[79] If these measures are not taken, the waste can become a potential

threat to local water quality and public health. Preliminary estimates indicated that about 20,000 currently installed septic systems are at risk of flooding over the next 100 years.[80]

Estimates of increases in future damages to water and sewer systems due to the expected increase in severity of hurricanes are uncertain. However, as a point of reference, Hurricane Florence is estimated to have caused roughly $88 million in damages in the state to water and sewer systems in 2018.[59]

Higher risks of dam failures due to more severe inland flooding is another potentially significant source of risk. Currently, of the roughly 1,700 dams in North Carolina that are classified as high or intermediate hazards if they breach, over 10% have been rated as in poor or unsatisfactory condition. The potential costs of dam failures vary widely depending on the specific reservoir and local conditions, but they can include extensive property damages, loss of life, repair costs, business interruptions, and other costs.[74]

Water quality changes

When combined with nutrient pollution, one potential impact of higher water temperatures is higher risks of harmful algal blooms in surface waters. When the affected waters are used as a source for drinking water, the presence of these blooms can greatly increase water treatment costs. For example, an outbreak of blue-green algae in an Ohio lake in 2010 resulted in over $13 million in additional spending for treatment systems at the local water utility.[81] Blue-green algae have also been detected--but at still relatively low levels--in major water supply reservoirs in North Carolina, such as Jordan Lake which supplies about 300,000 people in southern Wake County.[82]

3.6 Impacts on Commercial and Residential Property

About 1.6 million commercial properties are in North Carolina. These include office, industrial, retail, and other types of commercial real estate.[83] The state also has almost 5 million residential housing units (e.g., houses and apartments). Roughly 65% of these housing units are occupied by their owner (i.e., not rental properties) and have a median value of $165,000.[84] As the climate changes, both types of properties will face growing risks, particularly from natural hazards, such as hurricanes, floods, landslides, and wildfires.

Importantly, the growing threat of property losses and damages from natural hazards can have cascading effects on localities across the state, especially in more vulnerable low-income communities. Rising flood and other risks tend to increase insurance rates and decrease property values, which then erodes the local tax base needed for community services, like schools and hospitals. In poorer communities that are already struggling, such as Lumberton in the Coastal region, these changes can be particularly devastating.[85] [86]

Flooding and wind

Along the coast, continuing sea level rise will cause an increasing number of properties to be either more frequently or permanently flooded during high tides. Under current conditions, it is estimated that over 1,300 residential and commercial properties, valued at almost $340 million, are at risk of chronic flooding (i.e., at least 26 times per year). By 2045, under a no climate action scenario, this estimate increases to almost 15,600 properties valued at almost $4 billion.[87]

As hurricanes become more severe, so will the damages to commercial and residential properties across the state, but especially in areas closer to the coast. The size and value of these future damages are uncertain, but evidence from past hurricanes provides a useful reference point. For example, in North

Carolina, Hurricane Florence caused an estimated $3.8 billion in flood and wind damage to commercial properties and $5 billion in damage to residential structures, personal automobiles, and other personal property.[59]

The combination of sea level rise and more intense coastal storms in the future will be particularly threatening for coastal properties. Over the next 20 years, one study estimates that total damages to coastal properties in North Carolina from these two effects will average almost $130 million more per year under a no climate action scenario (compared to current climate conditions).[26] By 2060, it is estimated that almost 300,000 North Carolinians could be displaced by sea level rise.[88]

However, increasing flood risks will affect properties across the entire state. As the number and intensity of rainstorms continues to increase, so will the risks and damages from inland flooding. For example, flash flooding will become an increasing concern. From 2015 to 2019, an estimated $8 million in property damages has occurred across North Carolina due to flash flooding from rainstorms not associated with hurricanes or tropical storms.[89]

A recent analysis of both coastal and inland flooding across the state concludes that roughly 10% of all properties (residential and commercial) are currently at risk of flooding, meaning they have a 1% or higher chance of flooding each year.[90] These flood risks are projected to continue rising under a no climate action scenario, such that,

- in the Coastal region, the number of at-risk properties will increase by 10% from today to 2035 (and by 20% to 2050)
- in the Piedmont region, the number of at-risk properties will increase by 3% from today to 2035 (and by 6% to 2050)
- in the Mountain region, the number of at-risk properties will increase by 1% from today to 2035 (and by 3% to 2050)

Another study focused only on inland flooding due to climate change estimates that, by 2050, total flood damages to *currently* at-risk properties (i.e., currently with 1% or higher chance of flooding each year) across the state will be at least $6 million higher each year than they are today.[91]

Wildfire

Extreme heat and more intense droughts, anticipated with further climate change, will provide the conditions needed for wildfires to occur. The year 2017 provides an example of past wildfire damage to property in North Carolina. In that year, 425 homes and structures were damaged or destroyed, resulting in a total loss valued at roughly $3.5 million.[92]

Landslides

More frequent and severe rainfall events in the Mountain region are also expected to increase the frequency and severity of landslides. As a point of reference, since 1990, 57 documented landslides have destroyed or condemned 40 structures and damaged 24 others. The costs of property damages due to landslides vary widely; however, one previous example with severe impacts was the 2004 Peeks Creek landslide in Macon County, which caused over $3 million in damages to residential structures.[93]

3.7 Impacts on Public Health and Safety

Climate change is already affecting the health and safety of North Carolina residents, and these risks will continue to grow in the future. As discussed in this section, rising temperatures are associated directly and indirectly with a wide range of harmful health effects; however, in the near-term, the most serious temperature-related impacts are likely to be those associated with extreme heat. Changes in precipitation can also have a range of impacts, but more frequent and intense floods are likely to be the biggest threat to human safety.

The costs of these impacts will take many forms, including rising medical and health care costs, lost productivity, pain, and suffering, as well as increased spending on emergency response to protect at-risk populations during extreme events, such as extreme heat waves, floods, wildfires, and landslides. In many cases, these costs and impacts will be disproportionately felt by low-income and socially disadvantaged populations, who have fewer resources and options for protecting themselves against climate hazards.

Higher average temperature

Although higher average temperatures throughout the year can have some positive effects on human health and safety (e.g., fewer cold weather-related fatalities), in many ways the harmful effects are expected to outweigh the benefits. For example, it is estimated that over the next 20 years under a no climate action scenario, higher average temperatures in North Carolina will be responsible for:

- Overall 200 or more deaths per year, with most occurring in the Mountain and Piedmont regions
- A reduction of 0.2% in the productivity of workers in relatively high-risk industries, such as agriculture, construction, and manufacturing
- A 0.4% increase in the number of violent crimes committed each year across the state[26]

More generally across the country, higher average temperatures have been linked to a range of other adverse health and human development outcomes that may also affect North Carolina residents, including:

- Increases in suicides, emergency department visits for mental illness, and self-reported days of poor mental health.[94]
- Increases in low birth weights and preterm births, particularly invulnerable communities.[95]
- Decreased learning by children in schools lacking air conditioning.[96] While lack of air conditioning is not common in North Carolina's schools[97], the potential impact of high temperatures on educational achievement underscores the importance of continuing to successfully manage heat in schools.

Extreme heat

Heat-related health emergencies are certain to increase across the state as the number of very hot days increases. Over the last two decades, heat events in North Carolina have been strongly associated with substantially higher rates of emergency room visits for heat exhaustion and a wide range of other heat-related illnesses.[98,99] The medical costs alone from these emergencies are likely to be over $2 million per year, with additional costs from lost income and from pain and suffering.[100] **Figure 3.2** shows how annual rates of emergency room visits for these heat-related illnesses in recent years (2007–2016) have varied across the state.

