SOUTH CAROLINA DEPARTMENT OF NATURAL RESOURCES

DNR

CLIMATE CHANGE IMPACTS TO NATURAL RESOURCES IN SOUTH CAROLINA

This document is available on the Department of Natural Resources web site at http:www.dnr.sc.gov/

FOREWORD

In recent years state natural resource agencies including the South Carolina Department of Natural Resources (DNR) have been engaged in discussions about climate change. Staff at DNR, and many of our counterpart state agencies, are routinely asked some of the following questions:

1. What might happen to our fish, wildlife and marine resources if climate change should have an effect on them?
2. Are invasive and noxious species likely to be able to exploit subtle changes in air or water temperature or water quality or quantity?
3. What impact might climate change have on water resources and its continued availability for both humans and fish and wildlife?
4. What are some of the common-sense things we can do to adapt to climate change if it begins to occur?
5. How might recreational boating be affected if our lakes and reservoirs are impacted by climate change?
6. What monitoring programs are in place that will enable us to be able to predict impacts to natural resources or recreational use before they occur?
7. What technologies are necessary to enable science-based natural resource monitoring programs?

These are just a few of the questions we must consider given our mandate to be the stewards of natural resources in South Carolina. In reality, there are many more questions and none of them have easy answers. Facing complex issues and preparing for an uncertain future are nothing new to the DNR. We utilize a sound, science-based approach and have been doing this for many decades. DNR does not have experts in the field of climate change or personnel involved in pure climate change research. However, scientists, biologists, and other personnel from DNR have reviewed the available scientific literature on climate change and the possible impacts on the state's natural resources and drafted a guidance document to help us navigate the path forward.

Over the past few decades scientists have documented melting glaciers, diminishing polar sea ice, shifting of growing seasons, changes in migratory patterns of birds and fish, rising sea levels and many other climate-related phenomena. These changes and countless more like them may have substantial consequences for both the environment and the economy. Nationally, hunting, fishing and wildlife-related recreation alone add $122 billion to the economy each year. In South Carolina, natural resources are essential for economic development and contribute nearly $30 billion and 230,000 jobs to the state's economy. Access to abundant recreational opportunities and natural assets play an important role in economic growth and quality of life at the local, regional and state levels, so protection and enhancement of our natural resources can and should be part of our overall economic development strategy.

Any changes to our coastal environment could cause substantial economic consequences. Shoreline changes affect property uses, land values, tourism, and natural resources management as well as traditional uses such as hunting and fishing, timber management and agriculture.

Some have argued that natural variability and chance have the major influences over climate change, that this is a natural process, and that climate scientists have been overreacting. At DNR, we do not profess to know why all of these changes seem to be occurring, but we do understand that we have a responsibility to stay abreast of the latest science as we strive to make the best decisions possible in the management of the state's natural resources.

All of these potential impacts require a science-based approach to decision making. Moving forward, we should develop an efficient strategy incorporating baseline measurements, monitoring, and data analyses to provide decision makers accurate assessments and predictions of future environmental changes. We know that we must be prepared for change should it occur.

This report is a first step in the process of identifying and gathering published information on how climate change may affect wildlife, fisheries, water supply and other natural resources in South Carolina. We have identified some key adaptive steps necessary to respond to potential climate change in our state. This report is being released for public review, and we invite our citizens and leaders to participate by providing their comments. Public comments may be submitted electronically to climatechange@dnr.sc.gov or by mail to Climate Change, PO Box 167, Columbia, SC 29202. We will appreciate receiving your comments by May 24, 2013.

Signature:

Alvin A. Taylor
Director

ACKNOWLEDGEMENTS

This report is the product of the direct efforts of a number of dedicated South Carolina Department of Natural Resources staff from various internal divisions who both participated in the construction of and advocated for this document. Department of Natural Resources participating staff represented their respective divisions with the clear understanding that such an effort is vital in order to protect and conserve natural resources during a period of potentially rapid climate change. Many other agency employees provided input, and, most importantly, encouraged the preparers toward the goal of producing a draft and ultimately a final report. Staff contributors from their respective divisions included:

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Staff listed above constituted the South Carolina Department of Natural Resources Climate Change Technical Working Group, and they collaborated to provide direction and copy for this document. We are very grateful both to Ann Nolte who reviewed two versions of this document and provided very capable editorial assistance and also to Kay Daniels and Ivetta Abramyan who assisted the effort in many ways.

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DEFINITIONS

Sources:

1. Glossary of Terms used in the IPCC Fourth Assessment Report.[1]
2. American Geological Institute, Glossary of Geology.[2]
3. NOAA.[3]
4. Climate Literacy.[4]

Adaptation – Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, moderating harm or exploiting beneficial opportunities.

Albedo – The fraction of solar radiation reflected by a surface or object, often expressed as a percentage. Snow-covered surfaces have a high albedo; the albedo of soils ranges from high to low; vegetation-covered surfaces and oceans have a low albedo. The Earth's albedo varies mainly through varying cloudiness, snow, ice, leaf area and land cover changes.

Anadromous – Migration of aquatic organisms from the sea to freshwater to spawn.

Anthropogenic – Effects, processes or materials that are derived from human activities, as opposed to those occurring in biophysical environments without human influence. Resulting from or produced by human beings.

Assemblage – The smallest functional community of plants or animals.

Atmosphere – The mixture of gases surrounding the Earth, retained by gravity. It protects life by absorbing ultraviolet solar radiation, warms the surface through heat retention (the greenhouse effect), and reduces temperature extremes between day and night.

Benthic – Relating to the bottom of a sea or lake or to the organisms that live there.

Catadromous – Migration of aquatic organisms from freshwater to the sea to spawn.

Climate – The characteristic weather of a region, particularly as regards temperature and precipitation, averaged over some significant interval of time. Climate in a narrow sense is usually defined as the average weather, or more rigorously, as a statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the *climate system*. In various parts of this report different averaging periods, such as a period of 20 years, also are used.

Climate change – Climate change refers to a change in the state of the climate that can be identified, for instance by using statistical tests, by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal

[1] http://www.ipcc.ch/publications_and_data/publications_and_data_glossary.htm. Last accessed Jan 2011.
[2] http://www.agiweb.org/pubs/glossary/. Last accessed May 2011.
[3] http://www.weather.gov/glossary/. Last accessed Mar 2011.
[4] https://gcce.larc.nasa.gov/index.php?q=resources/climate-literacy&page=7. Last accessed Apr 2011.

processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climatology – The study of climate, the long-term average of conditions in the atmosphere, ocean, and ice sheets and sea ice described by statistics, such as means and extremes.

Demersal – Refers to species living near the benthic, or bottom, zone of the sea.

Diadromous – Migration of aquatic organisms between fresh and salt waters; includes both anadromous and catadromous.

Ecological services – Humankind benefits from a multitude of resources and processes supplied by natural ecosystems including products such as clean drinking water and processes such as decomposition and assimilation of wastes.

Endangered species – A species of flora or fauna whose numbers are so small that the species is at risk of extinction.

Evapotranspiration – The sum of water vapor evaporated from the Earth's surface and transpired from vegetation to the atmosphere from sources such as the soil, forest canopy interception and surface waters.

Feedback mechanism - A loop system in which the system responds to a change either in the same direction (positive feeback) or in the opposite direction (negative feedback).

Fossil fuel – A general term for any hydrocarbon that may be used for fuel, chiefly coal, petroleum and natural gas formed by decomposition and compression of buried dead organisms.

Glacial maximum – The time or position of the greatest advance of a glacier, or of glaciers.

Greenhouse effect – The natural effect produced as greenhouse gases allow incoming solar radiation to pass through the Earth's atmosphere, but prevent most of the outgoing infrared radiation from the surface and lower atmosphere from escaping into space. Life on Earth could not be sustained without the natural greenhouse effect. However, if the atmospheric concentrations of these greenhouse gases rise, the average temperature of the lower atmosphere will gradually increase.

Greenhouse gas (GHG) – The gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. There are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine containing substances.

Habitat – An ecological, environmental or physical area inhabited by a particular species of animal, plant or other organism.

Insolation – A measure of the amount or rate of solar radiation (Sun) energy received on a given surface area in a given time. **IN**cident **SOL**ar radi**ATION**

Last glacial maximum (LGM) – The time of maximum extent of the ice sheets during the last glacial period, 18,000 years ago. For the central and eastern United States this is referred to as the Wisconsin glaciations. The most recent glacial period lasted from 110,000-11,700 years ago, during the Pleistocene. The

Holocene begins at the end of the Pleistocene, and is considered an interstadial in Quaternary/Pleistocene glaciations.

Little Ice Age – An interval of time between approximately AD 1400-1900 when temperatures in the Northern Hemisphere generally were colder than today, especially in Europe. Originally employed for a mid-Holocene event in the Yosemite area, California, about 3,000 years BC.

Medieval Warm Period (MWP) – An interval of time between AD 1000-1300 in which some Northern Hemisphere regions were warmer than during the Little Ice Age that followed.

Milankovitch theory – An astronomical theory of glaciation, formulated by Milutin Milankovitch, Yugoslav mathematician, in which climatic changes result from fluctuations in the seasonal and geographic distribution of insolation, determined by variations of the Earth's orbital elements, namely eccentricity, tilt of rotational axis and precession. It is supported by recent radiometrically dated reconstructions of ocean temperature and glacial sequences.

Mitigation – An anthropogenic intervention to reduce the anthropogenic forcing of the climate system including strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks.

Outgassing –The release of trapped or embedded gases

Paleoclimate Proxies – A proxy climate indicator is a local record that is interpreted, using physical and biophysical principles, to represent some combination of climate-related variations back in time. Climate-related data derived in this way are referred to as proxy data. Examples of proxies include pollen analysis, tree ring records, characteristics of corals and various data derived from ice cores.

Paleoclimatology – The study of climate during periods prior to the development of measuring instruments, including historic and geologic time, for which only proxy climate records are available.

Paleotempestology – The study of past tropical cyclone activity (hurricanes) by means of geological proxies and historical records.

Pleistocene – The earlier of 2 Quaternary epochs, extending from the end of the Pliocene, about 1.8 million years ago, until the beginning of the Holocene, about 11,600 years ago.

Sea-level rise – The contextual relationship between land and the sea when the surface of the sea is increased in height relative to land due to increased water volume of the ocean and/or sinking of the land.

Sequestration – The removal and storage of carbon from the atmosphere in carbon sinks (such as oceans, forests or soils) through physical or biological processes, such as photosynthesis.

Stadial – A short period of colder temperatures during an interglacial (warm period) separating the glacial periods of an ice age. It can be marked by a glacial readvance. The Little Ice Age is a stadial event. This is opposite of an interstadial, which is a short, warm period occurring within a longer glacial period and is marked by a temporary glacial retreat.

Teleconnections – Refers to a recurring and persistent large-scale pattern of pressure and circulation anomalies spanning vast geographical areas. Teleconnection patterns also are referred to as preferred modes of low-frequency (or long time scale) variability. Although these patterns typically last for several weeks to several months, they sometimes can be prominent for several consecutive years, thus reflecting an important part of both the interannual and interdecadal variability of the atmospheric circulation. Many of the teleconnection patterns also are planetary-scale in nature, and span entire ocean basins and continents. For example, some patterns span the entire North Pacific basin, while others extend from eastern North America to central Europe. Still others cover nearly all of Eurasia. They are climate anomalies that are related to each other but occur at large distances from each other perhaps scanning thousands of miles.

Threatened species – A species likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

Troposphere – The lowest portion of Earth's atmosphere, from the surface to about 10 km in altitude at mid-latitudes (ranging from 9 km at high latitudes to 16 km in the tropics on average), where clouds and weather phenomena occur. In the troposphere, temperatures generally decrease with height. It contains approximately 75% of the atmosphere's mass and 99% of its water vapor and aerosols.

Vostok Ice Core – In January 1998, this ice-drilling project, a collaborative between Russia, the United States and France at the Russian Vostok station in East Antarctica yielded the deepest ice core ever recovered, reaching a depth of 3,623 m. Preliminary data indicate the Vostok ice-core record extends through four climate cycles, with ice slightly older than 400,000 years ago.

Water supply – The total amount of water within a defined area that is available for human and other uses.

Wisconsin Glaciation or Wisconsin Stage – the classical fourth glacial stage (and last) of the Pleistocene Epoch in North America. It followed the Sangamon Interglacial Stage and preceded the current Holocene Epoch.

Younger Dryas – A period 12,900-11,600 years ago, during the deglaciation, characterized by a temporary return to colder conditions in many locations, especially around the North Atlantic.

ACRONYMS AND ABBREVIATIONS

ACE Basin – Ashepoo, Combahee and Edisto rivers basin
ASMFC – Atlantic States Marine Fisheries Commission
AMO – Atlantic Multi-Decadal Oscillation
BMRI – Baruch Marine Research Institute, of the University of South Carolina
CO_2 – Carbon dioxide
COR – Coastal Reserves and Outreach of the MRD
CWCS – Comprehensive Wildlife Conservation Strategy
DHEC – South Carolina Department of Health and Environmental Control
DNR – South Carolina Department of Natural Resources
ENSO – El Niño-Southern Oscillation
FAA – Federal Aviation Administration
GIS – Geographic Information Systems
GHG – Greenhouse gas
GSP – Greenville-Spartanburg Airport National Weather Service Station
HAB – Harmful Algal Bloom
LED – Law Enforcement Division of DNR
LGM – Last Glacial Maximum
LWC – Land, Water and Conservation Division of DNR
MARMAP – Marine Resources Monitoring, Assessment and Prediction Program
MJO – Madden-Julian Oscillation
MRD – Marine Resources Division of DNR
MRRI – Marine Resources Research Institute, of MRD
NGO – Non-governmental organization
NOAA – National Oceanic and Atmospheric Administration
NWS – National Weather Service
OFM – Office of Fisheries Management of MRD
QBO – Quasi-Biennial Oscillation
SAB – South Atlantic Bight
SAMFC – South Atlantic Marine Fisheries Council
SEAMAP – Southeast Area Monitoring and Assessment Program
SENRLG – Southeast Natural Resource Leadership Group
SERTC – Southeastern Regional Taxonomic Center
USC – University of South Carolina, National Weather Service Station
USGS – United States Geological Survey
USHCN – United States Historical Climatology Network
WFF – Wildlife and Freshwater Fisheries Division of DNR

CONTENTS

EXECUTIVE SUMMARY

Global warming and cooling have occurred naturally throughout history, but changes in the past were usually much slower than the rate of warming that has occurred in the last few decades. Both land and ocean temperature measurements independently indicate a warming trend since around 1880, but since 1979, land temperatures have increased approximately twice as fast as ocean temperatures (0.25 °C per decade versus 0.13 °C per decade). Since the mid 1970s, the average surface temperature has increased by about 1°F (0.56 °C). If this trend continues, by the end of this century, average global temperature is projected to rise between 2-11.5ºF (1.1-6.4°C). Observed climate-related changes are expected to continue, and are likely to result in new natural resource impacts and changes that potentially disrupt or damage ecological services, water supplies, agriculture and forestry, fish and wildlife species and their habitats, endangered species and commercial and recreational fishing and hunting.

The South Carolina Department of Natural Resources (DNR) is charged by law with the management, protection and enhancement of natural resources in South Carolina and thus is the steward of the state's natural resources for their use and enjoyment by the public. In South Carolina, natural resources are essential for economic development and contribute nearly $30 billion and 230,000 jobs to the state's economy. The DNR recognizes the need to address potential climate change as a threat-multiplier that could create new natural resource concerns, while exacerbating existing tensions already occurring as a result of population growth, habitat loss, environmental alterations and overuse. Thoughtful and careful planning regarding climate change is needed in order to protect the valuable natural resources of the Palmetto State. In response to these challenges, DNR has identified potential impacts of climate change on the natural resources of South Carolina, and developed an adaptive response strategy to offset, minimize or delay the effects of a changing climate on natural resources. The agency will:

1. Gather factual, accurate information and data on how climate change may affect wildlife, fisheries, water supply and other natural resources within the state,
2. Identify monitoring and data needs required to assess impacts of climate change in the state,
3. Use factual information, data, research and modeling to determine what actions need to be taken to address climate change,
4. Ensure data quality; provide original research that addresses information needs; and validate modeling results with collected data,
5. Identify opportunities to partner with other state agencies and academic institutions where needed to accomplish this mission,
6. Identify ways for state officials, local government and citizens to assist in mitigation of or adaptation to natural resource impacts related to climate change, and
7. Locate and obtain available funding to assist in meeting agency mission and goals related to climate change.

Climatology is the study and analysis of weather records over an extended period of time. The study of climate prior to the use of instrumental records is known as paleoclimatology. Results from paleoclimate studies indicate that climate variation is a natural phenomenon; Earth's climate has changed many times throughout history. Currently, we are in an interglacial, or warm, period, which began at the end of the last glacial maximum 13,500 years ago. Other results from paleoclimate studies show that climate has changed episodically on a variety of timescales, and some of these changes have occurred quite abruptly. Climate has varied through time under the influence of its own internal dynamics involving changes such as volcanic eruptions and solar variations. Now, human-caused changes in atmospheric composition appear to be influencing climate change.

To date, no systematic study of South Carolina's paleoclimate has been completed. Some studies have addressed climatic conditions at a specific time or at a specific site, but no studies document the state's climate before instrumental records became available. The state's paleoclimate record should be studied at several time scales to establish a baseline for current climatic conditions and future trends. South Carolina climatological trend data, 1895-2010, has been analyzed and shows a warming trend that started during the 1970s continuing to the present. A warming trend was also observed in winter coastal water temperatures during a study performed from 1950-2010. Severe weather is a persistent feature of South Carolina's climatology. No discernible relation is seen between the number of tornadoes or coastal hurricanes land falls and the aforementioned warming trends.

Current climate models predict continued warming across the southeast, with the greatest temperature increases projected in summer. Average annual temperatures are projected to rise 4.5°F by the 2080s under a lower emissions scenario and 9°F under a higher emissions scenario with a 10.5°F increase in summer. The frequency, duration and intensity of droughts are likely to continue to increase with higher average temperatures and a higher rate of evapotranspiration.

Sea level rise is a serious concern in South Carolina due to our extensive coastline. Sea level rise will affect coastal habitats such as estuaries, creeks, marshes, managed wetlands, hammocks, sand dunes and beaches by modifying patterns of sea water encroachment, flooding, erosion and deposition. It will also affect fish and wildlife species that depend on these habitats, as well as any related activities such as fishing, hunting and tourism. Some habitats may adapt by depositional growth or inland migration, but coastal development could impede the latter in many areas. Potential management responses include inland retreat, coastal reinforcement and beach nourishment, but each option has ecological and economic costs.

A changing climate will present water-related challenges in several areas to include water quality, water quantity and changes in sea level. Rainfall and streamflow are tied directly to seasonal climatic conditions. Although DNR has no direct responsibility in regulating water quality, issues of water quality and quantity are difficult to separate when availability is in question. By statute DNR is responsible for water planning in

South Carolina. A comprehensive statewide water policy is needed to maintain and preserve surface- and ground-water supplies. Basic information needed for this work is lacking or threatened due to limited funding. Necessary steps are required to maintain and expand the availability of reliable information needed for a water assessment. Sea-level rise, drought and flooding are occurring, and sea-level rise already is creating shoreline change. Several drought periods in recent years have adversely affected agricultural interests, forestry and water supply. Planning and monitoring is needed prior to and during drought events. A predicted result of climate change is the increase in intense storm events causing greater water inputs in shorter periods of time, affecting flood frequency and duration.