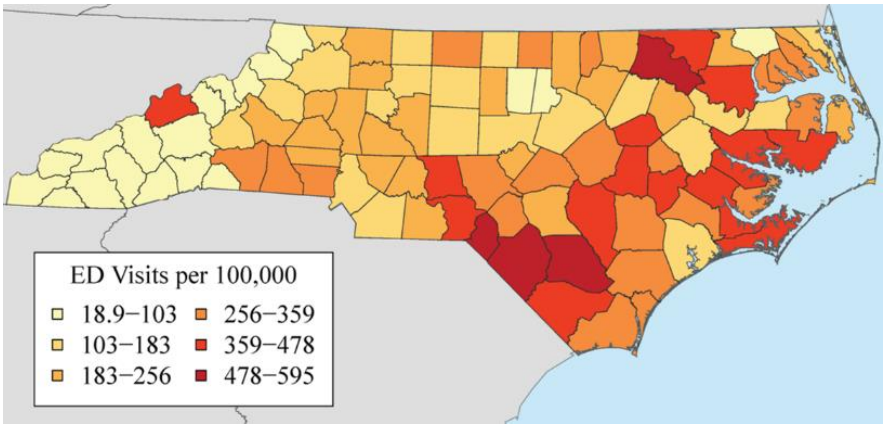


Figure 3.2. Heat-Related Emergency Department (ED) Visits by County[101]

The annual number of these health emergencies is predicted to grow substantially in the coming years. For example, in the Raleigh and Wilmington metro areas, emergency room visits due to heat stroke and other hyperthermia conditions are projected to more than double from 2010 to 2050 under a no climate action scenario.[102] In Fayetteville, these types of emergency room visits are projected to increase by almost three times over the same period.

Projected increases in extreme heat for the state also indicate that certain socially vulnerable communities will be particularly hard hit. This disproportionate impact can be seen by comparing where the largest temperature changes are projected to occur with the areas containing the largest percentages of potentially underserved populations (i.e., communities of color or socio-economically vulnerable groups that are less well equipped to manage climate impacts). **Figure 3.3** provides such a comparison. The first two panels show the NCCSR's projections for where the largest increases in the number of very hot (greater than 95°F) days will occur over the next four decades. In both the near term (2021-2040) and longer term (2041-2060), the largest increases are expected to occur in the south-central portion of the state, in an area mainly covering portions of Richmond, Scotland, and Robeson

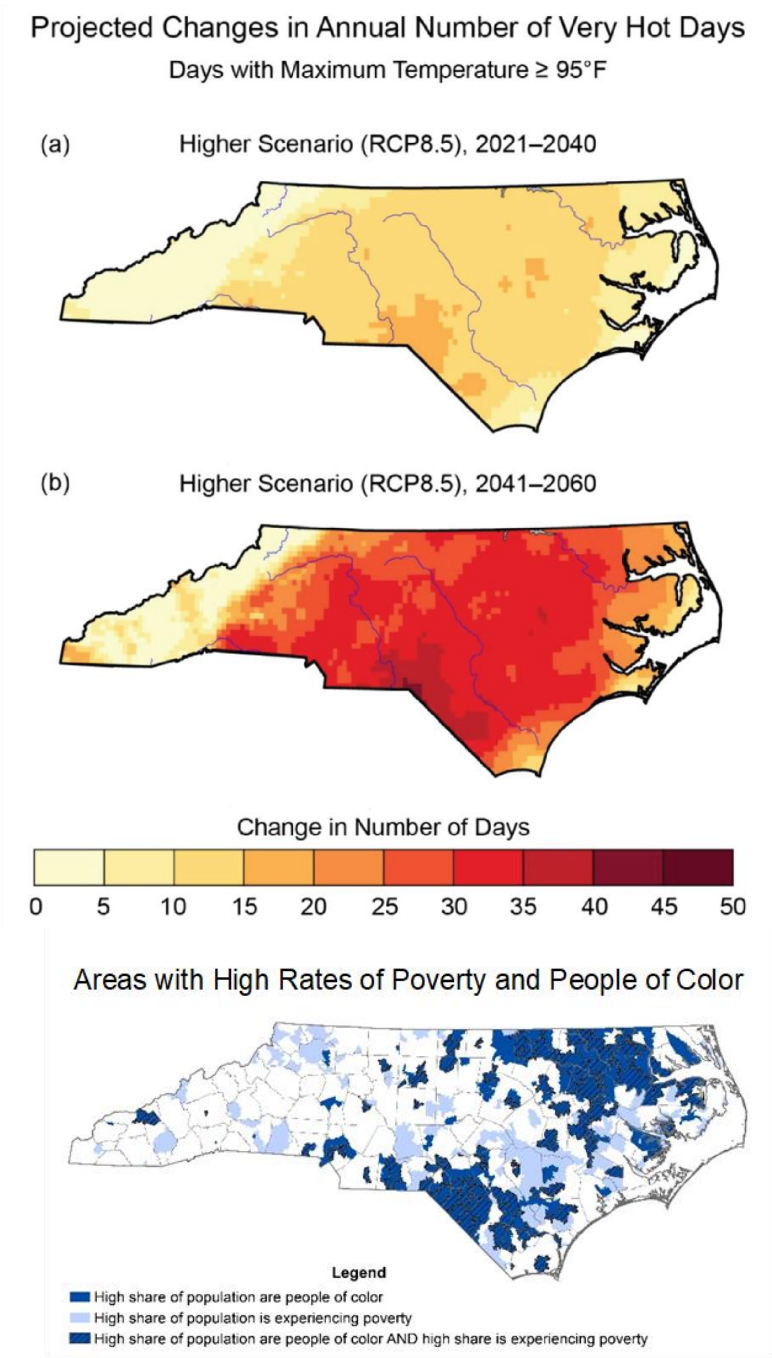


Figure 3.3. The Largest Increases in Very Hot Days Are Projected to Occur in or near Areas with Relatively High Rates of Poverty and People of Color[103]

counties. The third panel shows that this part of the state is also home to the highest concentrations of potentially underserved populations in the state. Using data at a census-tract level, it shows areas with high poverty rates in light blue and areas with high percentages of people of color residing in the area in dark blue.[104] Areas that meet both criteria are shown as dark blue with cross-hatches. The south-central area of the state with the highest projected increases in extreme heat days is also one of the main areas in the state with both high poverty rates and high percentages of people of color. Although not shown in these maps, this projected extreme heat area also has significant overlap with the population center of

the Lumbee Tribe (the Lumbee State-designated Tribal Statistical Area [SDTSA][105], which is the largest of seven SDTSAs in North Carolina).

Other portions of the North Carolina population who will be particularly hard hit by a growing number of high heat days include:

- **Outdoor workers, including construction and agricultural labor**. [28,106] Out of all occupational heat-related deaths and illnesses in the United States, about 33% are construction workers and 10–20% are in agriculture, fishing, forestry, or hunting. A large percentage of these workers in North Carolina —20 to 30% in construction and over 95% in migrant farm work—are of Hispanic origin.[107]
- **Military personnel.** Between 2015 and 2019, over 15% of all 12,300 heat-related illness events among active U.S. Armed Forces occurred on North Carolina bases. Putting these individuals at even more risk in the future, under a no climate action scenario, the average number of extreme heat (heat index > 100°) days at North Carolina bases will increase by almost five-fold to nearly 60 days per year by mid-century.[108]

Flooding and wind

As the intensity of hurricanes increase in the future, the number of deaths and injuries from storm events is likely to increase due to climate change. As a point of reference, over the last 20 years (1999-2019), hurricanes have caused roughly 150 deaths in North Carolina, with a large majority of these deaths caused by three events—Floyd (1999), Matthew (2015), and Florence (2018). In addition to physical injuries, survivors of major storm events often experience anxiety and other mental health symptoms, which can last for months.[109]

Wildfires and landslides

Although injuries and fatalities due to extreme events, such as wildfires and landslides, have not been very common in North Carolina—for example, 48 deaths due to landslides were recorded from 1916 to 2014[110]—they are likely to increase as a result of climate change.

Water temperature and quality changes

As previously discussed, one potential impact of higher water temperatures due to climate change will be a higher incidence of harmful algal blooms in surface waters. In addition, stronger rainstorms will cause more pollutants, such as bacteria, to be washed into the state's waterbodies.[111] Direct contact with or ingestion of these waters can cause a variety of adverse health outcomes, particularly for children.[112] [113]

Air quality changes

Changes in temperature and precipitation are projected to increase airborne levels of spring (oak, birch, grass) and summer (grass) pollen, which are triggers for allergic asthma episodes. In North Carolina, climate change is projected to cause an additional 62 asthma-related emergency room visits per year by 2030 and almost 123 per year by 2050.[114] An increased probability of wildfires due to a higher likelihood of extreme drought is also expected to increase risks of respiratory illness; however, the magnitude of these impacts is still uncertain.[115]

Insects and pathogens

In the Southeastern United States, changes in temperature and precipitation are projected to increase the population of ticks that carry the bacteria responsible for causing Lyme disease. This illness is still somewhat rare in the Southeast, with roughly 4,000 to 5,000 cases occurring over the last 10 years; however, roughly 600 additional cases are projected to occur during the period 2040-2050 as a result of climate change (under a no climate action scenario).[116]

Changes in average temperature across the Southeast are also projected to become more favorable for the West Nile virus, which is spread from birds to mosquitos to humans. Although the virus is still rare in North Carolina (e.g., fewer than five cases per year statewide from 2003-2012)[117], and only a small portion of cases cause severe illness or death, the number of annual cases is projected to more than double by 2050 under a no climate action scenario.[118]


Ocracoke Island, Outer Banks, North Carolina

3.8 Impacts on Recreation and Tourism

Climate change is already affecting popular outdoor recreation activities in the state, ranging from skiing in the Appalachian Mountains to beach visits along the coast. The range and size of these impacts on both residents and out-of-state visitors and the businesses that support them are likely grow in the future. They will also put increasing pressure on the budgets of the federal, state, and local agencies charged with managing park and recreation lands and facilities.

In recent years, the tourism and outdoor recreation industries in North Carolina have generated over $25 billion per year in visitor spending each year, supporting over 230,000 jobs and $2 billion in local and state tax revenue.[119] The state's coast, estuaries, lakes, and streams support over 20 million recreational fishing days each year, and its beaches receive over 15 million visitor-days.[120,121] National park sites in North Carolina, including the Great Smokey Mountains, Blue Ridge Parkway, and Cape Hatteras National Seashore receive over 25 million visitors each year, while the 39 state parks and recreation areas receive almost 20 million visitors per year.

Higher average temperatures

Warmer average temperatures will particularly affect the ski industry in the Mountain region. This industry depends on its ability to make snow, which requires extended periods below freezing. Estimates of future losses to the industry due to increasing temperatures are uncertain. However, as a point of reference, in a recent year with close to average temperatures (2014-2015), the North Carolina ski resort industry received over 650,000 visitors, generated almost $120 million in revenues, and indirectly supported almost $80 million more in sales from the surrounding areas.[122] Whereas in recent years the region has experienced an average of roughly 110 days with below freezing temperatures, this number is projected to be roughly 20% lower by 2040 under the no climate action scenario.

Coastal flooding

In the Coastal region, the value of beach tourism and recreation depends importantly on the width of the beaches visited. Therefore, beachgoers in North Carolina will experience lower values from beach trips as sea levels continue to rise, flood, and erode beaches. The size of these future losses is uncertain; however, results from several economic studies indicate that beachgoers lose an average of $1 in value per visit for each 1 meter (3.4 feet) decline in width.[123] Therefore, for example, assuming there are 20 million beach visits per year in North Carolina, an average of a 34-foot loss in beach width implies a total annual loss of $200 million.

A common but costly strategy for combating beach loss is to import sand from other areas. For example, since 1939, almost $1 billion has been spent by federal, state, and local governments to replenish beaches this way in North Carolina.[124,125] Rising seas are likely to increase the pace and total spending on these types of projects.

In addition to rising sea levels, surges of water from increasingly large coastal storms are expected to further damage the state's beaches. The magnitude of these increases in future hurricane-related damages is uncertain; however, evidence from past hurricanes provides a useful point of reference. Hurricane Florence is estimated to have required almost $300 million in beach repairs through nourishment projects that bring sand from other locations.[59]

Drought

More severe droughts have the potential to adversely affect a wide variety of water-based recreational activities in North Carolina, including swimming, boating, and fishing. Lack of water can also be damaging for the roughly 400 golf courses across the state, which employed over 12,000 people in 2017.[126,127]

Flooding and wind

As hurricanes become more severe, parks and recreation areas across the state are likely to experience increasing damages. The size and value of these future damages are uncertain, but for reference, Hurricane Florence is estimated to have caused as much as $17 million in damage to local parks and recreation facilities in the state.[59]

Wildfire

An increased probability of wildfires due to more extreme droughts is likely to have impacts across the state's extensive park and recreation lands. Although wildfires often have beneficial long-term impacts on the parks' ecosystems, they can also damage trails and facilities for recreational users and be costly to manage.[128]

Warmer water temperatures

In the Mountain region, increasing temperatures in cold-water streams will have a negative impact on recreational trout fisheries. For example, one study estimates that a 2°C increase in air temperature will decrease trout habitat by almost 14%, which will reduce the average recreation value experienced by trout anglers by $1,300 per year.[129] With an estimated 170,000 trout anglers in North Carolina per year, this translates to an annual loss of over $230 million.

Air quality changes

An increased probability of wildfires due to more extreme droughts is also expected to have a negative effect on air quality. In areas where visibility is highly valued by tourists and recreational visitors, such as the Smokey Mountains National Park and other parts of the Mountain region, these changes will have particularly damaging effects.[130]

Invasive species

In the Coastal region, the North Carolina Division of Parks and Recreation is already devoting significant resources to fight 35 invasive plant species (including privet and cogongrass) across 25 park sites. Higher temperatures, as well as sea level rise and higher intensity tropical storms, are expected to create additional pressures on park budgets by increasing introductions and spread of invasive species.[131]

Section 4

What Actions Can Be Taken to Address Climate Change in North Carolina?

Climate change is already impacting North Carolinians. Summers are hotter and longer. Storms are stronger and more frequent. Flooding is more common and pervasive. The damaging effects of these hazards are mounting, and they will continue to grow into the future.

So, what can be done? Aggressively moving away from fossil fuels, like coal, oil, and gas, will help avert the most catastrophic impacts of climate change. While there is no substitute for federal action on climate, state initiatives are essential to making critical near-term reductions, helping **mitigation** of greenhouse gas (GHG) emissions and offering a roadmap for ambitious federal action, especially since North Carolina ranks among the nation's top 15 emitters of CO_2. Not only could North Carolina set an example for other states but taking the lead on state climate action could lead to accelerated investment in the clean energy economy, promoting the growth of businesses and jobs.

Though mitigation is essential for reducing harm in the future, even if we cut emissions, our climate will continue to change because of past emissions. For the climate hazards we can no longer prevent, we must embrace measure that lessen their impacts through **adaptation** and strengthen our ability to recover faster through **resilience**. Adaptation will help avoid or lessen the impacts of climate change, for example by raising road surfaces to avoid sea level rise flooding. Resilience, or our ability to withstand and recover from the impact of climate change, might entail restoring river ecosystems to better slow and absorb flood waters or by strengthening disaster response teams and networks. Both approaches provide useful avenues for addressing climate hazards. They can sometimes be hard to distinguish from each other, with the terms often being used interchangeably. Many actions we take to deal with climate change can provide a mix of adaptation, resilience, and mitigation (ARM) benefits.

Measures taken to address climate hazards will often offer a combination of direct benefits, indirect benefits, and co-benefits. **Direct benefits** come from a measure's ability to lessen impacts (adaptation), improve our ability to recover from impacts (resilience), or prevent additional climate change (mitigation). **Indirect benefits** are additional ARM benefits that occur elsewhere because of the measure taken. For example, restoring a forested wetland to help with flood control (adaptation) may help to naturally remove carbon from the atmosphere (mitigation). **Co-benefits** are other non-climate-related benefits. For example, restoring a coastal marshland to provide natural protection against storm surges (adaptation) can also provide nursery habitat for fish, which benefits both commercial and recreational fisheries.

All three ARM approaches have a role to play in addressing climate hazards. Policy makers, industry, and the public face a wide array of options for each. Particularly for adaptation and resilience measures, the best option for addressing the impacts of climate hazards will depend on a community's local economy and supporting ecosystem. Evaluating the costs and benefits of each and identifying the best suite of options will require the combined support of careful research and engaged communities.

4.1 Recommended Actions for Climate Mitigation

North Carolina is currently participating with 24 other states in the U.S. Climate Alliance.[132] As part of this alliance, the state has committed to implement and accelerate policies to reduce greenhouse gas emissions and to promote clean energy policies. To meet these climate mitigation commitments, we recommend actions, such as the following.