Temperature rise is expected to affect a number of natural resource issues in South Carolina. Habitats and life histories of species within the state may be shifted both in terms of time and space. This could result in changes to feeding and nesting areas as well as reproductive cycles. Additionally, ecosystem-wide regime shifts may result in major changes in species diversity and interactions at all trophic levels. Temperature has a direct effect on the physiology and survival of aquatic species. Commercial and recreational landings of aquatic species may be affected when life histories shift. Ranges for species may shift so they no longer occur in South Carolina, while other more temperature tolerant species may thrive where they had not done so previously. Harmful algal blooms caused by certain species of microscopic, photosynthetic algae can cause a wide range of detrimental effects that are species-specific. These effects may include shading and destruction of estuarine grass habitat, shellfish poisoning and toxin production that can bioaccumulate in the food chain potentially inducing sickness and death in wildlife and humans. Increasing temperatures can reduce oxygen levels in coastal waters through a variety of mechanisms such as a decrease in the solubility of oxygen, an increase in productivity and stratification of the water column. These factors can result in dead zones in coastal and estuarine waters. Increasing ocean acidification is related to increasing carbon dioxide levels in the Earth's atmosphere. Ocean acidification (decreasing Ph) raises concerns about the future of coral reefs and other species that incorporate calcium carbonate into their skeletons including mollusks, crustaceans and some plankton.

Habitat decline, a shifting climate regime, increasing development, particularly in coastal areas, and rising sea level represent constraints and barriers to dispersal and migration of fish, wildlife and plant species. Maintenance of migratory corridors is essential for the ability of wildlife and fish to find suitable habitat and for population maintenance. Temperature changes likely will change the vegetative structure of wildlife habitats throughout the state. Habitat loss not only affects the area in which the species can live, it also affects food availability and availability of suitable nesting and breeding areas. Impacts associated with temperature changes most likely will be greater in the higher elevations of the state. Precipitation changes will affect both surface and groundwater levels and will result in impacts to both terrestrial and aquatic systems. As the nation strives to locate and develop alternative, cleaner and more carbon-neutral sources of energy, it is important to understand that such energy sources may result in additional impacts to wildlife, fish and their habitats.

Species of greatest conservation need are identified in the *South Carolina Comprehensive Wildlife Conservation Strategy*; these include endangered and threatened species and species of concern. Although DNR has collected some short- and long-term information relative to some of these species and their habitats, the collective database is insufficient to understand the role of climate change in the population trends of these species. It also is difficult to identify conservation actions needed to offset or mitigate the effects of climate change. DNR should strengthen and standardize the inventory and monitoring of greatest conservation need species and their habitats.

Increased temperatures, changes in rainfall and other environmental factors affected by climate shifts can create ideal conditions for proliferation of invasive plant and animal species, including parasites and pathogens. Regardless of the manner in which they have become established, these species already are affecting native animals and their habitats. As climate changes, we likely will see an increase of exotic species migrating to South Carolina. Habitats can be destroyed as resources are over-utilized. Invasive and non-indigenous species have the potential to outcompete native species for food and other resources. Species currently located in Florida and southern Georgia that come from more temperate parts of the world have been historically limited to ranges south of South Carolina by cold winters. They are now of major concern. Significant climate change could allow range expansion in these exotic species that would be detrimental to native species.

Climate warming has been linked with a general increase in pathogens of marine, aquatic and terrestrial organisms. This may negatively impact the populations of certain species, including some of economic importance.

Wildlife and fish populations likely will be altered as climate change occurs. While such changes may lead to a reduction of commercial and recreational hunting and fishing opportunities of some species, other opportunities may increase for those species which could benefit from an altered climate. Regardless of whether climate change produces commercial and recreational winners or losers, it will be important for DNR to implement long-term monitoring of harvested species in order to detect temporal and spatial changes in numbers and prevent unsustainable population declines. Further, it will be important for DNR to keep the public and policy makers informed, through outreach and education efforts, of changes as they occur in order to reduce the potential for conflict between human and natural resource needs.

A critical element of the agency's response to climate change is to increase public awareness of the potentially adverse and positive effects resulting from these changes. Agency efforts at outreach and education are first, to strengthen and increase partnerships with other agencies and organizations involved in climate change research and policy and planning; second, to assist local communities in planning for change, such as providing coastal resiliency to reduce overall vulnerability of economic and ecological systems to climate variations; and, third, to communicate information on climate change to citizens of South Carolina using the World Wide Web and public forums. Additionally, scientific research results will be published in peer-reviewed journals.

In order to meet the agency's long-term ability to respond to climate change impacts in South Carolina, numerous additional strategies and technologies will be required. First, DNR should implement a resource inventory and monitoring program to track trends in resource abundance and distributions at the species and landscape level. Second, the agency must expand its technology infrastructure to support the climate change studies including implementing various direct and remotely-sensed measurement platforms to provide *in situ* documentation of critical climate change parameters and the integration of these data into a comprehensive database. Third, DNR must develop appropriate data access, scientific analysis and resource management decision-support tools to assess climate change impacts and to develop appropriate resource management strategies. Fourth, DNR must develop the expertise required to meet the challenges of understanding and addressing the vast array of environmental impacts and natural resource management issues associated with climate change. Staff training in various analytical, modeling and geographic information systems software, and associated technologies is essential.

This report identifies the overriding natural resource issues and provides recommended actions to keep South Carolina at the forefront of conserving natural resources during an era of changing climate. These overarching issues include the potential for:

1. Detrimental change in habitat,
2. Detrimental change in abundance and distribution of species,
3. Detrimental change in biodiversity and ecosystem services,
4. Detrimental change to the traditional uses of natural resources,
5. Detrimental change in the abundance and quality of water, and
6. Detrimental change in sea level.

Specific tasks identified by DNR in order to move forward in an era of climate change while protecting natural resources include:

1. Spatial mapping,
2. Monitoring and establishing living and non-living resources and climate trends,
3. Habitat acquisition,
4. Adaptation strategies on DNR-titled properties,
5. Integration and analysis of data,
6. Outreach and education,
7. Developing additional partnerships and collaborating with others, and
8. DNR leading by example.

DNR is making climate change an integral part of the agency's ongoing mission by integrating climate change into the DNR organizational culture, its structure and all aspects of its work. These key steps include:

1. Develop an approach that will incorporate climate change into DNR strategic and operational plans and existing structure to be used as a vehicle for internal and external communication,
2. Ensure that all levels of agency staff are aware of and engaged in climate-change initiatives,
3. Update and align DNR actions with regional and national climate change initiatives as appropriate,
4. Work with stakeholders and partners on fish, wildlife and habitat adaptation and mitigation,
5. Prepare an internal and external outreach strategy to communicate climate change issues, and
6. Develop clear and measurable indicators to track the results of DNR climate change efforts.

To accomplish its mission, DNR recommends the following core climate change efforts:

1. Policies and Opportunities – focus on grants, legislation, partnerships and strategic planning,
2. Research and Monitoring – focus on standardized monitoring protocols and state-specific data (including gaps) and predictive modeling,
3. Communication and Outreach – focus on the DNR messages and a climate change communication plan,
4. Adaptation – focus on the activities related to unavoidable climate change impacts on natural resources
5. Operations – focus on positioning DNR as a leader by reducing the agency's carbon footprint, improving its energy efficiency and decreasing operational costs.
    a. Achieve increased fuel economy through various methodologies.
    b. Achieve increased energy efficiency through energy audits and adoption of practicable energy audit recommendations.
    c. Implement practicable water efficiency measures for agency buildings.
    d. Implement paperless internal communications and document management.

DNR is taking a lead role among South Carolina state agencies to advance the scientific understanding of the vulnerability of South Carolina's vital natural resources during an era of changing climate. This will enable the agency, its partners, constituents and all Palmetto State citizens to avoid or minimize the anticipated impacts while protecting South Carolina's natural resources.

TABLES

FIGURES

1.0 INTRODUCTION

1.1 Climate Change

Climate change, such as global warming and cooling, has occurred naturally throughout history over timescales that vary from decades to hundreds of thousands of years. However, changes in the past were usually much slower than the rate of warming that has been measured in the last few decades. Figure 1.1 provides the annual global temperature anomalies for the past 130 years, including both land and ocean temperature trends. Land temperatures increase faster than ocean temperatures due to the greater heat capacity of the ocean and its ability to transfer more heat to the atmosphere in the form of evaporative cooling.[5] Both land and ocean temperature measurements independently indicate a warming trend since around 1880, but since 1979, land temperatures have increased approximately twice as fast as ocean temperatures (0.25 °C per decade versus 0.13 °C per decade)[6]. Although temperature changes vary over the globe, since the mid 1970s, the average surface temperature has increased by about 1°F (0.56 °C) [7]. If this trend continues, by the end of this century, average global temperature is projected to rise between 2-11.5ºF (1.1-6.4°C)[8].

While some of this warming has a natural cause, there is evidence that human activity is disproportionally contributing to the measured warming. The concern over human activities arises primarily from fossil fuel combustion, which releases carbon dioxide and other greenhouse gases, and changes in land use. The introduction of external greenhouse gases into the atmosphere alters the radiative balance of the earth by changing its atmospheric composition, which enhances the natural greenhouse effect. There are complex interactions between many of these processes.

The increase in global temperatures is just one consequence of a changing climate. The various components of the climate and earth system are linked through complex feedback mechanisms, so that a change in one component, such as temperature, can induce changes and adjustments in other components. Changes already observed, or projected to occur, include sea level rise; changes in rainfall patterns; increases in

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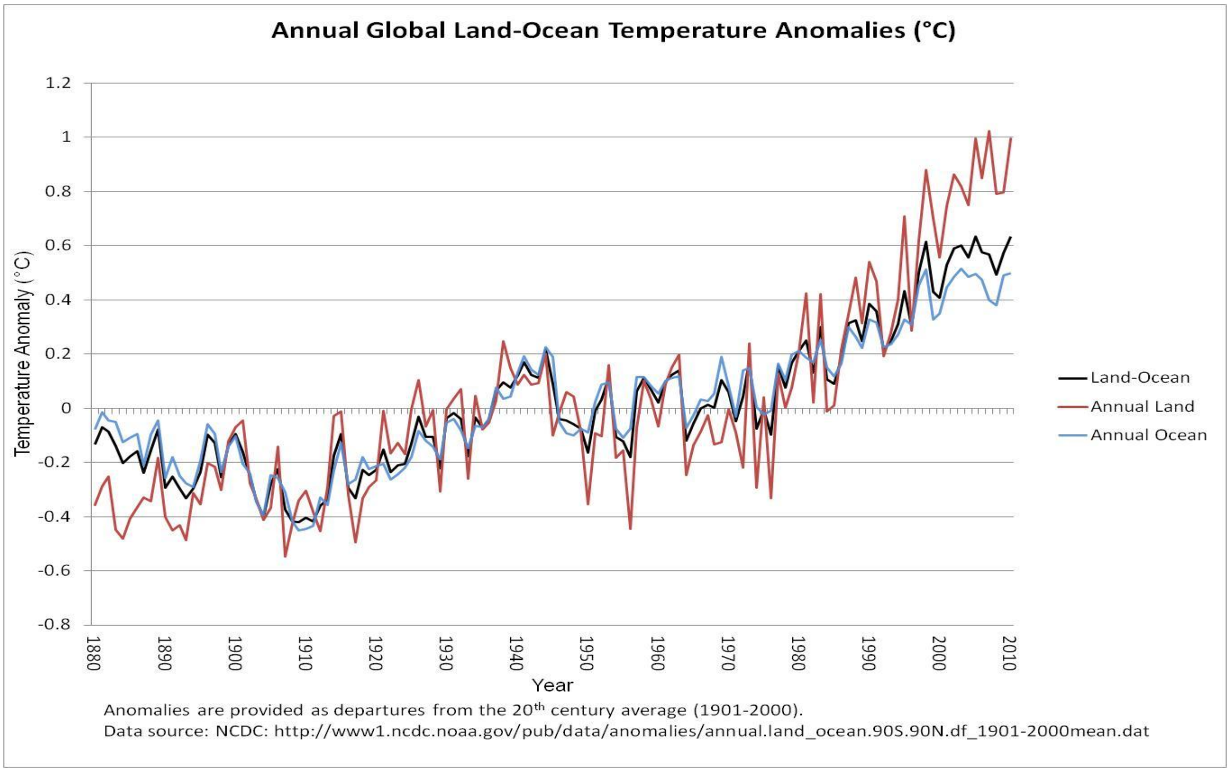
[5] Rowan T. Sutton, Buwen Dong, Jonathan M. Gregory (2007). "Land/sea warming ratio in response to climate change: IPCC AR4 model results and comparison with observations". *Geophysical Research Letters* **34** (2).
[6] Chapter 3, p. 237, in IPCC AR4 WG1 (2007). Solomon, S.; Qin, D.; Manning, M.; Chen, Z.; Marquis, M.; Averyt, K.B.; Tignor, M.; and Miller, H.L.. ed. *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press
[7] (NOAA)2008 State of the Climate Report
[8] IPCC, 2007: Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning,Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

frequency of extreme weather events; decreases in ice mass of glaciers, ice sheets and sea ice; ocean warming and acidification[9]; and alterations in ocean circulation patterns.

Figure 1.1 Annual land, annual ocean, and combined annual land-ocean global temperature anomalies for the past 130 years indicating a significant rise over the last 30 years. Land surface temperatures are generated from the Global Historical Climate Network-Monthly **(GHCN-M)**. Sea surface temperatures are determined using the Extended Reconstructed Sea Surface Temperature **(ERSST)** analysis[10].



The South Carolina Department of Natural Resources recognizes the need to address potential climate change as a threat-multiplier that could create new natural resource concerns, while exacerbating existing tensions already occurring as a result of population growth, habitat loss, environmental alterations and overuse. Climate-related changes may adversely affect the environment in many ways, potentially disrupting or damaging ecological services, water supply, agriculture and forestry, fish and wildlife species and their habitats, endangered species and commercial and recreational fishing. One particular impact is sea-level rise and its effects on coastal areas. Rising sea level may amplify problems of coastal flooding, coastal erosion, and general disruptions to sensitive coastal and estuarine ecosystems. Thoughtful and careful

[9] Effects of Climate Change and Ocean Acidification on Living Marine Resources, Written testimony presented to the U.S. Senate Committee on Commerce, Science and Transportation's Subcommittee on Oceans, Atmosphere, Fisheries, and Coast Guard, May 10, 2007

[10] http://www.ncdc.noaa.gov/cmb-faq/anomalies.php. Last accessed October, 2011

planning regarding climate change is needed in order to protect the valuable natural resources of the Palmetto State. In response to these challenges, DNR has prepared this report to address potential impacts of climate change on the natural resources of South Carolina and guide the agency's adaptive response strategy to offset, minimize, or delay these effects.

1.2 Background

South Carolina's natural resources contribute nearly $30 billion and 230,000 jobs to the state's economy. These economic benefits include forestry, mining, recreational fishing, hunting and wildlife viewing, a large part of the tourism market, and the recreational industry. South Carolina's beaches alone generate about $3.5 billion annually and support 81,000 jobs. Fishing, hunting and wildlife viewing contribute almost $2.2 billion annually to South Carolina's economy and support nearly 59,000 jobs, while the state's forestry industry exports more than $1 billion in forest products, supporting more than 83,000 jobs[11].

DNR is charged by law (Titles 48 and 50, South Carolina Code of Laws (1976), as amended) with the management, protection and enhancement of natural resources in South Carolina[12]. Additionally, DNR is charged with regulating watercraft operation and associated recreation, including establishing boating safety standards. Title 49, South Carolina Code of Laws, authorizes DNR as the state agency responsible for considering water supply (domestic, municipal, agricultural and industrial) issues, water quality facilities and controls, navigation facilities, hydroelectric power generation, outdoor recreation, fish and wildlife opportunities, and other water and land resource interests. This title also charges DNR with aquatic plant management, comprehensive drought planning, management and coordination of State Scenic Rivers and the conservation, protection, and use of floodplain lands.

DNR is the steward of the State's natural resources and is responsible for the protection and management of these resources for the use and enjoyment of the public. Natural resources within DNR's purview include land, water, mineral and biological resources. In carrying out its responsibilities, DNR must balance its objectives and actions holistically in order to most appropriately protect and sustain the natural resources of South Carolina.

DNR is a multifaceted agency consisting of the fish and wildlife sciences and the offices of the State Climatologist, State Geologist and State Hydrologist. Scientists in all divisions of the DNR are concerned over the potential impacts of climate change on natural resources. In fact, natural resource agencies across the nation, both state and federal, are examining climate change and the specific issues affecting their area of responsibility and core mission. DNR recognizes climate change as a real phenomenon, grounded in numerous scientific studies, and DNR recognizes that

[11] Underappreciated Assets: The Economic Impact of South Carolina's Natural Resources, University of South Carolina Moore School of Business, 2009, http://www.dnr.sc.gov/green/greenreport.pdf
[12] http://www.scstatehouse.gov/code/statmast.htm. Last accessed October 2011.

thoughtful and careful planning is needed in order to protect the natural resources of the Palmetto State to benefit its citizens in the future.

South Carolina state government has been involved in the climate change discussion primarily through the Climate, Energy and Commerce Advisory Committee called to action by former Governor Mark Sanford in 2007. The committee consisted of elected officials and leaders from government agencies, utilities, non-government organizations, businesses, and industry. The final committee report examined present and projected state contributions to GHG, and recommended ways to reduce GHG output over the next planning horizon, which was defined as by 2020 and beyond. Of particular note, the report recommended a comprehensive set of 51 specific policies to reduce GHG emissions and address climate-, energy-, and commerce-related issues in South Carolina[13]. The State has taken positive steps toward developing policies that will decrease the contribution of GHG emitted from Palmetto State sources, and the State has joined with states across the nation in an effort to mitigate the potential impacts of climate change by reducing the greenhouse effect [14].

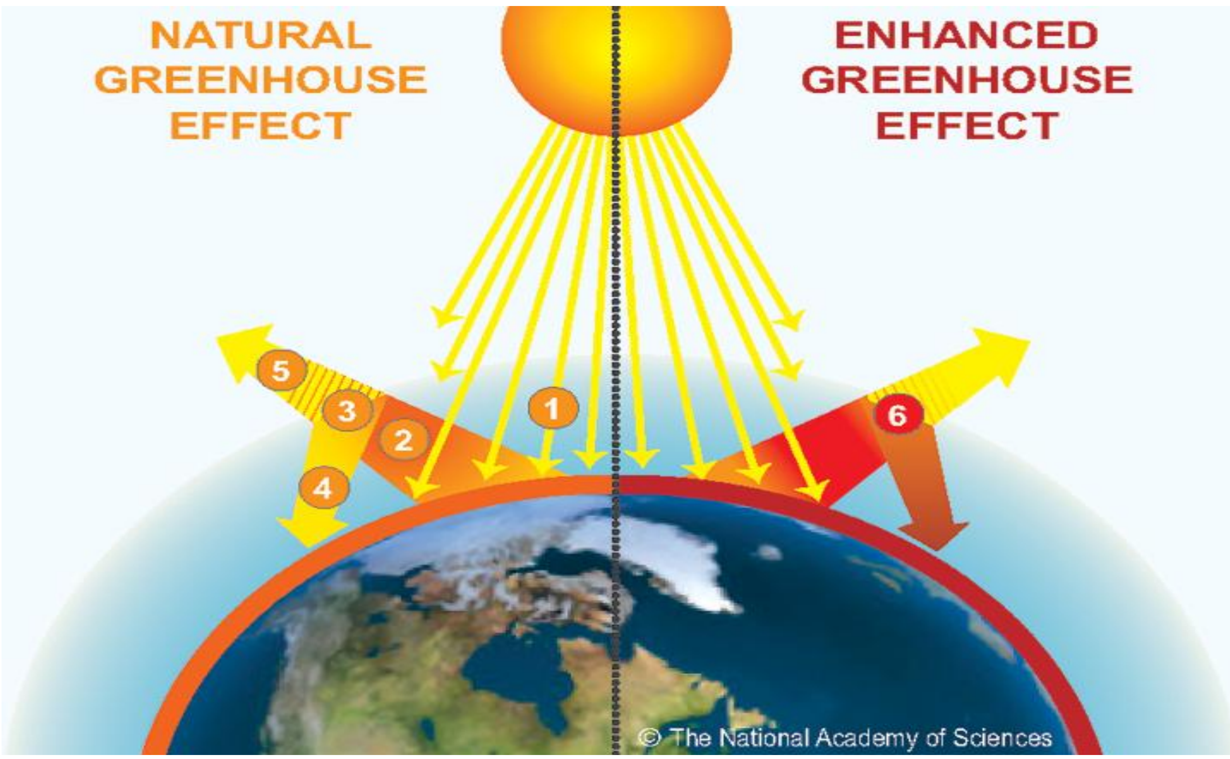
1.3 Greenhouse Effect

The greenhouse effect is a natural phenomenon that keeps the Earth insulated from the cold temperatures in space. Solar radiation enters the atmosphere and is absorbed and reemitted back from the Earth's surface as infrared energy. The greenhouse gases (GHGs) in the atmosphere prevent some of this heat energy from escaping back into space and reflect it back down to the surface. Since the industrial revolution, however, emissions of these gases have increased and accumulated. These larger volumes of atmospheric GHG are trapping more and more heat resulting in an enhanced greenhouse effect. The greenhouse effect is depicted in Figure 1.2.