Implement a concrete, declining, and enforceable limit on climate pollution, paired with a price on state emissions that will incentivize meaningful, cost-effective mitigation

- Establishing a declining enforceable limit and using a price for each ton of CO_2 (and other greenhouse gases) emitted to achieve that limit can ensure that emissions are reduced dramatically throughout the economy quickly and at low cost. A price can reduce pollution across the economy, but it must include provisions that tie it to clear, measurable pollution reduction goals and include provisions to help ensure those goals are met. Revenue from the price can be used to support any number of fiscal priorities, such as returning revenue to consumers, or used to support further clean energy investments – most importantly striving to achieve mitigation of GHGs and other pollutants in disproportionately impacted communities. Federal legislation that places a limit and a price on GHG emissions is critical; however, in the absence of such policy, many states can take concrete action to reduce GHG emissions through programs, like the Regional Greenhouse Gas Initiative (RGGI). This program puts a declining limit on total CO_2 emissions in the mid-Atlantic and northeast states' electricity sector. Since 2009, it has successfully reduced CO_2 emissions by over 35% across the region and lowered electricity prices by an average of 2%.[133] North Carolina can and should take action to curb climate pollution by joining initiatives, like RGGI, or by initiating its own approach to limit and cut its own emissions.

Reform state utility regulations in a way that removes barriers and creates incentives for clean energy and carbon reduction technology investment. Building on North Carolina's Renewable Portfolio Standard, a clean energy standard would help reduce emission in the electricity sector by requiring that a certain fraction of the energy come from low or non-emitting technologies. Low-emissions generators receive credits for their generation, making them more cost competitive against higher-emitting generators. With 35% of current emissions, stronger clean electricity policies can have a substantial impact on our emissions and support emissions reductions in other sectors through electrification.[134]

Spur the adoption of electric vehicles. Transportation accounts for 33% of greenhouse gas emissions in North Carolina. Electric vehicles have emerged as the most market-ready alternative to tailpipe emissions. Combined with stronger electricity sector emissions policies, hastening the adoption of electric vehicles, by lowering their cost through vehicle purchase incentives, electricity rebates, and expanded charging infrastructure, can provide substantial emissions reductions for North Carolina. In addition to providing incentives for personal vehicles, the state government and its municipalities can prioritize the purchase of electric fleet vehicles, such as school and city buses and public utility trucks.

Incentivize electrification and efficiency investments. Investing in industrial equipment that is more energy efficient and electric can substantially reduce North Carolina total emissions. North Carolina's industrial sector accounts for 12% of the state's greenhouse gas emissions. Paired with stronger clean energy policy in the electricity sector, state investment incentives to reduce and electrify industry's energy demand will reduce emissions and may improve North Carolina's economic competitiveness.

4.2 Recommended Actions for Climate Adaptation/Resilience in North Carolina

To strengthen resilience and most effectively adapt to climate change, public and private sector decision makers should **systematically evaluate and address climate-related risks in their planning and investment decisions**. The first step is to identify how relevant stakeholders or assets are expected to be impacted by different climate hazards. The next steps are to identify different courses of action and to evaluate how they affect (or are affected by) these risks.

Build partnerships and take advantage of resilience tools and lessons learned across the country. Even simple **checklist systems** can be useful starting points for assessing risks, preparedness, and options.[135] In other cases, more detailed approaches can be applied, such as the 5-step **Building Resilience Against Climate Effects (BRACE) Framework**, developed by the Centers for Disease Control and Prevention (CDC) to help communities prepare the health effects of climate change.[136]

Continue to implement and refine state-level resilience plans. North Carolina has been proactive in developing state-level plans for addressing climate-related risks. For example, the 2016 **Hazard Mitigation Plan** identifies hazards and actions to improve preparation for, response to, and recovery from natural disasters. More recently, the 2020 **North Carolina Climate Risk Assessment and Resilience Plan** outlines strategies and recommendations for applying the state's infrastructure, assets, programs, and services to strengthen resilience.

Incentivize resilient farming practices that have multiple benefits. Many farming practices, such as low-tillage and cover crops, not only improve soil productivity and control erosion from farm fields, but they can also reduce stormwater runoff, protecting downstream areas from flooding and poor water quality. In addition, they help mitigate climate change by sequestering carbon in farm soils.

Support data collection and research that advance understanding of resilience-building strategies. To be most effective, resilience strategies need to be supported by evidence and science. Valuable investments in this critical knowledge base can range from funding advanced research and development into climate resilient crops and building and road designs, to engaging ordinary citizens in data gathering activities and networks, as well as creating centralized repositories for the resulting findings and data.

Take advantage of public and private programs funding resilience planning and action. Building resilience to climate change requires resources. Fortunately, several funding sources, ranging from federal grant programs to private foundations and public-private partnerships, offer opportunities for communities committed to climate adaptation. A useful introduction and summary of these opportunities is provided in NOAA's *U.S. Climate Resilience Toolkit*.[137]

Protect and conserve multi-benefit natural lands. Many natural lands, such as forests, wetlands, and grasslands provide a wide variety of benefits to society, which can include not only climate mitigation and resilience benefits, like carbon storage and floodwater retention, but also a range of other benefits, including wildlife habitat, natural water filtration processes, and recreational resources. A priority for climate adaptation should be identifying and conserving natural lands with the highest combined value of benefits.

Incorporate nature-based shoreline protections. Although hard structures, like seawalls and dikes, can help to protect coastal communities from flooding due sea level rise and more intense storm surges, other approaches that mimic natural systems, such as expanded marshlands and dune ecosystems, can also provide these protections. These nature-based approaches can also be more cost-effective in the long-term, and they often provide additional benefits, such as habitat for coastal wildlife.

Incentivize voluntary relocation of homes and businesses away from high-hazard areas. For an increasing number of properties and residents across the state, the dangers and expected maintenance and repair costs due to high flood risks and other climate hazards are far greater than the cost of moving to similar property in a lower risk area. Programs that encourage and compensate property owners for voluntarily moving to lower risk locations can be cost-effective ways to reduce the toll and impacts of climate hazards. However, these programs can only be successful if they fully engage and are equitable for the communities involved.[138]

Invest in urban green infrastructure. Expanding the portion of urban lands that contain natural vegetative cover – such as with green roofs, rain gardens, wetlands, and parks – can help to offset many of the climate hazards made worse by hard surfaces. They can counteract the health risks and discomfort caused by urban "heat island" effects, and they can absorb rainwater that would otherwise flood downstream areas They can also improve urban quality of life by filtering pollutants from the air and by providing aesthetically pleasing and enjoyable outdoor areas. Investing in microgrid electric systems can also benefit areas most vulnerable to hurricane and storm impacts.

4.3 Conclusions

Although climate change will have wide-ranging impacts across the state, regions and sectors, there is an even broader array of promising actions that can be taken at the state, regional, and local level to lessen these impacts and create co-benefits, such as improved air quality and job creation. The actions listed above represent an important but relatively small sample of the many options available.

Selecting the best options for communities in North Carolina will require careful consideration of their costs, but it is equally important to fully account for the multiple and diverse benefits and co-benefits that so often come with climate action.

- Many nature-based solutions, such as restoring forest wetlands and planting trees, have a long list of benefits. As noted previously, these benefits include offsetting greenhouse gas emissions through carbon storage and strengthening resilience against climate hazards, like floods. In addition, they provide jobs, wildlife habitat, and opportunities for outdoor recreation.
- Many clean energy programs, in addition to reducing greenhouse gas emissions, also make important contributions to the state's regional and local economies. For example, it is estimated that from 2007 to 2018, clean energy programs in the state contributed almost $17 billion to the state's economy – especially in the Coastal region – and supported an average of over 14,000 jobs per year.[139]
- Expanding the scale of and experience with clean energy alternatives is critical for bringing down their costs and making them more competitive. In many cases, zero-emissions alternatives, such as renewable energy technologies and electric vehicles, have become less expensive to own and operate than their fossil fuel–based infrastructure. These trends are expected to continue.[140]

- In addition to lowering GHG emissions, reducing fossil fuel use can reduce other pollutants like airborne particulates that cause respiratory illnesses and can sometimes be fatal. In some cases, the total value of these air quality co-benefits can be just as large as the main climate-related benefits of reducing fossil fuel use.[141]
- Climate action can be an important vehicle for addressing social inequalities, particularly when socially vulnerable populations are disproportionately harmed by climate hazards. If equitably implemented, programs to protect citizens against the effects of hazards, like extreme heat and inland flooding, can be especially beneficial for people of color and low-income communities.
- Action is contagious. Evidence from observing community behaviors has repeatedly shown that healthy habits spread from person to person. [142] With these beneficial ripple effects, actions taken by a few to reduce fossil fuel use or to adopt resilient farming practices can motivate change across an entire community. Similarly, taking leadership on climate action in North Carolina can serve as a catalyst for change across the country.