There are ten primary GHGs, of which water vapor (H_2O) is the only GHG that is solely naturally occurring. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are naturally occurring and also are created from anthropogenic sources[15]. After water vapor, carbon dioxide is the second most abundant greenhouse gas. It occurs naturally as part of the carbon cycle, which includes inputs from animal and plant respiration, ocean-atmosphere exchanges of gases, as well as outgassing from volcanic eruptions. It is also estimated to be responsible for 9–26 percent of the greenhouse effect[16]. Since the mid 18th century, anthropogenic activity has increased the concentration of carbon dioxide and other greenhouse gases (Figure 1.3). This has resulted in atmospheric concentrations of carbon dioxide being 100 ppm higher than pre-industrial levels[17].

[13]South Carolina Climate, Energy and Commerce Advisory Committee. 2008. Final Committee report. 653 pp. Hereinafter CECAC 2008. http://www.scclimatechange.us/index.cfm Last accessed October 2011.
[14]http://www.scclimatechange.us/ Last accessed Jan 2011.
[15]Center for Sustainable Systems, University of Michigan. 2010. "*U.S. Greenhouse Gases Factsheet.*" Pub. No. CSS05-21. http://css.snre.umich.edu/css_doc/CSS05-21.pdf. Last accessed October 2011.
[16] [4]Kiehl, J.T.; Trenberth, K.E. (1997). "Earth's Annual Global Mean Energy Budget" (PDF). *Bulletin of the American Meteorological Society* **78** (2): 197–208
[17] Climate Change 2001: Working Group I: The Scientific Basis: figure 6-6.

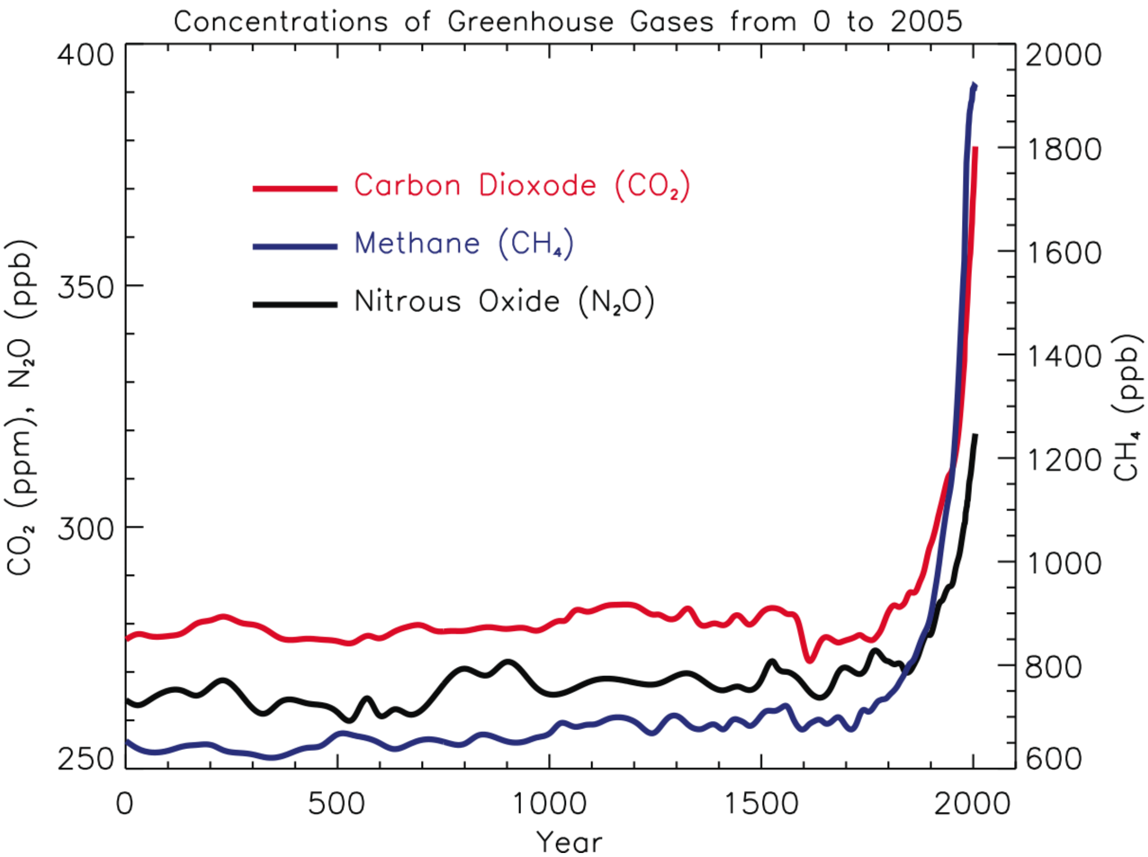
Figure 1.2 The greenhouse effect illustrated: visible sunlight passes through the atmosphere without being absorbed. Some of the sunlight striking the earth is (1) absorbed and converted to infrared radiation (heat), which warms the surface. The surface (2) emits infrared radiation to the atmosphere, where some of it (3) is absorbed by greenhouse gases and (4) re-emitted toward the surface; some of the infrared radiation is not trapped by greenhouse gases and (5) escapes into space. Human activities that emit additional greenhouse gases to the atmosphere (6) increase the amount of infrared radiation that gets absorbed before escaping to space, thus enhancing the greenhouse effect and amplifying the warming of the Earth[18].



Methane (CH_4) is the third most abundant greenhouse gas, and remains in the atmosphere for approximately 9-15 years. It is over 20 times more effective in trapping heat than carbon dioxide (CO_2) over a 100-year period[19]. It is formed from a variety of natural and anthropogenic processes. Methane occurs naturally when organic material decomposes. The main natural sources of methane are wetlands, termites, bodies of water, and gas hydrates. The major anthropogenic sources are landfills, natural gas and petroleum systems, agriculture, and coal mining.

[18] Reprinted by permission of the Marian Koshland Science Museum of the National Academy of Sciences, http://www.koshland-science-museum.org.
[19] http://www.epa.gov/methane/. Last accessed October 2011

Figure 1.3 This figure shows the concentrations of carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) in the atmosphere from year 0 to 2005.



Source: National Center for Atmospheric Research (NCAR), WMO:Concentrations of greenhouse gases from 0 to 2005, http://gcmd.nasa.gov/records/GCMD_WMO_Concentrations_greenhouse_gases0-2005.html

Nitrous oxide (N_2O) is the fourth most abundant greenhouse gas. Despite its lower concentration, it is 310 times more powerful at trapping atmospheric heat than carbon dioxide, and remains in the atmosphere for 120 years[20]. It is naturally emitted from oceans and soils, but anthropogenic sources include agricultural (mostly nitrogen fertilization) and industrial activities, fossil fuel combustion, and nitric acid production.

Between 10,000 and 150 years ago, atmospheric concentrations of CO_2, CH_4, and N_2O were relatively stable. In the last 150 years, concentrations of CH_4 and N_2O increased 148% and 18%, respectively[21]. Table 1.1 compares the preindustrial and current levels of the primary anthropogenically-produced GHG and their radiative forcing. Radiative forcing is a measure of the influence an external factor has on the balance of incoming and outgoing energy and is an index of the importance of the factor as a potential

[20] http://www.epa.gov/nitrousoxide/. Last accessed October 2011
[21] IPCC (2007) *Climate Change 2007: The Physical Science Basis*. Intergovernmental Panel on Climate Change; Ed. S. Solomon et al.; Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

climate change mechanism. Radiative forcing values are for changes relative to preindustrial conditions in 1750 and are typically expressed in watts per square meter (W/m^2).

Table 1.1 Preindustrial and current levels of the primary anthropogenically-produced GHG and their radiative forcing.

Gas	Preindustrial level	Current level	Increase since 1750	Radiative forcing (W/m^2)
Carbon dioxide	280 ppm	388 ppm	108 ppm	1.46
Methane	700 ppb	1745 ppb	1045 ppb	0.48
Nitrous oxide	270 ppb	314 ppb	44 ppb	0.15

Source: http://en.wikipedia.org/wiki/Greenhouse_gas, Last Accessed

1.4 Climate

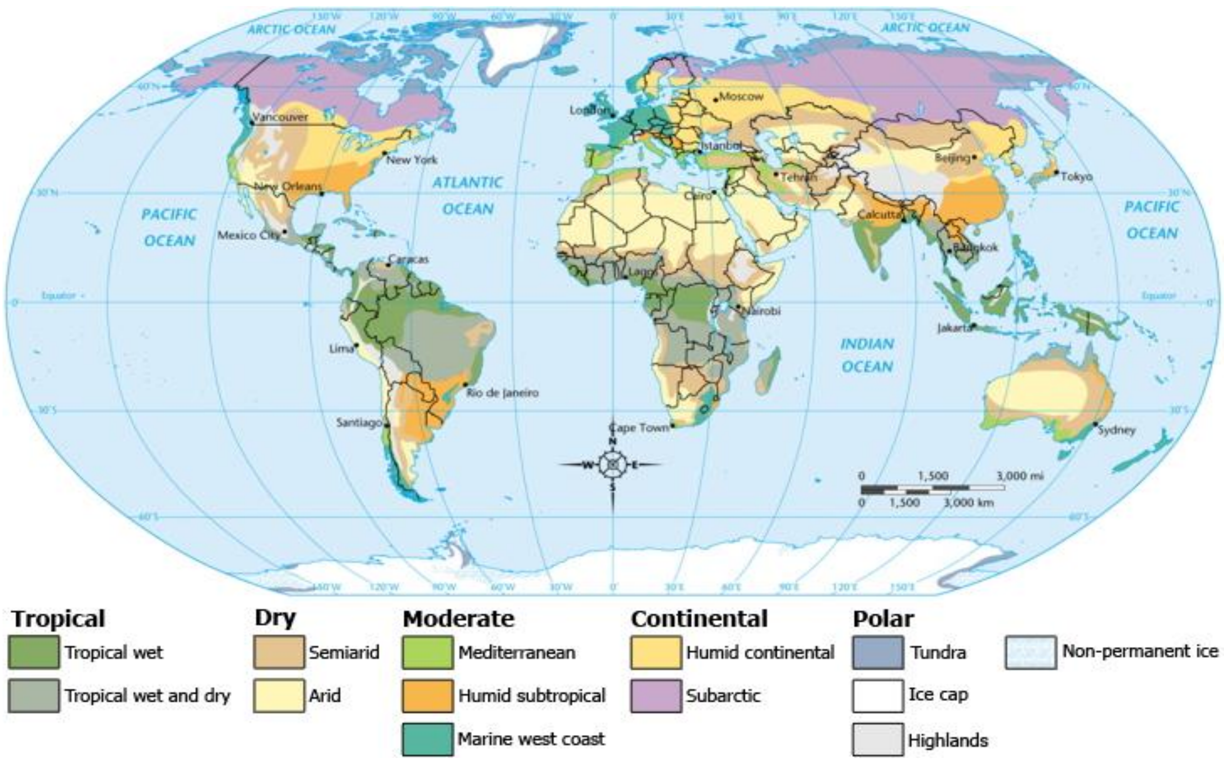
Climate is defined as the complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, flora and fauna. Climate can be described in terms of the average temperature, humidity, atmospheric pressure, precipitation, wind and other parameters over a period of time, ranging from months to millions of years. Modern climate studies tend to use intervals of 30 years to define climate norms. The climate of a location is affected by its latitude, terrain and altitude, as well as nearby water bodies and their currents[22]. The generalized worldwide climate classifications are depicted in Figure 1.4.

Climate has varied through time under the influence of its own internal dynamics involving changes such as volcanic eruptions and solar variations. Now, human-caused changes in atmospheric composition appear to be influencing climate change. Ultimately, the energy of the Sun drives the Earth's climate. Climate changes may occur in a limited number of ways including: (1) changes in incoming solar radiation resulting from changes in Earth's orbit or in the Sun itself, (2) changes in the fraction of solar radiation that is reflected back into space, otherwise known as albedo, and (3) changes in the amount of infrared radiation reflected back to to Earth by GHG concentrations. Although climate responds directly to these, it also can respond indirectly, through a variety of feedback mechanisms[23]. The climate system is

[22] Thornthwaite, C. W. 1931. The Climates of North America: According to a New Classification, Geo. Rev. 21(4):633-655.
[23] Le Treut, H., R. Somerville, U. Cubasch, Y. Ding, C. Mauritzen, A. Mokssit, T. Peterson and M. Prather, 2007: Historical overview of climate change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, *eds*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

characterized by positive and negative feedback effects between processes that affect the state of the atmosphere, oceans and land. An example of a climate feedback mechanism is the ice-albedo positive feedback loop. Melting snow exposes more dark ground, with lower albedo, which in-turn absorbs heat that would have been reflected back into space by snow or ice[24].

Figure 1.4 Generalized worldwide climate classifications noting the southeastern United States to be part of the humid subtropics.



1.5 <u>Weather</u>

Weather occurs in the troposphere, or the lowest portion of the atmosphere. It is the current, localized condition of atmospheric elements.[25] Common weather factors that affect daily life include wind, clouds, rain, sleet, snow and fog. Less common weather events that occur in South Carolina and the southeastern United States are tornadoes and hurricanes. These natural disasters cause economic distress as well as loss of property and life.

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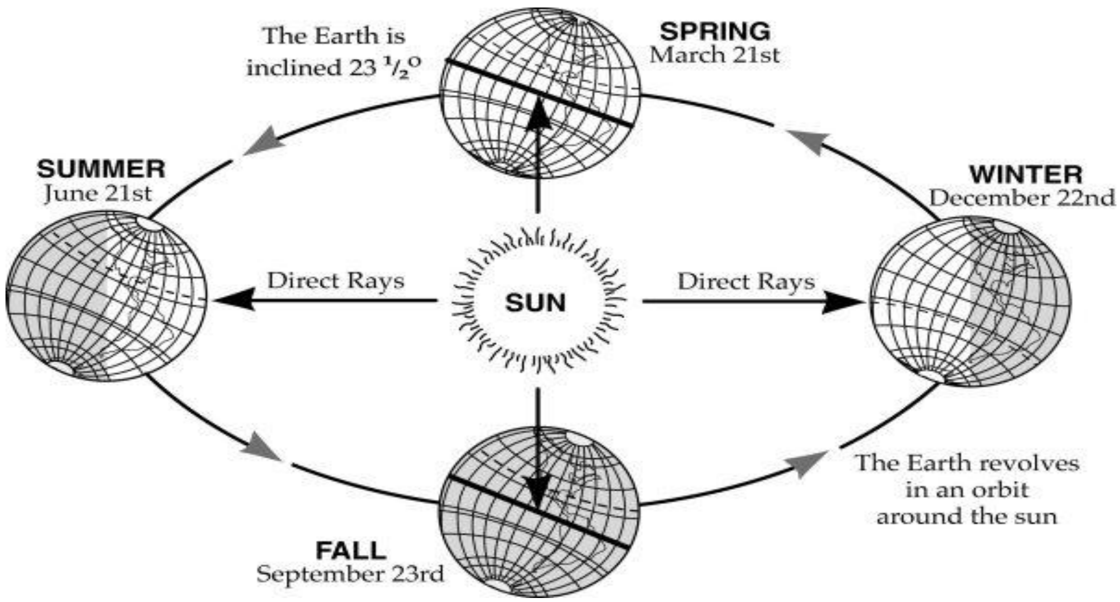
[24] Heimann, M. and M. Reischstein. 2008. Terrestrial ecosystem carbon dynamics and climate feedbacks. Nature. 451(289-292).
[25] Karl, T. R., J. M. Melillo and T. C. Peterson, eds. 2009. Global Climate Change Impacts in the United States. Cambridge University Press.

The Earth rotates daily on its axis, and its axis precesses, or wobbles, over the course of a year (Fig 1.5). Thus, the incident angle of solar insolation on a seasonal basis. Weather results from many factors, but the primary cause is differential heating of the Earth rotating on a variable axis and orbiting around the sun. This differential heating varies by time and location and is complicated by topography and bathymetry resulting in variability in temperature, moisture distribution and atmospheric dynamics. Figure 1.5 depicts the Earth's orbit around the Sun and the relative inclination of the Earth to the Sun.

Figure 1.5 The Earth orbits around the Sun. As the Earth moves around the Sun it is tilted 23.5° from the perpendicular. The Earth's revolution and inclination cause the changing seasons. The arrows extending from the Sun to the Earth represent where the direct rays of the Sun strike the Earth on the first day of each season.[26]



1.6 <u>Methodology</u>

Although temperature at the surface of the Earth is typically used as a primary indicator of climate change, there are other key measures that should be considered. Some of the other key measures and datasets include air temperature observed above both the land and sea, water temperature at the sea-surface extending hundreds of meters below the surface, changes in humidity, changes in sea level, and changes in sea-ice, glaciers and snow cover[27].

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[26] © Herff Jones, Inc. Used by permission. All rights reserved.
[27] Evidence: The state of the climate, Met Office, UK, 2010 http://www.metoffice.gov.uk/media/pdf/m/6/evidence.pdf Last accessed Oct. 2011

1.6.1 Satellite versus Surface Observations

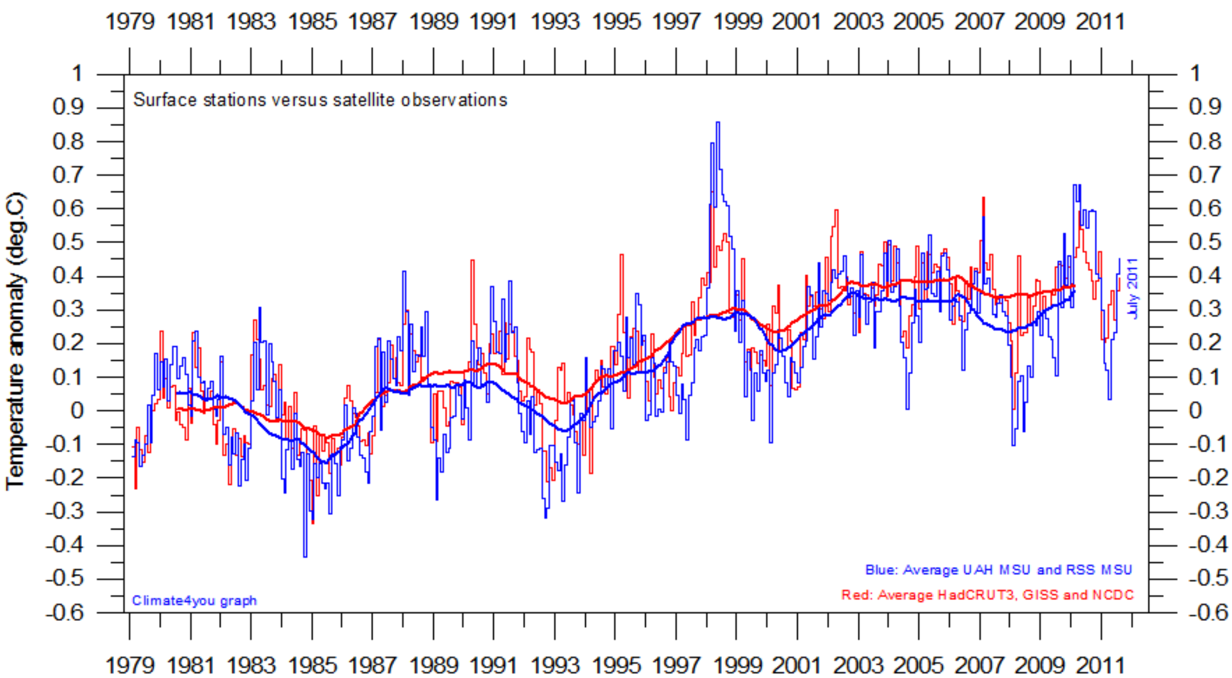
Deriving reliable global temperature from instrument data is a difficult task because the instruments are not evenly distributed across the planet, the hardware and locations have changed over time, and there has been extensive land use change around some of the sites. There are three main datasets showing analyses of surface global temperatures; the joint Hadley Centre/University of East Anglia Climatic Research Unit temperature analysis (HadCRUT), Goddard Institute for Space Studies (GISS), and the National Climatic Data Center (NCDC). These datasets are updated on a monthly basis and are generally in close agreement.