References & Notes

[1] Kunkel, K. E., Easterling, D. R., & Ballinger, A. (2020). North Carolina Climate Science Report. https://ncics.org/wp-content/uploads/2020/06/NC_Climate_Science_Report_FullReport_Final_revised_May2020.pdf
[2] Adapted from the World Bank Climate and Disaster Risk Screening Tools https://climatescreeningtools.worldbank.org/.
[3] Kopp, R. E., Horton, B. P., Kemp, A. C., & Tebaldi, C., 2015. Past and future sea-level rise along the coast of North Carolina, USA. Climatic Change, 132(4), pp.693-707.
[4] Reed, K. A., Stansfield, A. M., Wehner, M. F., & Zarzycki, C. M. (2018). The human influence on Hurricane Florence. https://cpb-us-e1.wpmucdn.com/you.stonybrook.edu/dist/4/945/files/2018/09/climate_change_Florence_0911201800Z_final-262u19i.pdf
[5] C2ES. (n.d.). Hurricanes and climate change. https://www.c2es.org/content/hurricanes-and-climate-change/.
[6] Dillon, G.K.; Menakis, J.; & Fay. F. (2015). Wildland Fire Potential: A Tool for Assessing Wildfire Risk and Fuels Management Needs. Pp. 60-76 in Keane, R. E.; Jolly, M.; Parsons, R.; and Riley, K. Proceedings of the large wildland fires conference; May 19-23, 2014; Missoula, MT. Proc. RMRS-P-73. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 345 p. https://www.firelab.org/project/wildfire-hazard-potential
[7] State of North Carolina. (2020). North Carolina Climate Risk Assessment and Resilience Plan: Impacts, Vulnerability, Risks, and Preliminary Actions. https://files.nc.gov/ncdeq/climate-change/resilience-plan/2020-Climate-Risk-Assessment-and-Resilience-Plan.pdf
[8] National Environmental and Modeling and Analysis Center (NEMAC). (2016). Western North Carolina Vitality Index: Working together through conservation to map a healthy and prosperous future. http://www.wncvitalityindex.org/sites/default/files/WNC_Vitality_Index_onscreen_012516.pdf
[9] NCDEQ. (2018). Lake & reservoir assessments: Tar-Pamlico River Basin. https://files.nc.gov/ncdeq/Water%20Quality/Environmental%20Sciences/Reports/TarPam_17.pdf; U.S. EPA (2019). Climate change and harmful algal blooms. https://www.epa.gov/nutrientpollution/climate-change-and-harmful-algal-blooms.
[10] USGS. (2016). USGS study reveals interactive effects of climate change, invasive species on native fish. https://www.usgs.gov/news/usgs-study-reveals-interactive-effects-climate-change-invasive-species-native-fish.
[11] USGCRP. (2008). The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity. https://www.globalchange.gov/browse/reports/sap-43-effects-climate-change-agriculture-land-resources-water-resources-and.
[12] USEPA. 2017. Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment. U.S. Environmental Protection Agency, EPA 430-R-17-001.
[13] Bradley, B.A., Wilcove, D.S., & Oppenheimer, M. (2010). Climate change increases risk of plant invasion in the Eastern United States. Biological Invasions, 12(6), 1855.
[14] All dollar values in this report have been inflation-adjusted to 2019 dollars using the consumer price index (CPI) (https://data.bls.gov/pdq/SurveyOutputServlet
[15] Walden, M. (2019). Agriculture and agribusiness: North Carolina's number one industry. https://cals.ncsu.edu/agricultural-and-resource-economics/wp-content/uploads/sites/12/2019/05/agribusiness2019Brochure.pdf
[16] Feeding the Economy. (n.d.). U.S. food and ag industries. https://goodstone.guerrillaeconomics.net/reports/a99a7a6e-17ad-44dd-8971-850cc2034b07
[17] United States of Agriculture National Agricultural Statistics Service (USDA). (2019) One hundred years and counting: 2019 North Carolina Agricultural Statistics. https://www.nass.usda.gov/Statistics_by_State/North_Carolina/Publications/Annual_Statistical_Bulletin/AgStat/NCHighlights.pdf
[18] North Carolina State University, College of Agriculture and Life Sciences. (2015). Economic contribution of North Carolina agriculture and agribusiness. https://www.ces.ncsu.edu/wp-content/uploads/2017/01/NC-Agriculture-Economic-Pocket-Guide_NC-State-CALS.pdf

[19] USDA. (2018). Income and prices farm income prices received prices paid. https://www.nass.usda.gov/Statistics_by_State/North_Carolina/Publications/Annual_Statistical_Bulletin/AgStat/Section03.pdf

[20] U.S. Energy Information Administration (EIA). (2019). North Carolina: Profile Analysis. https://www.eia.gov/state/analysis.php?sid=North Carolina

[21] North Carolina State Extension. (2020). Economic Contribution Data. https://forestry.ces.ncsu.edu/economic-impact-data/

[22] North Carolina State Extension. (2020). Economic Contribution of the Forest Sector in North Carolina, 2018. https://content.ces.ncsu.edu/economic-contribution-of-the-forest-sector-in-north-carolina

[23] North Carolina State Extension. (2016). North Carolina's Forest and Forest Products Industry by the Numbers. https://content.ces.ncsu.edu/north-carolinas-forest-and-forest-products-industry-by-the-numbers

[24] One effect of higher levels of CO_2 levels in the air is that it can increase photosynthesis by plants, which promotes plant growth; therefore, by itself, it can have a positive effect on some crop yields. For additional information see, for example, https://www.nasa.gov/feature/goddard/2016/carbon-dioxide-fertilization-greening-earth.

[25] Schlenker, W. and Roberts, M.J., 2009. Nonlinear temperature effects indicate severe damages to US crop yields under climate change. Proceedings of the National Academy of sciences, 106(37), pp.15594-15598.

[26] Hsiang, S., Kopp, R., Jina, A., Rising, J., Delgado, M., Mohan, S., Rasmussen, D.J., Muir-Wood, R., Wilson, P., Oppenheimer, M., & Larsen, K. (2017). Estimating economic damage from climate change in the United States. Science, 356(6345), 1362-1369. Retrieved from: https://escholarship.org/content/qt8db26620/qt8db26620.pdf

[27] Hsiang et al. (2017) include maize, soybeans, cotton, and wheat yields in their analysis, and also include the positive fertilization effects of ambient CO_2 concentrations.

[28] Union of Concerned Scientists. (2019). Killer Heat in the United States: Climate Choices and the Future of Dangerously Hot Days. https://www.ucsusa.org/sites/default/files/attach/2019/07/killer-heat-analysis-full-report.pdf

[29] Mirabelli, M.C. & Richardson, D.B. 2005. Heat-related fatalities in North Carolina. American Journal of Public Health, 95(4), 635-637.

[30] Baker. M. (2007) Report: Drought cuts $573 million from agriculture economy in '07. https://thetandd.com/business/report-drought-cuts-573-million-from-agriculture-economy-in-07/article_9d5c9ac2-628b-5f4f-9b36-d65028c18077.html

[31] Bhattachan, A., Jurjonas, M. D., Moody, A. C., Morris, P. R., Sanchez, G. M., Smart, L. S., Taillie, P. J., Emanuel, R. E. & Seekamp, E. L. (2018). Sea level rise impacts on rural coastal social-ecological systems and the implications for decision making. Environmental Science & Policy, 90, pp.122-134.