Since the satellite era took off in the late 1970s, both atmospheric and surface temperatures were able to be determined using satellite measurements. Satellites do not measure temperature directly, but instead measure how much light is emitted or reflected in different wavelength bands. Using mathematical calculations, temperature time series are indirectly inferred and reconstructed. This is advantageous over other methods because it provides global coverage. Because of slight differences in methodology, satellite-derived temperature datasets often differ. Thus it is imperative to make routine corrections due to orbital drift or decay, and sensor deterioration.

Two satellite datasets, the Remote Sensing Systems (RSS) dataset and the one prepared by the University of Alabama in Huntsville (UAH), utilize Microwave Sounding Units (MSU) of orbiting satellites to estimate lower tropospheric temperature. This is done by measuring microwave emissions of oxygen molecules, which increase proportionally to temperature. Lower tropospheric temperatures are expected to be slightly higher than surface temperatures, so the surface temperature record produced using these measurements is adjusted accordingly. Temperature measurements based on MSU also provide sparse coverage of Arctic and Antarctic regions. Figure 1.6 indicates that the average surface-based temperatures are slightly different to those obtained by satellites. Although the general agreement is good, satellites seem to record a larger temperature variability than surface observations. Additionally, over the entire time period shown in this plot, the average of the surface-based estimates suggests a less than 0.1^{o}C larger global temperature increase, compared to the average of satellite-based observations. The surface temperature record has increased at approximately 0.17 °C/decade since 1979. Comparing these values to satellite temperature estimates through January 2011, RSS shows an increase of 0.148 °C/decade while UAH finds an increase of 0.140°C/decade.[28]

[28] Remote Sensing Systems". http://www.ssmi.com/msu/msu_data_description.html. Retrieved 2009-01-13. "UAH". http://vortex.nsstc.uah.edu/data/msu/t2lt/tltglhmam_5.4. Retrieved 2011-01-14.

Figure 1.6 Average monthly global surface air temperature estimates (HadCRUT3, GISS and NCDC) and satellite-based temperature estimates (RSS MSU and UAH MSU). The thin lines indicate the monthly value and the thick lines represent the simple running 37 month average, nearly corresponding to a running 3 year average.



1.6.2. Climate Models and Projections

Climate models are based on computer programs that contain various mathematical equations. These equations quantitatively describe how atmospheric variables such as temperature, air pressure, wind, greenhouse gases and precipitation respond to incoming and outgoing solar radiation. Climate models are used for a variety of purposes from the study of climate system dynamics to future climate predictions. Predicting temperature changes caused by increases in atmospheric concentrations of greenhouse gases is one of the better known applications of climate modeling.

The Intergovernmental Panel on Climate Change (IPCC) is currently the leading international organization for the assessment of climate change. It was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). The IPCC is a scientific body that reviews the most recent scientific, technical, and socio-economic information produced worldwide. Although the IPCC does not conduct any original research or monitor climate data, its membership consists of the leading researchers and scientists in climate studies.

The IPCC delivered assessment reports in 1990, 1995, 2001, and 2007. Within these reports are model-derived estimates of future climate (i.e. projections). Some of these climate projections are based on scenarios that assume different levels of future CO_2 emissions. Each scenario has a range of possible outcomes associated with it. The most optimistic outcome assumes an aggressive campaign to reduce CO_2 emissions; the most pessimistic is a "business as usual" scenario, while other scenarios fall in between. In the Fourth Assessment Report published in 2007, some of the projections state that global temperatures could rise between 1.1 and 6.4 °C (2.0 and 11.5 °F) during this century and that sea levels could rise by 18 to 59 centimeters (7.1–23 in).

1.7 Climate Change Adaptation and Mitigation

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as:

> *The adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.*[29]

Adaptation may be more simply defined as *coping*. Climate scientists agree that climate change will occur in the future, even if the rates of GHG emissions decline. Adapting to climate change will therefore become necessary in certain regions in order to protect or sustain certain environmental systems, species and habitats. The need for adaptation may be increased by growing populations in areas vulnerable to extreme events. However, according to the IPCC:

> *Adaptation alone is not expected to cope with all the projected effects of climate change, and especially not over the long term as most impacts increase in magnitude.*[30]

Mitigation for climate change will involve changes in environmental and industrial behavior and practices such as reducing the rates of GHG emissions and increasing the rates of GHG sequestration. Decreasing consumption of fossil fuels is the best way to reduce GHG emissions, although these may be reduced by other ways such as conservation and recycling practices and utilizing alternative forms of energy. One of the best ways to sequester CO_2 is to protect acreage and growing timber – this is a natural fit for DNR's overall mission and is in keeping with DNR objectives to make land available to the using public.

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[29] Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[30] Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate ChangeCore Writing Team, Pachauri, R.K. and Reisinger, A. (Eds.) IPCC, Geneva, Switzerland. pp 104

1.8 DNR Climate Change Mission Statement

DNR's mission in response to the potential challenges of climate change to South Carolina is two-fold:

1. Identify issues and assess potential impacts of climate change on the natural resources of South Carolina, and
2. Develop an adaptive response strategy in order to offset, minimize, or delay the effects of climate change on natural resources.

The potential issues and impacts of climate change on people, landscapes, ecosystems, and other features will vary. Understanding these potential impacts and issues will play a significant role in adaptation planning by the agency, and it will provide a foundation for leaders to make informed and effective decisions. At a time when funding for climate change adaptation is scarce, understanding the potential consequences associated with climate change is vital. Table 1.2 provides a generalized summary of potential climate change phenomena.

Table 1.2 Generalized summary of potential climate change impacts and consequences.[31] While some impacts and consequences may not directly affect South Carolina, all are expected to create indirect effects.

Climate Change Phenomena	Potential Impacts	Potential Consequences
• Increasing land, surface water, sea surface and atmospheric temperatures • Rising sea level	• More frost-free days/year • More heat waves • Changes in precipitation cycles • More frequent and prolonged droughts • Increased evapotranspiration • Increased frequency of wildfire • More severe flood events • More problems with invasive species • Spatial changes in species' ranges • Changes in timing of ecological events such as animal migration • Intra- and inter-specific competition for available resources as food chains are altered • Loss of sea ice, glacial coverage and polar snowpack • Increased coastal flooding • Increased coastal erosion • Rising water tables • Saltwater intrusion • Increased nonpoint source pollution • Increases in toxic substances flowing from upstream to coastal areas • Increases in numbers of threatened and endangered species • Decline in forest growth	• Widespread human health impacts • Changes in ecosystem services such as the ability of streams and wetlands to naturally filter, assimilate and degrade pollution • Decline in water quality and quantity • Surface and sea-water pH changes • Decline in productivity and availability of fish and other aquatic species although some species could benefit • Economic losses directed toward business associated with natural resource management in both inland as well as coastal zones • Loss of beaches • Increased storm surge flooding • Impacts to coastal infrastructure • Salt marsh conversion to open water • Freshwater marsh conversion to salt marsh • Loss of important recreational and commercial fishing and shell fishing habitats • Loss of coastal forest habitats • Loss of cultural resources • Extinction of threatened and endangered species

[31] National Oceanic and Atmospheric Administration NOAA. 2010. Adapting to Climate Change: A Planning Guide for State Coastal Managers. NOAA Office of Ocean and Coastal Resource Management. Hereinafter NOAA 2010. http://coastalmanagement.noaa.gov/climate/adaptation.html. Last accessed Sept 2010

1.9 Agency Goals to Address a Changing Climate

In response to the DNR Climate Change Mission Statement the agency will have the following goals:

1. Gather factual, accurate information and data on how climate change may affect wildlife, fisheries, water supply and other natural resources within South Carolina,
2. Identify monitoring and data needs required to assess impacts of climate change in the state,
3. Use factual information, data, research and modeling to determine what actions need to be taken to address climate change,
4. Ensure data quality, provide original research that addresses information needs and validate modeling results with collected data,
5. Identify opportunities to partner with other state agencies, academic institutions and non-profit organizations where needed to accomplish the mission,
6. Identify ways for state officials, local government and citizens to assist in mitigation of or adaptation to natural resource impacts related to climate change, and
7. Locate and obtain available funding to assist in meeting agency mission and goals related to climate change.

1.10 DNR Resource Divisions, Organization and Responsibility

1.10.1 Land, Water and Conservation Division

The DNR Land, Water and Conservation Division (LWC) develops and implements programs that study, manage and conserve land and water resources. This is accomplished by providing guidance in resource development and management through planning, research, technical assistance, public education and development of a comprehensive natural resources database. The scope of the division is broad and incorporates expertise in climatology, flood-plain mapping, geology, hydrology, land use, rivers and water conservation.

1.10.2 Marine Resources Division

The Marine Resources Division (MRD) is responsible for the management and conservation of the state's marine and estuarine resources. It also works with regional authorities such as the Atlantic States Marine Fisheries Commission (ASMFC) and the South Atlantic Fishery Management Council (SAFMC) to ensure that marine resources are sustainably managed throughout their range. MRD has 3 main sections with the following responsibilities:

1. The Office of Fisheries Management (OFM) reviews coastal development activities, recommends marine fishing seasons and fish size/creel limits,

issues permits and conditions for the harvest of marine species (e.g. fish, shrimp, crabs and oysters) and tracks trends in the harvest of marine species.

2. The Marine Resources Research Institute (MRRI) conducts research and long-term surveys of inshore and offshore resources (e.g., finfish, shellfish and marine habitats), assesses the effects of human activities on coastal resources, and operates marine stocking research programs (e.g., red drum and striped bass).
3. Coastal Reserves & Outreach (CRO) is responsible for MRD functions relating to coastal land management, education and outreach, and all programs in the ACE Basin National Estuarine Research Reserve[32] (1 of 28 reserves in the National Estuarine Research Reserves System).[33]

Data from numerous MRD programs indicate that the physical and biological systems of the coastal zone have already been impacted by increasing population density and development. Additional pressure on these systems from climate change is likely to exacerbate system degradation, although the extent of future degradation related to climate change is uncertain.[34] Ecological, social, educational and technological issues associated with climate change impacts in the marine environment are reviewed in this report.

1.10.3 Wildlife and Freshwater Fisheries Division

The Wildlife and Freshwater Fisheries (WFF) Division of DNR develops and implements programs that manage and conserve the wildlife and freshwater fishery resources of the state. The Wildlife Section protects, manages and enhances the state's habitats and associated wildlife for the public benefit of present and future generations. The Wildlife Section also is responsible for the state's Endangered Species Program which protects and enhances a variety of declining species and diminishing habitats. The Freshwater Fisheries Section provides protection, enhancement, and conservation of South Carolina inland aquatic resources. It also provides recreational fishing opportunities for the state's citizens through its operation of hatcheries, regional fisheries management, state public fishing lakes, research and diadromous fisheries coordination.

Pressures from increasing development, habitat loss and increasing numbers of invasive species have changed the landscape of South Carolina, negatively affecting wildlife and fish resources.[35] Climate change will exacerbate the effects of these pressures. Given the potential for severe impacts to our natural resources, it is critical

[32] http://www.nerrs.noaa.gov/Doc/SiteProfile/ACEBasin/html/resource/protland/lunerr.htm. Last accessed Dec 2010.
[33] http://www.chbr.noaa.gov/ecosystems/nerrs.aspx. Last accessed Oct 2011.
[34] NOAA. 2000. The potential consequences of climate variability and change on coastal areas and marine resources: Report of the Coastal Areas and Marine Resources Sector Team U.S. National Assessment of the Potential Consequences of Climate Variability and Change U.S. Global Change Research Program. D. F. Boesch, J.C. Field and D. Scavia, *eds*. NOAA Coastal Analysis Prog. Decision Analysis Series No. 21. 181 pp. http://www.cop.noaa.gov/pubs/das/das21.pdf. Last accessed Dec 2010.
[35] Environmental Law Institute. 2002. Mitigation of impact to fish and wildlife habitat: Estimating costs and identifying opportunities. http://www.elistore.org/Data/products/d17_16.pdf. Last accessed Oct 2011.

to plan ahead to address the effects of climate change on our native wildlife and fish species and essential habitats.

2.0 THE CLIMATE OF SOUTH CAROLINA – PAST AND PRESENT

2.1 Paleoclimatology: Recent Studies and Contributions to Climate Modeling

Climatology is the study and analysis of weather records over an extended period of time. Instruments such as thermometers and rain gauges have evolved since the 1700s and are now routinely used to record weather conditions. To reconstruct climate from an earlier time, it is necessary to use natural climate recorders, such as ice cores, tree rings, ocean and lake sediments, and corals. Measurements collected from these natural climate archives are called proxies because they do not provide a direct measurement of climate, as an instrument does. Rather, scientists deduce past climatic conditions from the physical and biological parameters contained in the proxy. The study of climate prior to the use of instrumental records is known as paleoclimatology.

Climatic conditions preserved in various proxies provide a way of understanding past changes in the environment where the proxy grew or existed. The ring width of a tree is an example of a proxy for temperature, or in some cases rainfall, because the thickness of the annual ring is sensitive to the temperature and rainfall of that year. The greatest understanding of paleoclimate comes when there are multiple data sets, providing a robust view of conditions. Figure 2.1 illustrates a reconstruction of global average temperature and CO_2 concentrations using both proxy measures of CO_2 from the Vostok ice core and instrumental CO_2 records from Mauna Loa Observatory in Hawaii.

Paleoclimate studies indicate that the earth's climate has changed many times throughout its history, and cycles of climate change have been recognized on a variety of time scales. Results from paleoclimate studies include the identification of regular episodic changes and the concept of abrupt climate change. The first is the result of a robust and expanding paleoclimate database. The second result owes, in part, to the greater precision of the datasets that have revealed dramatic climate shifts occurring in very short time spans.[36]

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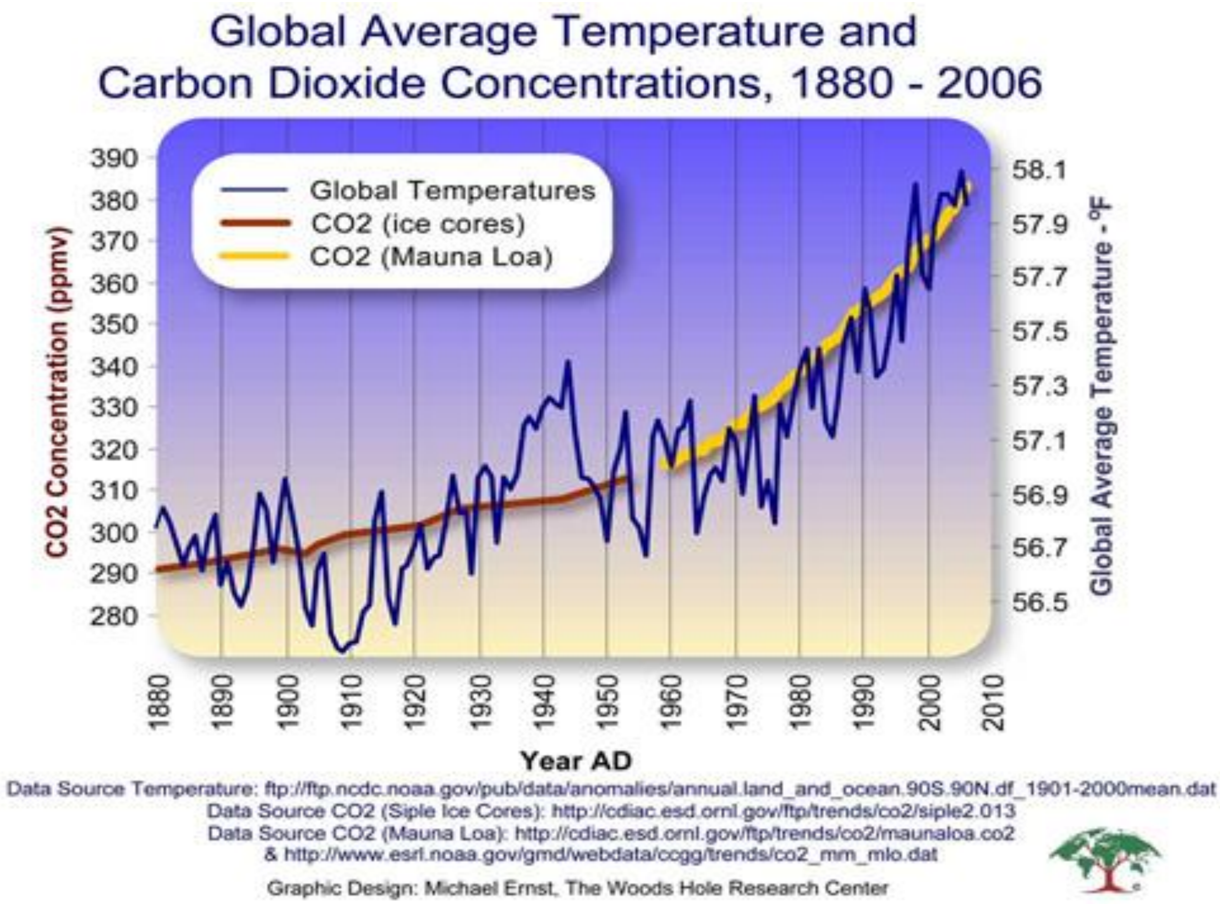
[36] NANRC 2001.

Figure 2.1 Global Temperature and CO_2 Concentration Since 1880. Data from NOAA's National Climate Data Center (NCDC) & Oak Ridge National Laboratory.[37]



2.2 Results of Studies

Paleoclimatic records are more precise and accurate in the last million years, and the last 650,000 years have been extensively studied because of well-preserved glacial and geological records. Currently, we are in an interglacial, or warm, period, which began at the end of the last glacial maximum (LGM) 13,500 years ago. The identification of episodic climates shows that glacial-interglacial, or cooling-warming, cycles can be recognized in the last million years, and that recurring intervals can be recognized. A well-supported theory suggests that these intervals correspond to Earth's orbital deviations. The relationship between orbital variations and glacial periods is referred to as a Milankovitch cycle. Although the Milankovitch Theory accounts for many glacial periods, some periods still defy a solely celestial cause.

[37] Data from NOAA's National Climate Data Center (NCDC) and Oak Ridge National Laboratory. http://www.whrc.org/resources/primer_fundamentals.html last accessed July 2010.

Much research has focused on the last 13,500 years, since the end of the last glacial period, and particularly on the last 2,000 years. The last 2,000 years are of interest because interglacial conditions were relatively stable, and thus provide a baseline to study modern climate variations. Three significant periods of climate variation, however, have occurred since the end of the LGM. In the upper latitudes of the Northern Hemisphere 12,800-11,500 years ago, oxygen-isotope-derived temperatures from an ice core in Greenland indicate conditions approximately 45-59°F (7-15°C) colder than present-day Greenland. This late Pleistocene glacial stadial event, or cooler period, is referred to as the Younger Dryas. The end of the Younger Dryas was marked by rapid transition from stadial to interglacial conditions and occurred in a time span of 20 years, possibly even less. The Medieval Warm Period occurred between 800-1300 AD and is primarily documented in Europe. It is recognized as an interglacial period bracketed by older and younger stadial events, so the description of warm is relative. Another stadial event in more recent times is also of interest. The Little Ice Age occurred from the 16th until the mid-19th centuries and affected the Northern Hemisphere, although in lesser magnitude than the Younger Dryas. There are numerous historical records documenting the shifts which occurred during the Little Ice Age.[38]

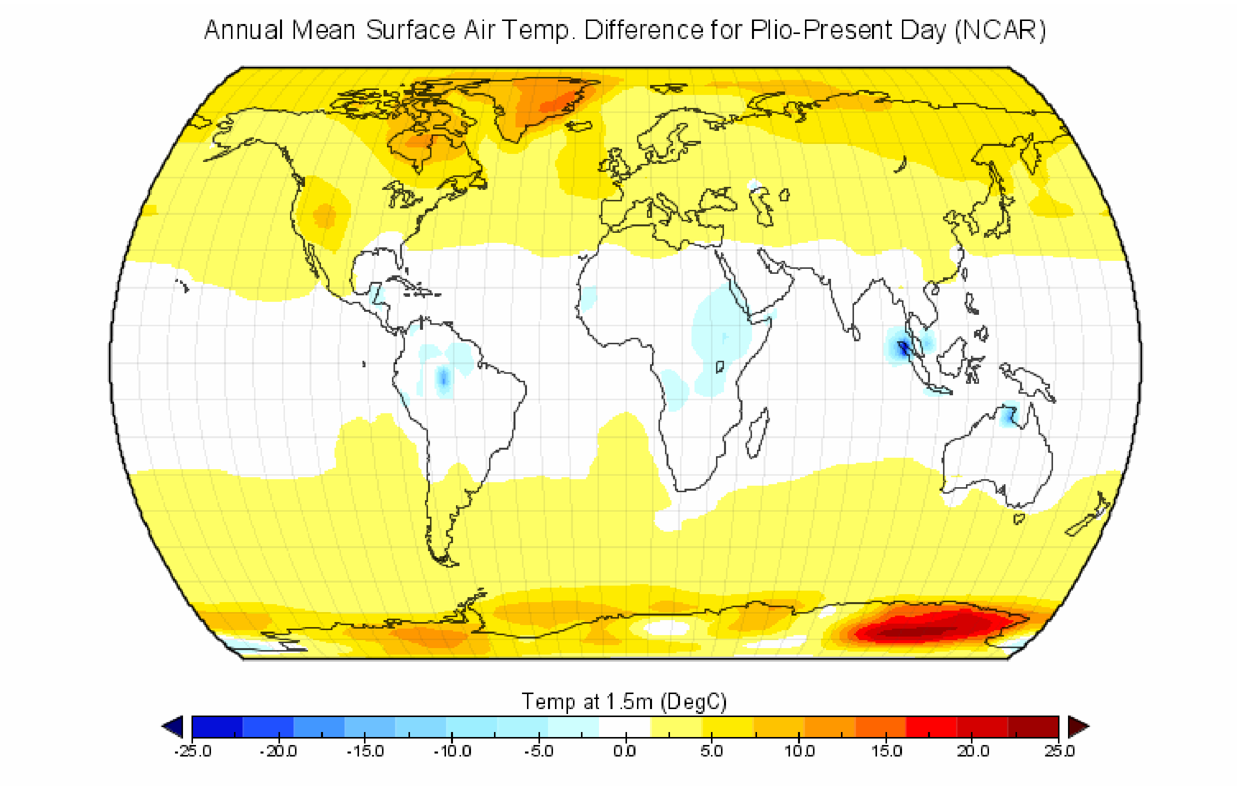
The recognition of a mid-Pliocene warm period (Fig 2.2), approximately 3.3 to 3.0 million years ago, may provide insight into what could happen during the present period of climate change. The mid-Pliocene change happened recently enough that the configuration of continents and oceans has not changed significantly, and air and ocean currents probably were similar to those of today. Mean-global temperatures during the mid-Pliocene warm period were 2-3°C above pre-industrial-age temperatures. CO_2 levels were in the range of 360-400 ppm, and the extent of ice sheets was reduced compared to today. These conditions resulted in sea level being 15-20 meters above present-day levels, and there was lower continental aridity.

The second major result of paleoclimate studies is the recognition of abrupt shifts in climatic conditions. Some of these shifts involved extreme changes in conditions, such as large magnitude warming events with increases of up to 61°F (16°C). The time scale of some shifts is as little as 10 years. The causes of rapid climate shifts are not fully understood, but it is thought they result from a combination of several natural processes.[39] The question now is whether human inputs of GHGs, along with trends in natural processes, trigger an abrupt climate change. If an abrupt shift in climate is possible, prudent planning necessitates efforts to predict both the magnitude and duration of the change.

[38] Jansen, E., J. Overpeck, K.R. Briffa, J.-C. Duplessy, F. Joos, V. Masson-Delmotte, D. Olago, B. Otto-Bliesner, W.R. Peltier, S. Rahmstorf, R. Ramesh, D. Raynaud, D. Rind, O. Solomina, R. Villalba and D. Zhang, 2007: Palaeoclimate. *in* Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, *eds.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 66 pp.

[39] NANRC 2001.

Figure 2.2 Annual Mean Surface Air Temperature Difference between Pliocene and Present Day. Global temperatures, particularly at high latitudes, are believed to have been significantly warmer than today.[40]



2.3 Paleoclimate Summary and Recommendations for the Future

Paleoclimate studies indicate that climate variation is a natural phenomenon. The focus of paleoclimate studies is shifting now toward identifying the processes and causes of climate change. To date, no systematic study of South Carolina's paleoclimate has been done. Some studies have addressed climatic conditions at a specific time or at a specific site, but no studies have been done to document the state's climate over an extended period of time. The state's paleoclimate record should be studied at several time scales. First, the climate since European settlement should be reconstructed by examining local and state records, which would provide a detailed account of climate over the last 400 years. Instrument records can be integrated into this history. In addition to shorter term studies, studies extending back several thousand to several hundred thousand years could be useful.

[40] http://geology.er.usgs.gov/eespteam/prism/products/agu3.pdf

2.4 South Carolina Climate in the Early 21st Century[41]

South Carolina's location provides a mild climate and, in normal years, generous rainfall. Several factors responsible for this include our relatively low latitudinal location and a strong moderating influence from Atlantic Ocean warm water. Also of importance are the Blue Ridge Mountains to the north and west, which help block or delay movement of cold air masses from the northwest.

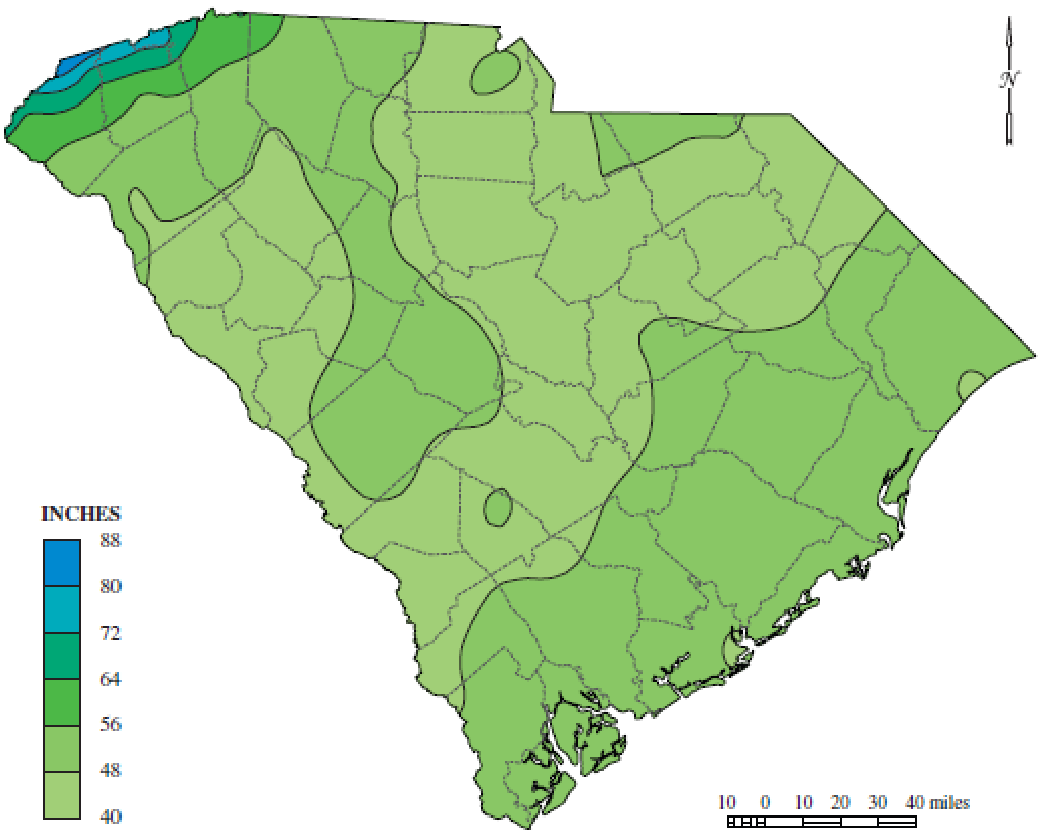
2.4.1 Precipitation

Precipitation in South Carolina is ample and distributed with two maxima and two minima throughout the year. The maxima occur during March and July; the minima occur during May and November. There is no wet or dry season; only relatively heavy precipitation periods or light precipitation periods. No month of the year averages less than 2 inches (5 cm) of precipitation anywhere in South Carolina. In the northwestern corner of the state, winter precipitation is greater than in summer and the reverse is true for the remainder.

The South Carolina average annual precipitation is slightly more than 48 inches (122 cm). Average annual precipitation is heaviest in the northwestern counties because moist air is forced up the mountains to higher and cooler elevations, where condensation and precipitation are initiated. In the Blue Ridge Mountains, 70-80 inches (179-203 cm) of rainfall occur on average at the highest elevations (Fig. 2.3), with the highest annual average of 79.29 inches (201.40 cm) occurring at Caesars Head. Across the foothills, average annual precipitation ranges from 60 inches (152 cm) to more than 70 inches (179 cm). In the eastern and southern portions of the Piedmont, the average annual rainfall ranges from 45-50 inches (114-127 cm). Areas in the northern Midlands report the lowest rainfall on average, between 42-47 inches (107-119 cm). Precipitation amounts are a little higher across the Coastal Plain. A secondary statewide maximum occurs parallel to the coast 10-20 miles (16-32 km) inland. This maximum, 50-52 inches (127-132 cm) is a result of the diurnal sea-breeze front thunderstorms prevalent during summer.

[41] http://www.dnr.sc.gov/climate/sco/ClimateData/cli_sc_climate.php. Last accessed May 2011.

Figure 2.3 South Carolina average annual precipitation, 1971-2000.



There is little difference in monthly rainfall distribution for the months of December-March, with the exception that the monthly total for March is somewhat higher than for any of the previous three months. During March, rainfall along the coast begins to increase, and by May the normal for the southern coast exceeds 5 inches (13 cm). At the same time, the central part of South Carolina receives only about 3 inches (8 cm) of rain and the mountains more than 5 inches (13 cm). During the summer, our weather is dominated by a maritime tropical air mass known as the Bermuda high, which forces warm, moist air inland from the ocean. As the air comes inland, it rises and forms localized thunderstorms, resulting in a precipitation maximum. Summer rainfall (June – August) is heaviest in the mountains, with 4-7 inches (10-18 cm) monthly, and along the coast with 6-8 inches (15-20 cm) monthly. During September, the greatest rainfall on average occurs along the coast. This is due to the passage of tropical storms and hurricanes that may influence coastal weather at this time of year. During October-November precipitation on average is at a minimum throughout the state. Any heavy precipitation during this period is likely to be the result of a hurricane or early winter storm. The greatest documented 24-hour rainfall was 14.80 inches (35.56 cm) observed at Myrtle Beach on September 16, 1999. The greatest total annual precipitation occurred in 1979 at Hogback Mountain in Greenville County, where more than 120 inches (305 cm) was recorded.

Wintry precipitation, such as snow, sleet and freezing rain, also affect South Carolina. Snow and sleet may occur separately, together, or mixed with rain during the winter months from November-March, although snow has occurred as late as May in the mountains. Measurable snowfall may occur from 1-3 times in a winter in all areas except the Lowcountry, where snowfall occurs on average once every 3 years. Accumulations seldom remain very long on the ground except in the mountains.

Typically, snowfall occurs when a mid-latitude cyclone moves northeastward along or just off the coast. The greatest snowfall in a 24-hour period was 24 inches (61 cm) at Rimini in February 1973. During December 1989, Charleston experienced its first white Christmas on record, and other coastal locations had more than 6 inches (15 cm) of snow on the ground for several days following. Episodes of sleet and freezing rain are observed statewide, although less frequently in the Lowcountry. One of the most severe cases of ice accumulation from freezing rain took place in February 1969 in several Piedmont and Midlands counties with significant timber losses and power disruptions.

Abnormal weather patterns can alter or restrict precipitation, resulting in prolonged dry spells. Periods of dry weather have occurred in each decade since 1818 (National Water Summary 1988-1989 Hydrologic Events and Floods and Droughts, 1991). The earliest records of drought indicate that some streams in South Carolina went dry in 1818, and fish in smaller streams died from lack of water in 1848. The most damaging droughts in recent history occurred in 1954[42], 1986[44], 1998-2002[43], and 2007-2008.[44] Severe droughts occur about once every 15 years, with less severe widespread droughts about once every 7 years. In 1954, the beginning of one of South Carolina's record droughts, only 20.73 inches (52.65 cm) of precipitation fell at Rimini, in Clarendon County, to set the record annual low precipitation value for the State.

2.4.2 Temperature

The state's annual average temperature is about 61°F (16°C). Local averages range from 55°F (12°C) at Caesars Head in the mountains to 66°F (19°C) along the southern coast at Beaufort (Fig 2.3). Elevation, latitude and distance from the coast are the main influences on temperature. The state's record low of -19°F (-28°C) was recorded at Caesars Head on January 21, 1985. Along the coast, ocean water temperatures vary a very small amount daily and annually when compared with adjacent land areas. The air

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[42] National Water Summary 1988-1989 - Hydrologic Events and Floods and Droughts (1991), 2375, United States Geological Survey, United States Government Printing Office, Denver, Colorado.

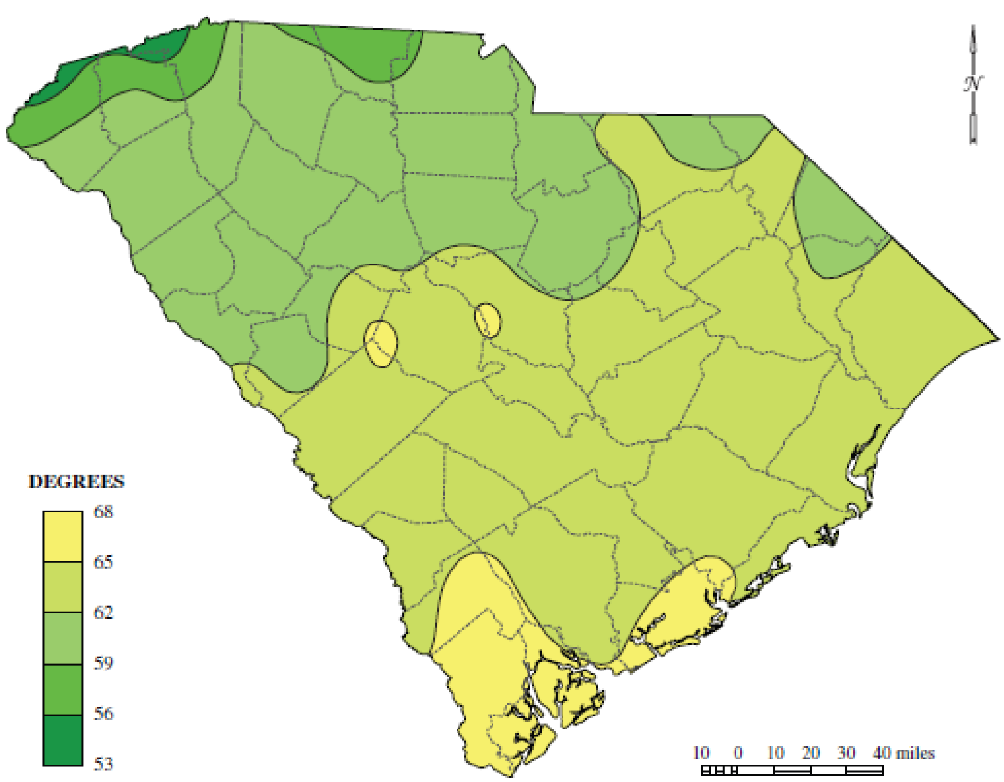
[43] Gellici, J.A., M. Kiuchi, S.L. Harwell, and A.W. Badr (2004), Hydrologic Effects of the June 1998-August 2002 Drought in South Carolina, South Carolina Department of Natural Resources Open File Report, Columbia, S.C.

[44] South Carolina Department of Natural Resources On-line Archived Drought Status, http://www.dnr.sc.gov/climate/sco/Drought/drought_press_release.php, 2008.

over coastal water is cooler than the air over land in summer and warmer than the air over land in winter, thus providing a moderating influence on temperatures at locations near the coast. Records show maximum temperatures along the coast to average 4-5°F (2°C) lower than maximum temperatures in the central part of the State. The record high temperature, 111°F (44°C), has occurred in central South Carolina 3 times: at Calhoun Falls on September 8, 1925; at Blackville on September 4, 1925; and at Camden on June 28, 1954. January is the coldest month, with monthly normal temperatures ranging from 39°F (4°C) at Caesars Head to 51°F (11°C) at Beaufort. July is the hottest month, with monthly average temperatures ranging from 72°F (22°C) at Caesars Head to 82°F (28°C) at Charleston.

The growing season for most crops is limited by fall and spring freezes and ranges from 200 days in the coldest areas to about 280 days along the south coast. In areas where most of the major crops are grown, the growing season ranges from 210-235 days. The average date of the last freezing temperature in spring ranges from March 10 in the south to April 1 in the north. Fall frost dates range from late October in the north to November 20 in the south. Minimum temperatures of less than 32°F (0°C) occur on about 70 days in the upper portion of the state and on 10 days near the coast. The central part of South Carolina has maximum temperatures of 90°F (32°C) or more on about 80 summer days. There are 30 such days along the coast and 10-20 in the mountains.

Figure 2.4 South Carolina average annual temperature, 1971-2000.



2.4.3 Severe Weather

Severe weather in the form of violent thunderstorms, hurricanes and tornadoes occurs occasionally. Thunderstorms are common in the summer months, but violent storms usually accompany squall lines and cold fronts in the spring. These storms are characterized by lightning, hail, high winds and they sometimes spawn tornadoes. Most tornadoes occur from March-June, with April being the peak month. In the 61-year period 1950-2010, South Carolina averaged 15 tornadoes per year. The majority of these tornadoes (81%) were short-lived EF-0 and EF-1 tornadoes on the Enhanced Fujita scale.[45] Stronger, more destructive tornadoes are rare, but do occur with a consistent annual frequency of 2-4 per year. Since 1950 eleven destructive EF-4 tornadoes have touched down in South Carolina with wind speeds of 166-200 miles per hour.