[32] Roberson, R., (2012). Saltwater intrusion threatens eastern North Carolina crops. FarmProgress. https://www.farmprogress.com/management/saltwater-intrusion-threatens-eastern-north-carolina-crops

[33] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2020). https://www.ncdc.noaa.gov/billions/, DOI: 10.25921/stkw-7w73

[34] North Carolina Office of State Budget and Management. (n.d.). Hurricane Florence: Preliminary Damage and Needs Assessment. https://files.nc.gov/ncosbm/documents/files/Florence_Agriculture_rev20181026.pdf

[35]Davis, W. (2018). Overflowing hog lagoons raise environmental concerns In North Carolina https://www.npr.org/2018/09/22/650698240/hurricane-s-aftermath-floods-hog-lagoons-in-north-carolina

[36] Stradling, R. (2019). Hurricane Florence killed millions of chickens and turkeys. Now farmers are putting them to use. https://www.newsobserver.com/news/business/article226258150.html

[37] National Centers for Environmental Information- National Oceanic and Atmospheric Administration (NOAA). (2020). Storm events database. https://www.ncdc.noaa.gov/stormevents/choosedates.jsp?statefips=37%2CNORTH+CAROLINA

[38] Bhattachan, A., Jurjonas, M.D., Moody, A.C., Morris, P.R., Sanchez, G.M., Smart, L.S., Taillie, P.J., Emanuel, R.E. and Seekamp, E.L. (2018.) Sea level rise impacts on rural coastal social-ecological systems and the implications for decision making. Environmental Science & Policy, 90, pp.122-134.

[39] Carolinas Integrated Sciences and Assessments and South Carolina Sea Grant Consortium. (2012). Assessing the Impact of Saltwater Intrusion in the Carolinas under Future Climatic and Sea Level Conditions. https://cpo.noaa.gov/sites/cpo/Projects/RISA/2013/reports/2012_CISAandSCSeaGrant_SalinitySARPReport.pdf

[40] Bradley, B. A., Wilcove, D. S., & Oppenheimer, M. (2010). Climate change increases risk of plant invasion in the Eastern United States. Biological Invasions, 12(6), 1855-1872. http://people.umass.edu/bethanyb/Bradley%20et%20al.%2C%202010%20Biol%20Invasions.pdf
[41] Jennings, L., Treasure, E., Myers, J. M., McNulty, S., Brogan, S., & Jones, D. (2012). North Carolina's Emerging Forest Threats: Management Options for Healthy Forests. Information Pamphlet: North Carolina Forest Service, Raleigh, North Carolina. 4p., 1-4. https://ncforestservice.gov/Managing_your_forest/pdf/EmergingThreatsHealthyForestMngtOptionsNC.pdf
[42] Hamblin, A.L., Youngsteadt, E. and Frank, S.D., 2018. Wild bee abundance declines with urban warming, regardless of floral density. Urban Ecosystems, 21(3), pp.419-428.
[43] Kjøhl, M., Nielsen, A. and Stenseth, N.C., 2011. Potential effects of climate change on crop pollination. Food and Agriculture Organization of the United Nations (FAO).
[44] North Carolina Division of Marine Fisheries. (2019). Annual Fisheries Bulletin: 2019 Commercial and Recreational Statistics. http://portal.ncdenr.org/c/document_library/get_file?p_l_id=1169848&folderId=33602532&name=DLFE-143022.pdf
[45] North Carolina Division of Marine Fisheries. (n.d.). Fisheries Economics. http://portal.ncdenr.org/c/document_library/get_file?p_l_id=1169848&folderId=33372974&name=DLFE-141808.pdf
[46] North Carolina Department of Agriculture & Consumer Services. (2020). State Update: 2019 farm data and industry statistics from the NC aquaculture industry. 2020 NC Aquaculture Development Conference. http://www.ncagr.gov/markets/aquaculture/documents/FINAL2020STATEUPDATENCADC.pdf
[47] USDA-National Agricultural Statistics Service Homepage. (2018). Value of Aquaculture Products Sold by Type: 2018 and 2013. https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Aquaculture/aqua_1_0001_0001.pdf
[48] North Carolina State Extension. (2020). Information by Species. https://aquaculture.ces.ncsu.edu/information-by-species/
[49] North Carolina Office of State Budget and Management. (n.d.)Hurricane Florence: Preliminary Damage and Needs Assessment. https://files.nc.gov/ncosbm/documents/files/Florence_Agriculture_rev20181026.pdf
[50] Incremona, M. (2019). North Carolina shellfish aquaculture suffers losses near $10 million from 2018 storms. https://ncseagrant.ncsu.edu/news/2019/01/nc-shellfish-aquaculture-suffers-losses-of-nearly-10-million-from-2018-storms/
[51] Rogers, L. A., Griffin, R., Young, T., Fuller, E., Martin, K. S., & Pinsky, M. L. (2019). Shifting habitats expose fishing communities to risk under climate change. Nature Climate Change, 9(7), 512-516.
[52] Van Dam, B. R., & Wang, H. (2019). Decadal-scale acidification trends in adjacent North Carolina estuaries: competing role of anthropogenic CO2 and riverine alkalinity loads. Frontiers in Marine Science, 6, 136.
[53] Baker-Austin, C., Trinanes, J., Gonzalez-Escalona, N., & Martinez-Urtaza, J. (2017). Non-cholera vibrios: the microbial barometer of climate change. Trends in microbiology, 25(1), 76-84.
[54]Jessel, S.G. & Hernández, D. (2019). Energy, poverty, and health in a changing climate: A conceptual review of an emerging literature. Frontiers in Public Health, 7, 357. https://www.tandfonline.com/doi/full/10.1080/01944363.2019.1647446
[55] U.S. EIA (2019). North Carolina Profile Analysis. https://www.eia.gov/state/analysis.php?sid=North Carolina.
[56] U.S. EIA. (2019). North Carolina: Profile Data. https://www.eia.gov/state/data.php?sid=North Carolina
[57] Hsiang et al. (2017) estimate energy impacts using a version of the Energy Information Administration's (EIA) National Energy Modeling System (NEMS) which projects production, conversion, consumption, trade, and price of energy in United States through 2040 by combining an energy sector with a macroeconomic model.
[58] Kern, J. D. & Characklis, G. W., 2017. Evaluating the financial vulnerability of a major electric utility in the southeastern US to drought under climate change and an evolving generation mix. Environmental Science & Technology, 51(15), 8815–8823.
[59] Cooper. R. (2018). Hurricane Florence Recovery Recommendations: Building Communities Stronger and Smarter based on preliminary damage and needs assessments. https://files.nc.gov/ncosbm/documents/files/Florence_Report_Full_rev20181016v10.pdf