Tropical cyclones affect the South Carolina coast on an infrequent basis, but do provide significant influence annually through enhanced rainfall during the summer and fall months. Depending on storm intensity and proximity to the coast, tropical systems can be disastrous. Historically, hurricanes are more frequent in late summer and early fall; however, tropical cyclones have affected South Carolina as early as May and as late as November. From the late 1800s-2010, 171 tropical cyclones have affected the state. South Carolina has experienced 3 major hurricanes since the 1950s: Category 4 Hazel on October 15, 1954; Category 3 Gracie on September 29, 1959; and Category 4 Hugo on September 21, 1989.

2.4.4 El Niño-Southern Oscillation Influence on South Carolina's Climate

The Palmetto State's climate is complicated by a number of oscillations in the global atmosphere and ocean that can shift and alter distant weather patterns. There are many of these oscillations, some better known and studied than others: Quasi-Biennial Oscillation (QBO), Madden-Julian Oscillation (MJO), El Niño-Southern Oscillation (ENSO) and Atlantic Multi-Decadal Oscillation (AMO). Each oscillation can interact with others to provide a complex forcing for downstream sensible weather. Thus, changes in these oscillations and their interactions produce changes in regional climate.

The ENSO with embedded Kelvin waves is the best understood oscillation. ENSO is a coupled atmosphere-ocean circulation pattern that induces teleconnections in the Northern Hemisphere atmosphere, complicating South Carolina weather and climate by shifting the position of the jet stream. The ENSO has 3 phases: warm, neutral and cold. El Niño is the warm phase of the ENSO and is characterized by abnormally warm ocean water occurring along the coast of Peru and eastern equatorial Pacific Ocean. The ENSO cold phase, La Niña, is characterized by a deep pool of abnormally cold water across the eastern equatorial Pacific affecting upper atmospheric circulation patterns. During the El Niño portion of ENSO, increased precipitation falls along the Gulf Coast and Southeast due to a stronger than normal, and more southerly, polar jet

[45] http://www.spc.noaa.gov/efscale/. Last accessed May 2011.

stream.[46] During La Niña events, the storm track is shifted northward. Analysis of past La Niña winter events indicates that South Carolina weather was warmer and drier than the weather observed during neutral or El Niño events. Periods of severe to extreme drought experienced in South Carolina during 1954, 1988, 1998-2002 and 2007-08 are correlated with La Niña events in the Eastern Pacific Ocean. There is no clear periodicity of these drought-producing events. Conversely, El Niño winters in South Carolina on average tend to be wetter and cooler than the weather during neutral or La Niña events.

2.5 Analyzing South Carolina Climate Trends

A major hurdle for any climate study is locating a long-term continuous record of observational data. The National Oceanic and Atmospheric Administration United States Historical Climate Network (USHCN) is a well-documented, accurate source of daily and monthly state climate data for the period 1895-to the present. These data consist of minimum, mean and maximum temperatures and precipitation totals measured at 28 stations located across the state and provide the longest record of weather conditions in South Carolina.

To evaluate climate variability in South Carolina, a first-order analysis of the annual mean monthly USHCN temperature data was performed. Temperature data recorded at the Greenville-Spartanburg (GSP) Airport in Greer, University of South Carolina (USC) in Columbia, Beaufort and Georgetown were used to investigate trends in temperature variability. These stations were selected to represent the three major geographic divisions of South Carolina: mountains-piedmont, midlands-sandhills, and coastal plain. The data from these 4 climate observing stations revealed similar temperature trends that are presented in Figures 2.5-2.8.

After a pronounced cool period occurring from 1895-1904, a net average warming period occurred at USC, Beaufort and Georgetown (Fig. 2.5-2.8). During the 1905-1938 warming trend, mean temperatures at GSP rose rapidly in the first 8 years, remaining neutral until 1958 (Fig. 2.5); the GSP data demonstrated the cooling trend lagged approximately 10 years behind the other stations studied. Another pronounced cooling period is observed in the coastal station data from the period 1948-1968. This cooling period also is noted in the data collected at USC.

Of particular importance in the discussion over climate change is the good agreement of a warming trend beginning in 1970 to the present for all 4 stations. This warming trend is most pronounced in the GSP and Beaufort data sets.

[46] Climate Prediction Center, El Nino and La Nina-related Winter Features over North America, http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/nawinter.shtm. Last accessed Dec 2010.

Figure 2.5 Annual mean temperatures at Greenville-Spartanburg Airport (GSP), South Carolina, 1895-2010.[47]

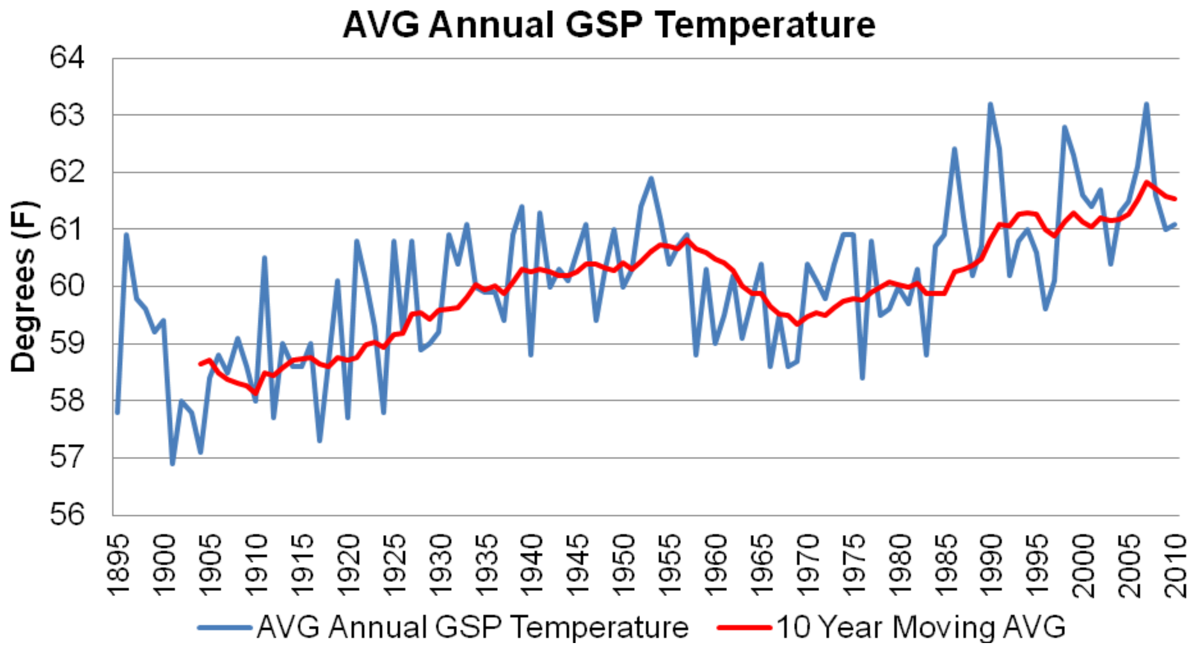
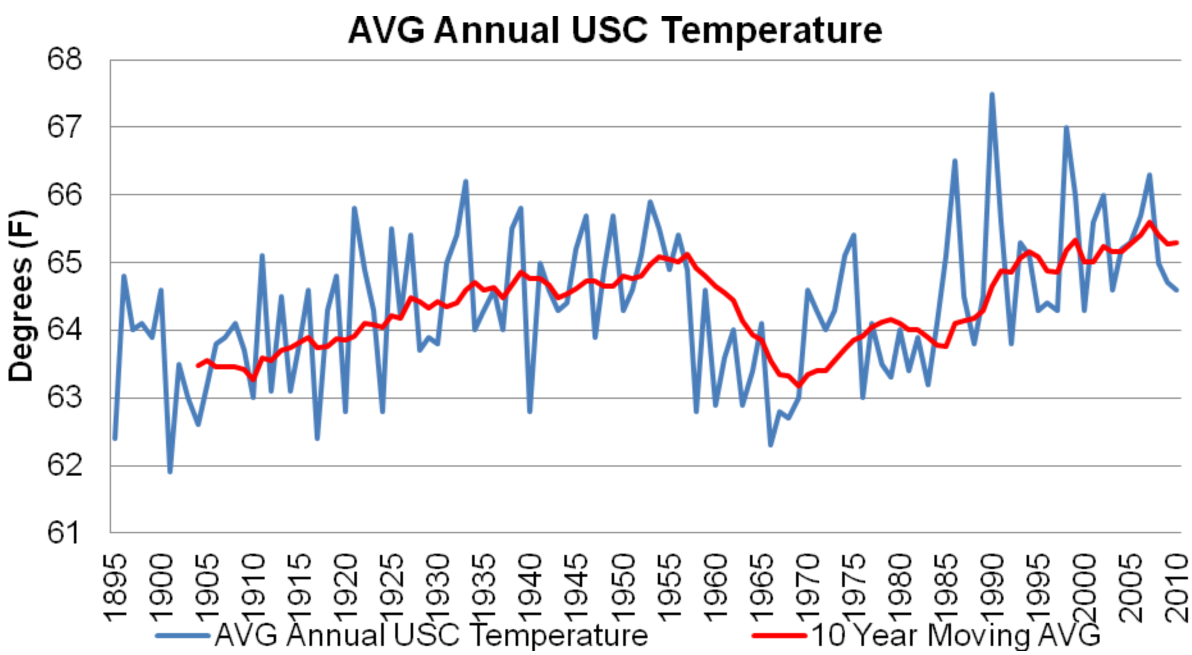


Figure 2.6 Annual mean temperatures at University of South Carolina (USC), Columbia, South Carolina, 1895-2010.[48]



[47] National Oceanic and Atmospheric Administration Climate Research Data. The Daily Historical Climatology Network
http://www.ncdc.noaa.gov/oa/climate/research/ushcn/ushcn.html . Last accessed July 2010. Hereinafter NOAA/USHCN.
[48] NOAA/USHCN.

Figure 2.7 Annual mean temperatures at Beaufort, South Carolina, 1895-2010.[49]

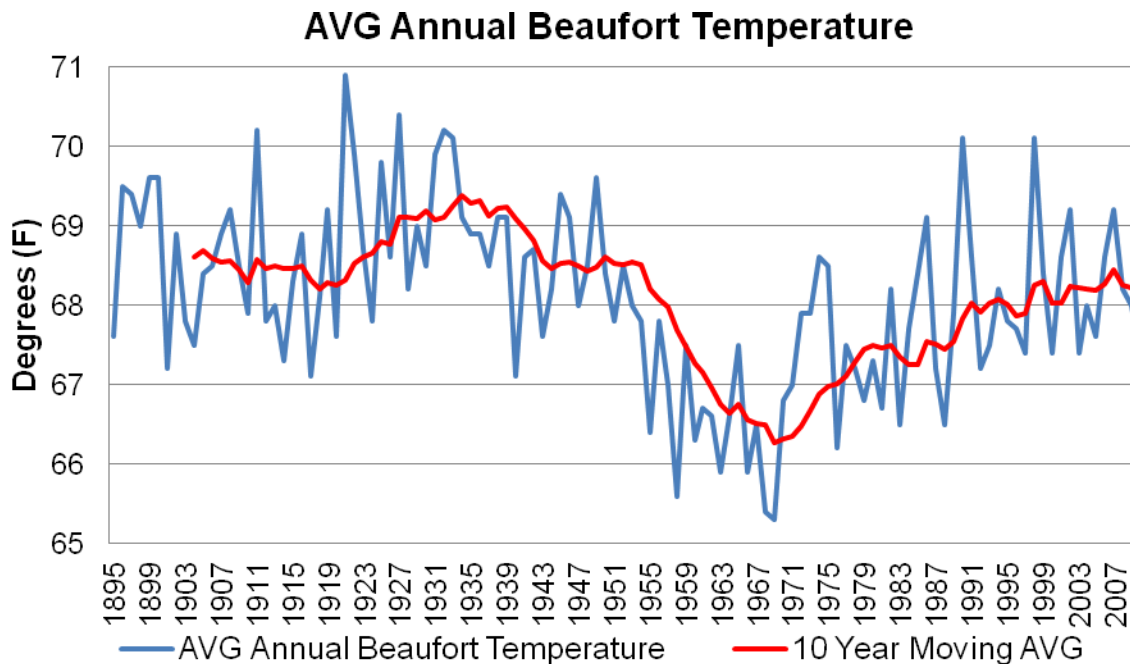
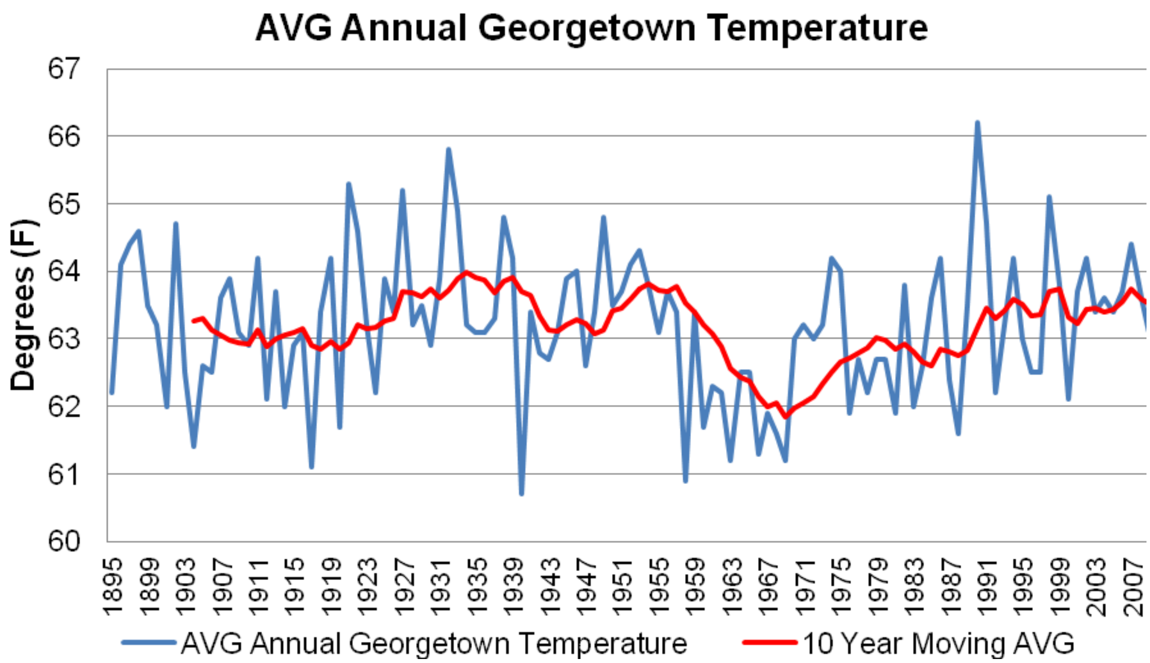


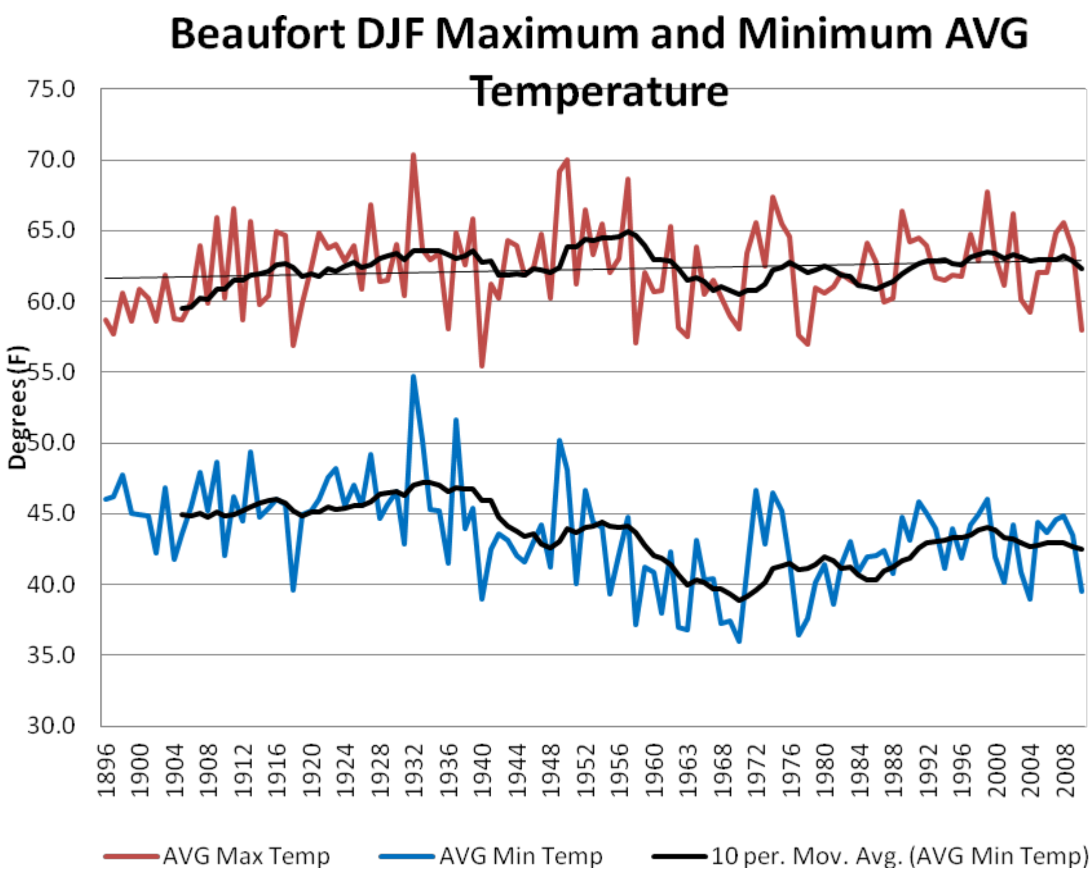
Figure 2.8 Annual mean temperatures at Georgetown, South Carolina, 1895-2010.[50]



[49] NOAA/USHCN.
[50] NOAA/USHCN.

USHCN data for Beaufort were investigated further to explore winter temperature trends. The December-January-February (DJF) monthly mean temperature data were plotted for the period of record 1896-2010 (Fig 2.9). Winter maximum temperatures demonstrated a slight warming trend for the period and conversely, minimum winter temperatures showed a very slight cooling trend. The long-term winter temperature trend was similar to the cool-warm-cool-warm trend seen in Beaufort's annual mean temperature data presented in Figure 2.7.

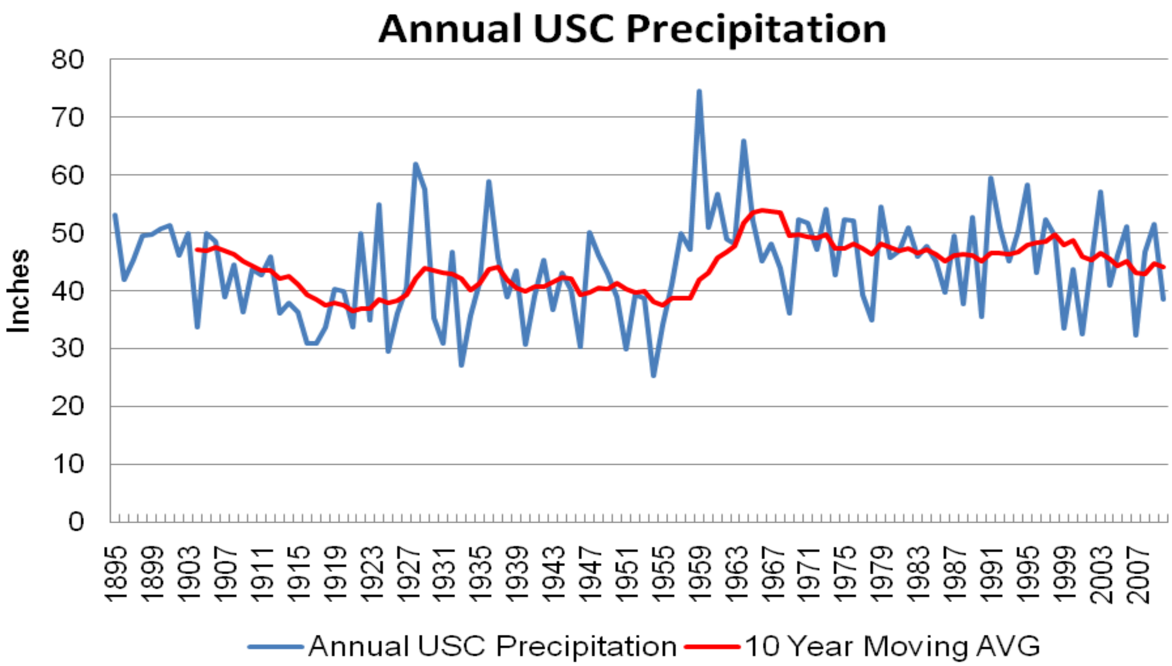
Figure 2.9 December, January, February average and median air temperatures recorded in Beaufort, South Carolina, 1895-2010.[51]



Examination of the USHCN annual rainfall data for the 5 stations showed no discernible trends, as shown, for example, in Figure 2.10. Lengthy periods of drought were evident in the data record as well as years with precipitation maxima. Some of the wetter years coincided with tropical cyclone activity, which can deliver a quarter to a third of the total annual rainfall amount in a single tropical storm event. There was poor correlation of the precipitation data and the annual temperature data (Fig 2.6, 2.10).

[51] NOAA/USHCN.

Figure 2.10 Cumulative annual precipitation, USC, Columbia, South Carolina, 1895-2010.[52]

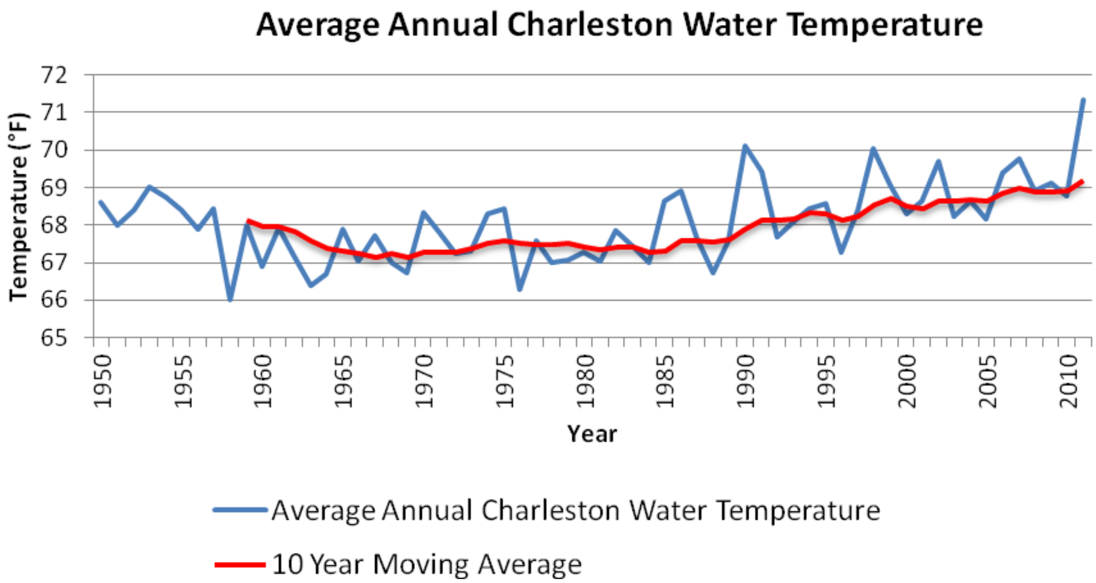


In addition to the temperature and precipitation study, a trend analysis of annual sea-water temperature data was completed using annual water temperature samples collected from the Charleston Harbor (Figure 2.11). The 10-year moving average of annual Charleston water temperature (Figure 2.11) shows relatively constant water temperatures from 1970 through 1985 before a steady warming trend began in 1985.

Data on severe storms were examined to discern any trends in severe storms. These data proved to be problematic due to the subjective nature of calculating the number of storm reports. Tornadoes and coastal hurricane landfalls provide a more objective measure to evaluate trends and variability; however, each has some inherent limitations. Tornado data from the period 1950-2010 (Fig. 2.12) demonstrate an increasing trend in these severe storms. This increasing trend is believed to be due to improved communications and detection capability, rather than climate change, and is attributable to increased population levels and the advent of Doppler radar technology in the early 1990s.

[52] NOAA/USHCN.

Figure 2.11 Average annual water temperature for Charleston, South Carolina, 1950-2010[53]



A tally of tropical cyclones making landfall along the South Carolina coast from 1878-2010 was plotted with a 10-year moving average calculation in order to note any trends (Fig. 2.13). Despite improvements in satellite technology, which can identify tropical cyclones, and indications that coastal water temperatures may be increasing, there is no evidence that tropical cyclone activity has increased along the South Carolina coast over the last 122 years .

[53] South Carolina Department of Natural Resources, Marine Resources Division

Figure 2.12 Annual observed South Carolina tornadoes, 1950-2010, demonstrating a Linear trend. [54]

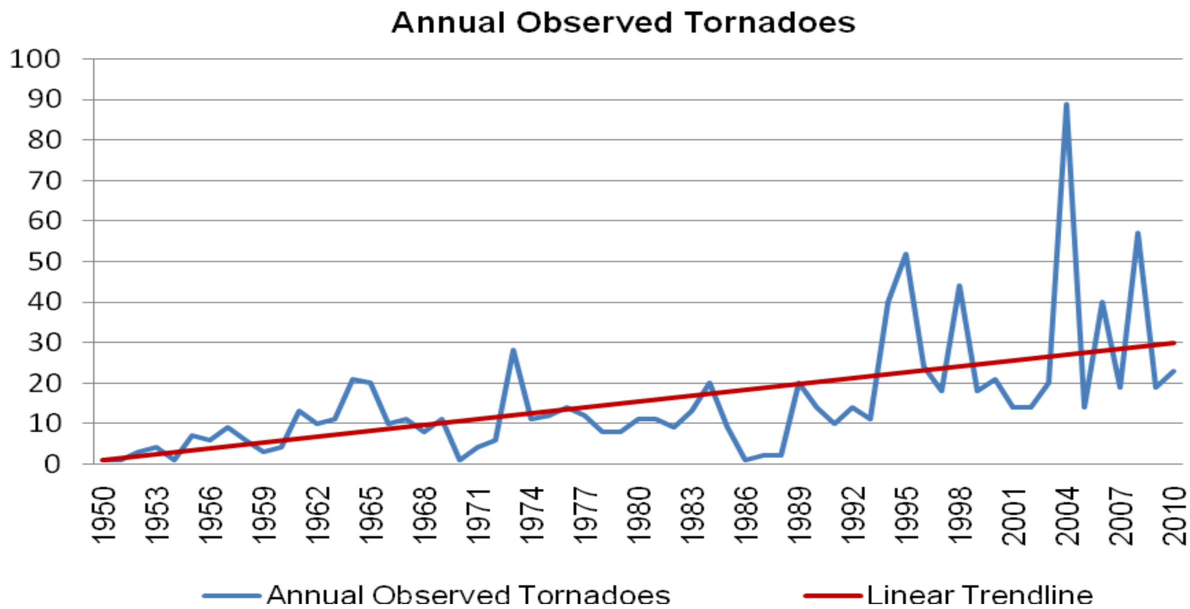
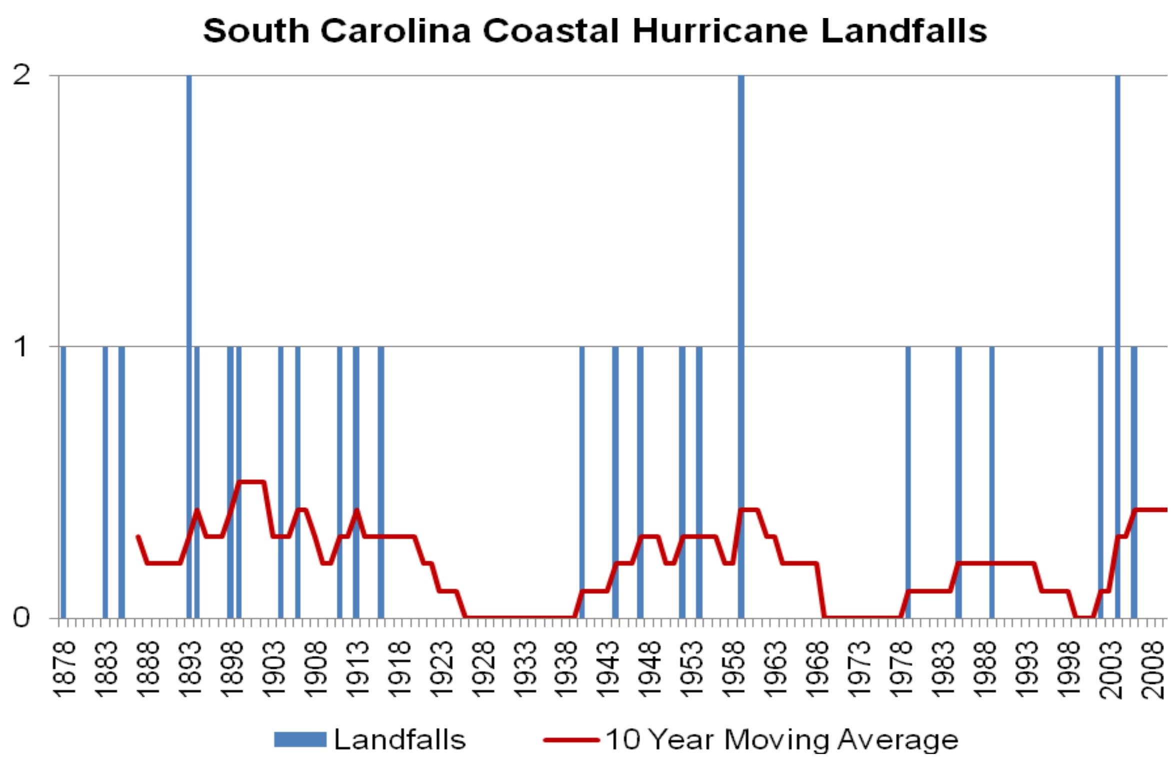


Figure 2.13 South Carolina coastal hurricane landfalls with a 10-year moving average applied.[54]



[54] http://www.nhc.noaa.gov/pastall.shtml. Last accessed Sept 2010.

2.6 Conclusions Based on South Carolina Data Examination

Temperature and precipitation data provide a record of variations in South Carolina climate extending back into the late 1800s. Air-temperature data from 1970 to the present show a steady increase in mean annual temperatures. Coastal water temperatures also support the recent warming phase, but the water temperature data record is not as extensive and continuous as the air temperature data. At this time, there is no definitive signal that tornadoes and hurricanes making landfall are increasing in the state. It must be noted that there is uncertainty in drawing broad conclusions on the recent and future climate of South Carolina based on examination of these kinds of localized data sets. In order to reduce uncertainty, more comprehensive data sets collected over a longer period of time and covering a larger geographic area must be examined.

2.7 Examination of Regional Climate Data and Predictive Models

The southeastern United States may be particularly vulnerable to climate change because of the risks associated with its low-lying coastline, periodically occurring winter storms and tropical systems.[55] The rich biodiversity of the Southeast could be exposed to more risks related to drought, plant and animal pathogens and invasive species. The Southeast is home to more than 400,000 farms on almost 80 million acres (32 million ha),[56] over 127 million acres (51 million ha) of timberland[57] and 33% of estuaries[58] and almost 30% of all wetlands in the conterminous United States.[59]

Since it is harder to examine climatic trends at the state level variations over the past in order to make climatic predictions, it is important to examine regional climate trends and models. Compared to the continental United States, the climate of the Southeast is uniquely warm and wet, with mild winters and high humidity. Southeastern average annual temperature has exhibited natural variation for most of the past century; however during the past 40 years annual average temperature has increased about 2°F (1°C).[60] The greatest seasonal change has occurred during winter with freezing days declining 4-7 days per year over the period (Fig. 2.14). Changes in precipitation have been occurring over the past 3 decades with increases in heavy downpours in many parts of the Southeast, even though much of the region has experienced moderate to severe droughts during the same period.[61] While there is uncertainty in projecting trends in

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[55] Karl, T.R., J.M. Melillo, and T.C. Peterson (eds.). 2009. Global Climate Change Impacts in the United States. Cambridge University Press, New York.

[56] USDA. 2008. Data Sets: Regional Agricultural Profile System. USDA Economic Research Service. Presentation tool for the 2002 Census of Agriculture. http://www.ers.usda.gov/data/RegionMapper/index.htm. Last accessed July 2010.

[57] USFS. 2010. Stream Temperature Modeling. US.Forest Service. http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temperature.shtml. Last accessed June 2010.

[58] NOAA. 1990. Estuaries of the United States: Vital Statistics of a National Resource Base. Monograph. NOAA National Ocean Service, Strategic Assessment Branch, Rockville, MD.

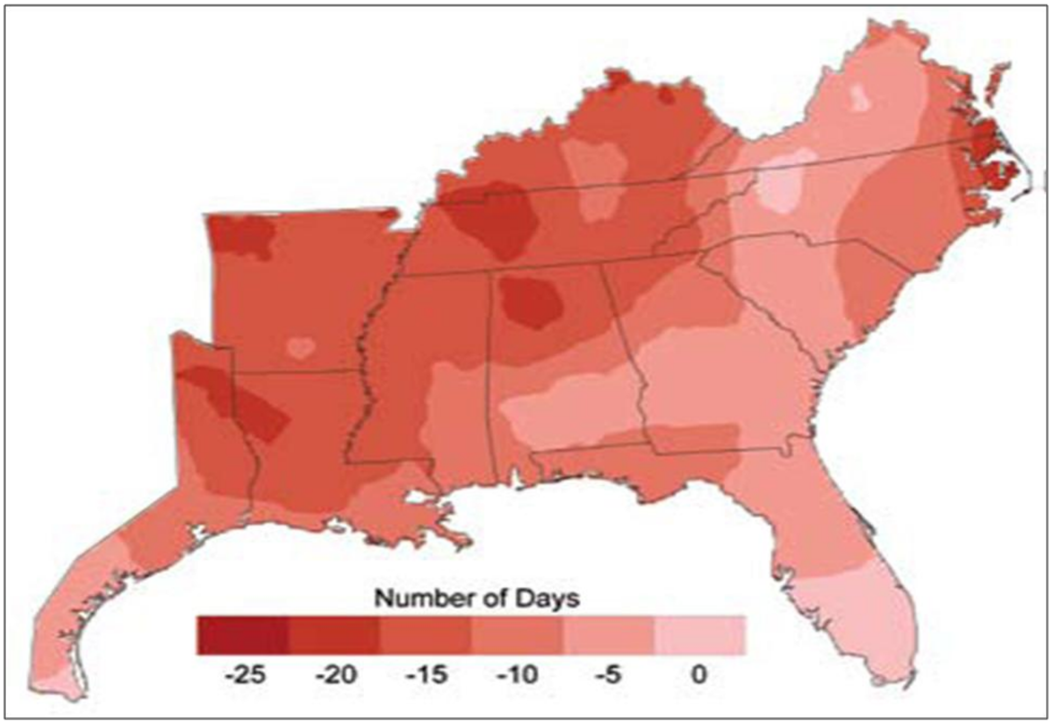
[59] Dahl, T.E. 1990. Wetland Losses in the United States 1780s to 1980s. US Department of the Interior, Fish and Wildl. Serv, Washington, DC. 167 pp.

[60] Regional Climate Impacts: Southeast. USGCCRP 2009. http://www.globalchange.gov/images/cir/pdf/southeast.pdf. Last accessed Aug 2010. Hereafter USGCCRP 2009.

[61] USGCCRP. 2009.

tropical activity, it is important to address that changes in tropical intensity and frequency has the potential for major implications.

Figure 2.14 Change in freezing days per year from1976 to 2007 in the southeastern United States demonstrating that since the mid-1970s the number of days per year during which the temperature falls below freezing has declined by 4-7 days over much of the Southeast but over 15 days for much of Arkansas, Louisiana, Mississippi and Tennessee.[62]



Current climate models predict continued warming across the Southeast with the rate of warming more than twice the current rate. The greatest temperature increases are projected to occur in the summer months. The number of very hot days of ≥ 100°F (38°C) is projected to rise at a greater rate than the average temperature. Under the lower GHG emissions scenario average temperatures in the Southeast are projected to rise by about 4.5°F (2.5°C) over the next 70 years, while a higher GHG emissions scenario is predicted to yield about 9°F (5°C) of average warming. Summers by the 2080s are projected to be about 11°F (6°C) hotter with a much higher heat index. The frequency, duration and intensity of droughts are likely to continue to increase with higher average temperatures and a higher rate of evapotranspiration.[63]

Interest in the effects of climate change in the Southeast is increasing, but there are any number of impediments to understanding and predicting climate change, including public apathy and a lack of awareness, lack of outreach on adaptation options, lack of

[62] USGCCRP. 2009.
[63]USGCCRP. 2009.

uniform access to information on current climate change risks and a lack of guidance on what information and tools are available. Climate change documentation and development of adaptation strategies also are limited primarily by a lack of funding, a lack of political will and lack of government leadership. Leadership issues may be a result of division of authority across topics as well as geographic and political boundaries across federal, state and municipal governments. All of these factors impede development of effective climate change adaptation policies across the Southeast.[64]

2.8 Climate and Weather Assessment

How will climate change affect day-to-day weather conditions, and how will these weather changes impact South Carolina natural resources and their public use and enjoyment? Can we monitor climate change at useful scales? The recognition and description of climate change and weather patterns are vital to the management of natural resources.

Detailed information about temperature, soil moisture, precipitation and humidity, when combined with long-term weather models and historical climate data, provide valuable information, such as duration of droughts and shifts in the duration of seasons. In turn, this information is used to help citizens in many ways. An important application of accurate climate data is monitoring the shift in frost-free days. An accurate, statewide monitoring system should be integrated with a warning system to alert local officials and citizens when temperatures or weather conditions become hazardous.

Extreme weather events are also of concern. For example, it has been proposed that climate change can influence the intensity and number of storm events.[65] Although supporting data are not entirely conclusive, the physics behind models are well understood. Warmer ocean temperatures potentially can provide more energy to hurricanes, leading to more intense storms. Increased precipitation patterns could have an adverse affect on flooding issues. High intensity rainfalls could lead to greater flooding hazards and mud- or landslides.

Enhanced support is needed for weather-station systems to forecast short-term events and monitor longer term trends. Weather stations that have reliable, long-term homogeneous data provide data needed for the detection and attribution of present and future climate change. Costs and maintenance associated with these systems require partnerships between federal, state and local governments and non-governmental organizations (NGOs). There needs to be a stable, long-term commitment to these weather station systems and to the monitoring and management of the data.

Our understanding of climate change also can benefit from paleoclimate studies. Past climates can indicate the potential range of physical and biological conditions we might

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[64]USEPA. 2010. Report on the USEPA Southeast Climate Change Adaptation Planning Workshop. http://epa.gov/region4/clean_energy/Task.5.Report.05.10.2010.pdf. Last accessed Sept 2010.
[65]H. Tompkins. 2002. Climate change and extreme weather events: Is there a connection? Cicerone 3:1-5.

expect. Paleoclimate studies also can provide insight into rates of climate change, conditions prior to major changes and the overall effect to the landscape resulting from climate change. Several lines of research could provide detailed information about past climates. For example, the stratigraphic record in the coastal plain can provide information about sea-level positions, minimums, maximums and rates of change. Carolina bays are known to have detailed fossil assemblages that can help interpret climatic conditions. Coastal lagoons may contain evidence of ancient hurricanes, providing information about the number, age and intensity of storms in the past. The study of ancient hurricanes (paleotempestology) could provide useful information about the frequency and intensity of hurricanes affecting South Carolina during the past. This information could be related to climatic conditions anticipated over the next several decades.