[60] Rice, D. (2018). Hurricane Florence power outages top 890,000 could hit 3 million as storm unleashes fury. https://www.usatoday.com/story/news/nation/2018/09/14/hurricane-florence-power-outages/1301060002/
[61] Van Vliet, M. T., Wiberg, D., Leduc, S., & Riahi, K. (2016). Power-generation system vulnerability and adaptation to changes in climate and water resources. Nature Climate Change, 6(4), 375-380.
Van Vliet, M. T., Yearsley, J. R., Ludwig, F., Vögele, S., Lettenmaier, D. P., & Kabat, P. (2012). Vulnerability of US and European electricity supply to climate change. Nature Climate Change, 2(9), 676-681.
[62] Federal Highway Administration. (2019). Functional system lane-length. https://www.fhwa.dot.gov/policyinformation/statistics/2018/pdf/hm60m.pdf
[63] Federal Highway Administration. (2020). Bridge condition by county. https://www.fhwa.dot.gov/bridge/nbi/no10/county.cfm
[64] Keane, T. (2017). The economic importance of the national highway system. https://www.fhwa.dot.gov/publications/publicroads/96spring/p96sp16.cfm
[65] Federal Highway Administration. (2019). FHWA Route log and finder list. https://www.fhwa.dot.gov/planning/national_highway_system/interstate_highway_system/routefinder/table03.cfm
[66] ASCE, North Carolina Section. (2013). 2013 Report Card for North Carolina's Infrastructure. https://www.infrastructurereportcard.org/wp-content/uploads/2016/10/2013-Report-Card-for-North-Carolina-Infrastructure-Lo-Res.pdf
[67] Feigenbaum, B., Fields, M. G., & Purnell, S. (2019). 24th Annual Highway Report. https://reason.org/wp-content/uploads/24th-annual-highway-report-2019.pdf
[68] EPA. (2017). Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment. U.S. Environmental Protection Agency, EPA 430-R-17-001.
[69] Federal Highway Administration. (2020). Tables of Frequency Requested NBI Information. Retrieved from: https://www.fhwa.dot.gov/bridge/britab.cfm
[70] Roughly 11% of bridges in the Southeast U.S. are located in North Carolina.
[71] Jacobs, J. M., Cattaneo, L. R., Sweet, W., & Mansfield, T. (2018). Recent and Future Outlooks for Nuisance Flooding Impacts on Roadways on the U.S. East Coast. Transportation Research Record, 2672(2), 1–10.
[72] National Environmental and Modeling and Analysis Center (NEMAC). (2016). Western North Carolina Vitality Index: Working together through conservation to map a healthy and prosperous future. http://www.wncvitalityindex.org/sites/default/files/WNC_Vitality_Index_onscreen_012516.pdf
[73] US EPA. (n.d.). Safe drinking water search for the state of North Carolina. https://enviro.epa.gov/enviro/sdw_form_v3.create_page?state_abbr=North Carolina.
[74] North Carolina Department of Environmental Quality. (n.d.) Dam Safety. .https://deq.nc.gov/about/divisions/energy-mineral-land-resources/energy-mineral-land-permits/dam-safety
[75] North Carolina Department of Environmental Quality. (2020). North Carolina. Department of Environmental Quality online GIS. .https://data-ncdenr.opendata.arcgis.com/datasets/a86af4f7549343419b4c8177cedb3e4b_0/data
[76] North Carolina State Extension. (2016). Septic System Owner's Guide-Soil Facts. https://content.ces.ncsu.edu/septic-system-owners-guide.
[77] North Carolina Division of Water Resources Department of Environment and Natural Resources. (2008). North Carolina Drought Management Advisory Council Activities Report – 2008. https://www.ncdrought.org/files/documents/2008_annual_report.pdf
[78] North Carolina Climate Office. (n.d) North Carolina drought overview. https://climate.ncsu.edu/drought/about
[79] https://www.homeadvisor.com/cost/plumbing/install-a-sewer-main/
[80] Ricker M., Gorczynski, L., Jordan, S., Severson, E., & Taylor, G. (2019). Coastal Zone Soil Research in North Carolina: Blue Carbon and Septic System Vulnerability to Saltwater Intrusion.
[81] U.S. Environmental Protection Agency. (2015). A compilation of cost data associated with the impacts and control of nutrient pollution. https://19january2017snapshot.epa.gov/sites/production/files/2015-04/documents/nutrient-economics-report-2015.pdf
[82] Wiltsie, D., Schnetzer, A., Green, J., Vander Borgh, M. and Fensin, E., 2018. Algal Blooms and Cyanotoxins in Jordan Lake, North Carolina. Toxins, 10(2), p.92.

[83] Reonomy. (2020). Commercial real estate in North Carolina. https://www.reonomy.com/properties/commercial-real-estate/us/north-carolina/1
[84] U.S. Census Bureau. (2019). North Carolina: Quick facts. https://www.census.gov/quickfacts/North Carolina
[85] Lustgarten, A. (2020). How climate migration will reshape America. New York Times. https://www.nytimes.com/interactive/2020/09/15/magazine/climate-crisis-migration-america.html
[86]Bidgood, J. (2016). Poor, Displaced and Anxious in North Carolina as Floods Climb After Hurricane. https://www.nytimes.com/2016/10/14/us/poor-displaced-and-anxious-in-north-carolina-as-floods-climb-after-hurricane.html
[87] Union of Concerned Scientists. 2018. UCS When Rising Seas Hit Home Data. www.ucsusa.org/underwater
[88] Lustgarten, A. (2020). How climate migration will reshape America. New York Times. https://www.nytimes.com/interactive/2020/09/15/magazine/climate-crisis-migration-america.html?searchResultPosition=1
[89] National Centers for Environmental Information, NOAA. (2020). Storm events database. https://www.ncdc.noaa.gov/stormevents/choosedates.jsp?statefips=37%2CNORTH+CAROLINA
[90] First Street Foundation. 2020. The The First National Flood Risk Assessment Defining America's Growing Risk
[91] Wobus, C., Gutmann, E., Jones, R., Rissing, M., Mizukami, N., Lorie, M., ... & Martinich, J. (2017). Modeled changes in 100 year flood risk and asset damages within mapped floodplains of the contiguous United States. Natural Hazards and Earth System Sciences Discussions, 1-21. And communication from C. Wobus.
[92] North Carolina Forest Service. (2017). Annual Legislative Report on Wildfires. https://www.ncleg.gov/documentsites/committees/govops/Full%20Commission/2017%20Meetings_Materials/10_October%202017/Reports/ANER/DACS_NCFS-Annual_Report_On_Wildfires-2017_09_27.pdf
[93] National Environmental and Modeling and Analysis Center (NEMAC). (2016). Western North Carolina Vitality Index: Working together through conservation to map a healthy and prosperous future. http://www.wncvitalityindex.org/sites/default/files/WNC_Vitality_Index_onscreen_012516.pdf
[94] Mullins, J. T., & White, C. (2019). Temperature and mental health: Evidence from the spectrum of mental health outcomes. Journal of health economics, 68, 102240.
[95] Bekkar, B., Pacheco, S., Basu, R., & DeNicola, N. (2020). Association of air pollution and heat exposure with preterm birth, low birth weight, and stillbirth in the US: a systematic review. JAMA network open, 3(6), e208243-e208243.
[96] Park, R.J., Goodman, J., Hurwitz, M. and Smith, J., 2020. Heat and learning. American Economic Journal: Economic Policy, 12(2), pp.306-39.
[97] Barnum, M. (2017, June 14). Too hot to learn: Records show nearly a dozen of the biggest school districts lack air conditioning. The 74. https://www.the74million.org/article/exclusive-too-hot-to-learn-records-show-nearly-a-dozen-of-the-biggest-school-districts-lack-air-conditioning/
[98] Fuhrmann, C. M., Sugg, M. M., Konrad, C. E., & Waller, A. (2016). Impact of extreme heat events on emergency department visits in North Carolina (2007–2011). Journal of community health, 41(1), 146-156.
[99] Sugg, M. M., Konrad, C. E., & Fuhrmann, C. M. (2016). Relationships between maximum temperature and heat-related illness across North Carolina, USA. International Journal of biometeorology, 60(5), 663-675.
[100] Based on Sugg et al. (2016) estimate of 2000 average visit per year in North Carolina and Lay et al. (2018) estimates of average medical costs per visit in the U.S. ranging from $304 to $1,819 (in 2015 dollars)
[101] Convergence of Climate-Health-Vulnerabilities. (2020). Heat Health Vulnerability Tool (HHVT). https://convergence.unc.edu/tools/heat/
[102] Lay, C. R., Mills, D., Belova, A., Sarofim, M. C., Kinney, P. L., Vaidyanathan, A., Jones, R., Hall, R., & Saha, S. (2018). Emergency department visits and ambient temperature: Evaluating the connection and projecting future outcomes. GeoHealth, 2(6), 182-194 (with additional data through personal communication with Claire Lay on August 27,2020).
[103] Maps for Figure 3.3.a and 3.3.b are from Kunkel et al. (2020).[1] Figure 3.3.c was created by RTI.
[104] A high poverty rate Census tract is defined as one with (1) more than 20% of the population experiencing poverty is over twenty percent OR (2) a percentage in poverty that is at least 5% higher than its county or the state share. A Census tract with a high rate of people of color is defined as one where (1) more than 50% of the population is not in white race category) OR (2) the share of population not in the whiter race category is at least 5% higher than its county or the state share.

[105] U.S. Census Bureau (n.d.) My Tribal Area. https://www.census.gov/tribal/?st=37&aianihh=9970
[106] CPRW. (n.d.). Percentage of Hispanic construction workers, by state, 2015 (all employment). https://www.cpwr.com/wp-content/uploads/2018/03/16d.JPG
[107] SAF. (2007). Facts about North Carolina Farmworkers. https://saf-unite.org/content/facts-about-north-carolina-farmworkers.
[108] Dahl, K., & Udvardy, S. (2019). US Military on the Front Lines of Extreme Heat. Cambridge, MA: Union of Concerned Scientists. https://www.ucsusa.org/resources/us-military-bases-risk-extreme-heat
[109] Anderson, H., Brown, C., Cameron, L. L., Christenson, M., Conlon, K. C., Dorevitch, S., … & BRACE Midwest and Southeast Community of Practice. (2017). Climate and Health Intervention Assessment: Evidence on Public Health Interventions to Prevent the Negative Health Effects of Climate Change. https://www.cdc.gov/climateandhealth/docs/ClimateAndHealthInterventionAssessment_508.pdf
[110] Bauer, J. B. (n.d.). Landslides in Western North Carolina: Learning from the Past to Protect our Future. https://appalachianlandslide.files.wordpress.com/2014/01/2014-01-08-landslides-in-wnc-for-avl-green-drinks.pdf
[111] USGCRP. (2008). The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity. https://www.globalchange.gov/browse/reports/sap-43-effects-climate-change-agriculture-land-resources-water-resources-and.
[112] North Carolina Department of Health and Human Services. (2020). Algal blooms. https://epi.dph.ncdhhs.gov/oee/a_z/algal_blooms.html
[113] North Carolina Department of Environmental Quality. (n.d.). Chapter 10—Bacteria and Water Quality Impacts. https://files.nc.gov/ncdeq/Water%20Quality/Planning/BPU/BPU/Supplemental%20Guide/Chapter%2010.pdf.
[114] Neumann, J. E., Anenberg, S. C., Weinberger, K. R., Amend, M., Gulati, S., Crimmins, A., ... & Kinney, P. L. (2019). Estimates of present and future asthma emergency department visits associated with exposure to oak, birch, and grass pollen in the United States. GeoHealth, 3(1), 11-27. Additional information received through personal communication with Jim Neumann on August 31, 2020.
[115] Reid, C. E., & Maestas, M. M. (2019). Wildfire smoke exposure under climate change: Impact on respiratory health of affected communities. Current Opinions on Pulmonary Medicine 25(2), 179-187. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6743728/#:~:text=Wildfires%20and%20smoke%20exposures%20are,research%20is%20not%20as%20consistent.
[116] Couper, L. I., MacDonald, A. J., & Mordecai, E. A. (2020). Impact of prior and projected climate change on US Lyme disease incidence. bioRxiv.
[117] North Carolina Department of Health and Human Services. (2013) Mosquito Borne Illness in North Carolina, 2003-2012. https://epi.dph.ncdhhs.gov/cd/arbo/figures/arbo2003_2012.pdf
[118] Belova, A., Mills, D., Hall, R., Juliana, A. S., Crimmins, A., Barker, C., & Jones, R. (2017). Impacts of increasing temperature on the future incidence of West Nile neuroinvasive disease in the United States. American Journal of Climate Change, 6(01), 166.
[119] N.C. Commerce News. (2019). Visitor spending in North Carolina grows at near record pace. https://www.nccommerce.com/news/press-releases/visitor-spending-north-carolina-grows-near-record-pace
[120] Albemarle-Pamlico-National Estuary Partnership. (2016). 2016 Economic Valuation of AP Watershed Natural Resources. https://apnep.nc.gov/documents/2016-economic-valuation-of-ap-watershed-natural-resources
[121] U.S. Fish and Wildlife Service (2011). 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: North Carolina. Retrieved from: https://www2.census.gov/programs-surveys/fhwar/publications/2011/fhw11-nc.pdf
[122] Grimes, J. (2015). WNC ski resorts outpacing industry nationwide. https://carolinapublicpress.org/23722/wnc-ski-resorts-outpacing-industry-nationwide/
[123] Phaneuf, D. & Van Houtven, G. L. (2015). Structural benefits transfer using Bayesian econometrics. In R. Johnston, J. Rolfe, R. Rosenberger, & R Brouwer (Eds.), Benefit Transfer of Environmental and Resource Values: A Handbook for Researchers and Practitioners. Springer, Economics of Non-Market Goods and Resources series
[124] Song, L. & Shaw, A. (2018). A never-ending commitment: The high cost of preserving vulnerable beaches. https://www.propublica.org/article/the-high-cost-of-preserving-vulnerable-beaches
[125] ASBPA-APTIM. (2020) National Beach Nourishment Database. https://gim2.aptim.com/ASBPANationwideRenourishment

[126] U.S. Bureau of Labor Statistics. (2018). Golf Anyone? A Look at Golf Courses and Country Clubs by State. https://www.bls.gov/opub/ted/2018/golf-anyone-a-look-at-golf-courses-and-country-clubs-by-state.htm.
[127] North Carolina Department of Environmental and Natural Resources. (2009). The Water Connection. https://www.ncwater.org/Reports_and_Publications/primer/The_Water_Connection_Booklet_9x12_300dpi.pdf.
[128] North Carolina Division of Parks and Recreation. (2016). Repairs at South Mountains after the wildfire will take time. https://www.ncparks.gov/repairs-south-mountains-after-the-wildfire-will-take-time.
[129] Ahn, S., De Steiguer, J. E., Palmquist, R. B., & Holmes, T. P. (2000). Economic analysis of the potential impact of climate change on recreational trout fishing in the southern Appalachian Mountains: An application of a nested multinomial logit model. Climatic Change, 45(3-4), 493-509.
[130] National Park Service. (2019). Park air profiles—Great Smoky Mountains National Park. https://www.nps.gov/articles/airprofiles-grsm.htm ; https://www.epa.gov/sites/production/files/2018-03/documents/ee-0405_all.pdf
[131] Taggart, J. B., Sasser, J. G., Dodson, J. W. & Ellis, J.M. (2015). Distribution and management of invasive plant populations in state park properties of the North Carolina coastal plain. Natural Areas Journal, 35(3), 476-484.
[132] United States Climate Alliance. (2019). 2019 Fact Sheet. https://static1.squarespace.com/static/5a4cfbfe18b27d4da21c9361/t/5f1f0b2cf13e090f828e58dc/1595869997700/USCA+Factsheet_Dec+2019.pdf.
[133] Ceres. (n.d.). The Regional Greenhouse Gas Initiative: A Fact Sheet. https://www.ceres.org/sites/default/files/Fact%20Sheets%20or%20misc%20files/RGGI%20Fact%20Sheet.pdf
[134] For North Carolina emissions by sector, see https://deq.nc.gov/energy-climate/climate-change/greenhouse-gas-inventory
[135] HHS. (n.d.). HHS Sustainable and Climate Resilient Health Care Facility Initiative Toolkit. https://toolkit.climate.gov/sites/default/files/SCRHCFI%20Checklist%20Composite_Form.pdf and https://toolkit.climate.gov/tool/flood-resilience-checklist
[136] CDC. (2019). CDC's Building Resilience Against Climate Effects (BRACE) Framework. https://www.cdc.gov/climateandhealth/brace.htm
[137] NOAA. (2020). U.S. Climate Resilience Toolkit. Funding Opportunities. https://toolkit.climate.gov/content/funding-opportunities
[138] Georgetown Climate Center. (n.d.). Managed Retreat Toolkit. https://www.georgetownclimate.org/adaptation/toolkits/managed-retreat-toolkit/introduction.html. Carey, J. (2020). Managed retreat increasingly seen as necessary in response to climate change's fury. PNAS Core Concepts. https://www.pnas.org/content/pnas/early/2020/05/26/2008198117.full.pdf,
[139] Petrusa, J., Brown, R., Lim, B., & Gonzales, M. (2019). Economic impact analysis of clean energy development in North Carolina–2019 update. https://energync.org/wp-content/uploads/2019/05/v3NCSEA_Economic_Impact_Analysis_of_Clean_Energy_Development_in_North_Carolina_2019.pdf
[140] IRENA. (2019). Renewable power generation costs in 2018. International Renewable Energy Agency, Abu Dhabi.
[141] Woollacott, J. (2018). The economic costs and co-benefits of carbon taxation: A general equilibrium assessment. *Climate Change Economics*, *9*(1).
[142] Bollinger, B. and Gillingham, K., 2012. Peer effects in the diffusion of solar photovoltaic panels. Marketing Science, 31(6), pp.900-912.