Climate change has the potential to increase flooding events requiring up-to-date flood mapping. The potential for increased flooding events or increased magnitude of flooding events or both could diminish the accuracy of current flood-plain maps. A strong flood-mapping program is needed. Through climate and stream monitoring, DNR may be able to better understand increased hazards, translate the results into a new generation of flood maps and design better emergency response programs.

3.0 CLIMATE CHANGE IMPACTS TO NATURAL RESOURCES IN SOUTH CAROLINA

3.1 Potential Physical Effects Resulting from a Changing Climate

3.1.1 Potential Effects Related to Change in Sea Level

3.1.1.1 Sea-level Rise

Sea level is rising,[66] and whatever the cause, it is a serious concern.[67] The evidence for the rise is visible to anyone who visits the beach. Communities have seen their shoreline retreat, requiring an increased need for beach nourishment. Along some beaches, downed trees and drowned tree stumps are an obvious sign of shoreline retreat. One of the most pronounced effects of sea-level rise will be the effects on shoreline and estuarine habitats and the species that depend on them. Sea-level rise and land subsidence also will affect coastal zone development. Shoreline change takes several forms: erosion, deposition and migration. Monitoring changes in magnitude, direction and rates of these parameters will provide important information to policy and decision makers. Beaches are among the most economically valuable natural resources in South Carolina, and the frequency of beach nourishment projects has accelerated over the past several decades. Impacts to beaches could be exacerbated by increasing intensity and frequency of damaging tropical storms, as predicted under some climate

[66] IPCC. 2007.
[67] EPA, 1989: The Potential Effects of Global Climate Change on the United States. Report to Congress. US Environmental Protection Agency. EPA 230-05-89-052. 401 pp. http://www.epa.gov/climatechange/effects/downloads/potential_effects.pdf. Last accessed Aug 2010.

change scenarios. While the magnitude of sea-level rise expected over the next century is not known with certainty, most models project approximately a 2.0 feet (0.6 m) rise. Estimates of sea-level rise have used multiplier factors ranging from 20-100 to estimate landward intrusion, indicating a potential intrusion boundary of 39-197 feet (12-60 m)[68] – clearly placing much of current beach development in South Carolina in jeopardy. In addition, outflow of coastal rivers, which act as a sand replenishment source, has been altered through more than a century of dam and hydroelectric reservoir development, the Santee and Pee Dee rivers being good examples. Not only are the physical threats of shoreline loss important, but the natural beauty of coastal beaches and the wildlife they sustain are extremely important to the state's economy and cultural heritage, and their sustainment is in doubt.

3.1.1.2 DNR Response and Recommendations

A comprehensive shoreline change strategy is needed to define the rate and magnitude of relative sea-level rise, as well as associated effects including shifting shoreline position, erosion rates and shifting salinity. Consideration of vegetation and aquatic organisms also is important to assess ecosystem change. Tracking sea-level rise and concomitant coastal change is a substantial task, but it is most effective when performed in cooperation with other state, federal and local efforts. Partnerships will be needed to acquire and protect habitat, as well as to collect, host and share regional, specific coast-wide data.

3.1.1.3 Coastal Habitats Affected by Sea-level Rise

The coastal zone is home to a number of unique habitats that are critical to support important wildlife and marine species. These include hammocks, salt and brackish emergent wetlands, that accommodate nesting, resting, and feeding areas for birds and beach dune systems where sea turtles (superfamily *Chelonioidea*) nest. These species and their habitats are especially vulnerable to the treat of sea-level rise.[69] [70]

South Carolina has several thousand small, unique coastal islands associated with larger barrier islands. The hammocks provide valuable resting and feeding stations for migratory shore birds as well as natural refuges for coastal mammals including deer, otter, mink and others. These small islands, ranging in size from less than an acre to several hundred acres, are most numerous between the Santee and Savannah rivers. Termed marsh hammocks or back barrier islands, they typically are located behind the oceanfront barrier islands and adjacent to the larger barrier islands. Other hammocks are located along the Atlantic Intracoastal Waterway or adjacent to coastal rivers and

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[68] IPCC. 2007.
[69] Daniels R. C., T. W. White and K. K. Chapman. 1993. Sea-level rise: destruction of threatened and endangered species habitat in South Carolina. Environ. Manage. 17: 373-385.
[70] Cheung, W., W. Vicky, J. Lam, K. Sarmiento, R. Kearney, R. Watson and D. Pauly. 2009. Projecting global marine biodiversity impacts under climate change scenarios. Fish and Fisheries. 10(3):235-251.

estuaries. Almost all are surrounded by expanses of salt marsh, occasionally being bordered by tidal creeks or rivers.[71]

Sea-level rise poses the following risks to hammocks:

1. Low elevation (< 0.3 meters in some cases) increases susceptibility to even modest sea-level rise,
2. They provide preferred habitat for biota requiring freshwater ponds or wetlands for reproduction and are sensitive to sea-water intrusion, and
3. Increased demand for marsh front or water front property has made these formerly unattractive and inaccessible areas economically attractive for development.

Sand dunes and beach habitat on the South Carolina coastline are vital for nesting of sea turtles, including the loggerhead sea turtle (*Caretta caretta*) and for feeding of sea birds. It is widely accepted that most female sea turtles return to their natal region every 2–3 years to nest.[72] Because of this vital link in their natural history, loss of front beach nesting habitat to beach erosion is a serious problem for this threatened species. Furthermore, since beach erosion is typically exacerbated by sea-level rise, rising water levels clearly pose a long-term threat to sea turtle populations. If beach erosion occurs on undeveloped islands, impacts to sea turtles may be minimal as the island simply retreats. However, aerial observations suggest that undeveloped islands in South Carolina are not retreating in a manner that would sustain turtle nesting because erosion is occurring at such a rapid pace.[73] *Bone yards or* dead tree trunks and limbs in the surf zone, exposed peat from geologically older marshes and a general loss of sand, due to dams on major rivers and nourishment projects, all appear to be diminishing the nesting quality of these beaches.[74] Although nourishment on developed beaches can restore some beach function as a nesting area, steep scarps sometimes develop just above the surf zone preventing female sea turtles from nesting or limiting them to lower sites where nests are vulnerable to tidal inundation and wave action.[75] Additionally, research indicates the nourishment process creates significant disruption to the physical and biological compositions of offshore sites where sand is mined and not replenished naturally.[76]

Estuarine flats, salt marshes and creeks form essential habitat to the juvenile stages of many marine species that support important inshore fisheries such as shrimp (*Litopenaeus* and *Farfantepenaeus*), blue crab (*Callinectes sapidus*), spot (*Leiostomus*

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[71] Whitaker, J. D., J. W. McCord, P. P. Maier, A. L. Segars, M. L. Rekow, N. Shea, J. Ayers and R. Browder. 2004. An ecological characterization of coastal hammock islands in South Carolina. Final report to Ocean and Coastal Resources Management, SC Dept. of Health and Environmental Control. SC Dept. Nat. Resour. Rept. 115 pp.

[72] Bjorndal, K. A., A. B. Meylan and B. J. Turner. 1983. Sea turtle nesting at Melbourne Beach, Florida, I. Size, growth and reproductive biology. Biological Cons. 26: 65-77.

[73] Dubose Griffin, DNR, personal communication.

[74] Dubose Griffin, DNR, personal communication.

[75] M. Steinitz, M. Salmon, and J. Wyneken. 1998. Beach renourishment and loggerhead turtle reproduction: A seven year study at Jupiter Island, Florida . J. Coast. Resour. 14(3):1000-1013.

[76] Posey M. and T. Alphin. 2002. Resilience and stability in an offshore benthic community: Responses to sediment borrow activities and hurricane disturbance. J. Coast. Resour. 18(4):685-697.

xanthurus), flounder (*Paralichthys spp.*), red drum (*Sciaenops ocellatus*), spotted seatrout (*Cynoscion nebulosus*) and gag grouper (*Mycteroperca microlepis*). These flats also sustain high densities of other small species, such as fiddler crabs (*Uca* spp.), snails and killifish (*Fundulus,* spp.), which are important prey for larger fish, crabs and birds. Rising sea levels could contribute to a reduction in the area of intertidal marsh available, especially if coastal development impedes their inland expansion in response to inundation. Reduced salt marsh area would be expected to have a negative impact on the populations of species that rely on salt marsh habitat.

3.1.1.4 DNR Response and Recommendations

The effects of rising sea level and its biological ramifications are at best uncertain and potentially devastating to the coastal zone ecosystem. Substantial resources need to be dedicated to reducing these uncertainties. Support should be given to spatial mapping projects that can model the effects of sea-level rise and assist in identifying methods of reducing its impacts.

Migratory routes and utilization of hammock islands by birds should be quantitatively compared to the mainland and the larger barrier islands. In order to determine relative abundance of birds and mammals, utilization of truly isolated hammocks should be compared to the more accessible hammocks. Other research interests include the importance of woodland edges for birds, the influence of the physical shape on bird utilization (complex shorelines vs. a circular-shaped island), predator-prey interactions and the interrelationships between plants and animals should be studied. Efforts should be made to ensure that land is set aside to serve as isolated hammocks as salt marshes migrate inland as a result of rising sea level.

Cooperative studies and management efforts with beachfront communities should continue to ensure the protection and enhancement of sea turtle nesting beaches. The rate of sea-level rise should be monitored, and resultant information should be used to determine appropriate management options as conditions change. Long-term management plans for beach nourishment should be developed through collaboration among beach communities, researchers and state/federal agencies. These plans should included examination and identification of likely renewable sand resources, beach nourishment funding sources and beach nourishment impacts upon other natural resources.

3.1.1.5 Sea-level Rise Effect on Marine and Coastal Resources

Implications of sea-level rise will require societal considerations that will have both direct and indirect effects on marine and coastal resources. Regarding the gradual inundation of beaches, river banks, and marsh edges, only three basic options are available: retreat inland, armor with sea walls or revetments or, in the case of beaches, nourishment by physically moving sand, usually from offshore. Each of these options has high economic costs as well as potential biological costs.

Sea-level rise could have profound effects on coastal salt marshes, inland brackish marshes and further inland freshwater marshes. Some believe that marshes, with time, can migrate inland and maintain their viability;[77] however if development and armored shorelines prevent potential inland retreat, marsh area will be reduced along with associated living marine resource productivity. Even without the opportunity for marshes to migrate landward, studies in South Carolina have shown that some salt marsh habitats may be resilient to sea-level rise due to sufficient sedimentation that allows the marshes to rise with sea level, while other marsh habitats will not be able to do so, resulting in drowning of those marshes. Similar problems could occur in the state's valuable shellfish beds if the beds cannot migrate landward, or changes in existing habitat conditions destabilize the beds.

If populations that are targeted by recreational and commercial fishing are negatively impacted by climate change, particularly loss of estuarine nursery habitat, mitigation in the form of aquaculture replenishment stocking or for pond grow out of seafood may be in greater demand.

3.1.1.6 DNR Response and Recommendations

Efforts should be undertaken to proactively address marsh migration through the use of migration models that identify likely areas where marshes could migrate. On the basis of these models, strategies should be cooperatively developed to protect these areas from further and future development. Research and development of mariculture techniques for important fishery species should continue or be initiated.

3.1.1.7 Sea-level Effects on the Fresh and Saltwater Interface

Changes in the location of the saltwater/freshwater interface will affect many freshwater and diadromous fish species. As sea level rises, saltwater will move further up the river systems of the state. Species with low salt tolerances and diadromous fish will be limited in their ability to move upstream into better quality habitat due to dams and hydroelectric reservoirs constructed on most South Carolina riverine systems. The amount and distribution of aquatic vegetation also will change in response to increases in salinity, limiting cover and food sources for aquatic organisms. Additionally, the potential exists for increased demand for water releases from reservoirs to fight the salt wedge that will be moving inland.

3.1.1.8 DNR Response and Recommendations

For shifting salinity profiles, a contemporary, comprehensive hydrological survey of the coastal rivers is needed to determine existing and normal salinity patterns. Predictive models to analyze potential for salinity change by river mile should be developed throughout the coastal zone. Information obtained from sound scientific research could

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[77] Feagin, R. A., M. Luisa Martinez, G. Mendoza-Gonzalez and R. Costanza. 2010. Salt marsh zonal migration and ecosystem service change in response to global sea level rise: a case study from an urban region. Ecology and Society. 15(4):14. [online] URL: http://www.ecologyandsociety.org/vol15/iss4/art14/. Last accessed June 2011.

be used to support development of adaptive management strategies to cope with shifting salinity in coastal rivers.

3.1.1.9 Sea-level Rise Effects on Coastal Managed Wetlands

The coastal landscape of South Carolina has both beauty and ecological significance. Managed tidal wetlands, also known as *rice fields, diked marshes* and *coastal impoundments* are a unique category of tidal coastal wetlands that exist in substantial acreage in and primarily only in South Carolina, largely as relics of a long-past agricultural era. Predominantly occurring in the traditional freshwater tidal zone, the infrastructure of most of the original acreage of managed tidal wetlands has been abandoned for a variety of reasons. However, a portion of the original acreage of these historically, culturally and economically important habitats in the coastal landscape is maintained intact for utilization by migratory birds and for recreational hunting. Conservation of rice plantations and associated managed wetlands in South Carolina is unique and is the predominant basis for habitat protection initiatives enabling modern preservation of tens of thousands of acres of ecologically important wetlands and upland buffer.

Waterfowl migrate during autumn from northern production areas to southern wintering areas, then in spring return northward to nesting areas.[78] Southern wintering allows dispersal over a broad area resulting in diverse foraging opportunities and maintenance of body condition.[79] Optimum wintering waterfowl habitat such as that located within South Carolina managed tidal wetlands is critical to the maintenance of this national trust resource.

Rudimentary wetland habitat management strategies were improved during the period between 1945 and 1985 until they became highly refined and specific.[80] [81] [82] Numerous papers have described prescriptive water quality parameters and water level manipulations designed to produce standing crops of preferred naturally occurring emergent and submerged wetland plants in fresh, intermediate, brackish, saline and hypersaline marshes.[83] [84] [85] [86] [87] [88]

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[78] Welty, J. C. 1975. The life of Birds, 2nd edition. W. B. Saunders Co. Philadelphia, PA. 662 pp.
[79] Baldassarre, G. A. and E. G. Bolen. 1994. Waterfowl ecology and management. John Wiley & Sons, New York, NY. 609 pp.
[80] Gordon, D. H., B. T. Gray, R. D. Perry, M. P. Prevost, T. H. Strange and R. K. Williams. 1989. South Atlantic coastal wetlands. Pages 57-92 *in:* Habitat Management for Migrating and Wintering Waterfowl in North America, L. M. Smith, R. L. Pedersen and R. M. Kaminski, eds. Texas Tech University Press, Lubbock, TX. 574 pp. Hereinafter: Gordon et. al. 1989.
[81] Conrad, W. Brock. Conrad. 1966. A food habits study of ducks wintering on the lower Pee Dee and Waccamaw rivers, Georgetown, South Carolina. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm, 19:93-99.
[82] W. P. Baldwin. 1950. Recent Advances in Managing Coastal Plain Impoundments for Waterfowl, An. Conf. SE Assoc. Game and Fish Comm. 11 pp.
[83] Williams, R. K., R. D. Perry, M. B. Prevost and S. E. Adair. 1998. Management of South Atlantic coastal wetlands for waterfowl and other wildlife. Ducks Unlimited, Inc., Memphis, TN. 26 pp.
[84] Morgan, P. M., A. S. Johnson, W. P. Baldwin and J. L. Landers. 1975. Characteristics and management of tidal impoundments for wildlife in a South Carolina estuary. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 29:526-539.
[85] Landers, J. L., A. S. Johnson, P. H. Morgan and W. P. Baldwin. 1976. Duck foods in managed tidal impoundments in South Carolina. Journal Wildl. Manage. 40:721-728.

Coastal wetland managers have made significant strides in habitat management employing diverse, holistic habitat management plans that incorporate a wide variety of strategies to maximize production of favored plant material, seeds, and tubers and associated invertebrates while allowing for estuarine connectivity.[89] As a result of these successes some coastal landowners in the tidal regime constructed dikes in brackish and saline wetlands not previously included in rice culture.[90] By the mid-1970s over 70,000 acres (112,630 ha) of South Carolina coastal wetlands were in some form of wetland management primarily directed toward attracting waterfowl for recreational hunting and enjoyment.[91] Waterfowl since have flourished in managed tidal wetlands along with other wetland dependent wildlife, most notably shore and wading birds, the bald eagle (*Haliaeetus leucocephalus*) and the American alligator (*Alligator mississippiensis*).[92] DNR manages a total of 32,940 acres (13,331 ha) of managed wetlands at 6 locations that occur in the intertidal zone. The Yawkey Wildlife Center and Santee Coastal Reserve are located in Charleston and Georgetown counties and have dikes and wetlands that front directly on the ocean. These properties have 26.4 miles (42.5 km) and 15.8 miles (25.4 km) of perimeter dikes with 32 and 25 water control structures in these dikes, respectively. These 2 properties are under direct threat from sea-level rise. Existing dikes are minimally adequate in height and any rise will threaten the management of these wetlands. Bear Island WMA in Colleton County and Santee Delta WMA in Georgetown County are located more inland but will be affected by sea-level rise. They have 15.0 miles (24.1 km) and 5.8 miles (9.3 km) of perimeter dikes with 35 and 10 water control structures in these dikes, respectively. Samworth WMA located in Georgetown County and Donnelley WMA located in Colleton County are even further inland but still depend upon the tide to provide water for flooding of the wetlands. These 2 properties have 14.2 miles (22.8 km) and 0.7 miles (1.1 km) of perimeter dikes with 22 and 5 water control structures located in these dikes, respectively.

An embankment of sufficient composition and height is mandatory to seasonally restrict tide water from a managed tidal wetland; water control structures installed in embankments are necessary to adjust, raise or lower water levels in accordance with regularly occurring tides and a desired wetland management strategy.[93] Because the

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[86] Prevost, M. B., A. S. Johnson and J. L. Landers. 1978. Production and utilization of waterfowl foods in brackish impoundments in South Carolina. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 32:60-70.
[87] Perry, R. D. 1987. Methods to enhance target species production in freshwater impoundments. Pages 33-43 *in*: M. R. DeVoe and D. S. Baumann, eds. SC Coastal Wetland Impoundments: Management Implications, Workshop Proc. SC Sea Grant Consortium. Tech. Rep. No. SC-SG-TR-87-1.
[88] Perry, R. D. 1995. Management of tidal freshwater wetlands for waterfowl. Pages D124-D134 *in*: W. R. Whitman, et al. eds. Waterfowl habitat restoration, enhancement and management in the Atlantic Flyway. Third ed. Environmental Manage. Co., Atlantic Flyway Coun. Tech. Sect. and Delaware Div. Fish and Wildl., Dover, DE.
[89] Gordon et. al. 1989.
[90] Miglarese, J. V. and P. A. Sandifer, eds. 1982. An ecological characterization of South Carolina wetland impoundments. SC Mar. Resour. Cent. Tech. Rep. 51. SC Wildl. & Mar. Resour. Dept. Columbia, SC. 132 pp.
[91] Tiner, R. W., Jr. 1977. An inventory of South Carolina's coastal marshes. SC Mar. Resour. Cent. Tech. Rep. 23. SC Wildl. & Mar. Resour. Dept. Columbia, SC. 33 pp.
[92] Gordon et. al. 1989.
[93] Williams, R. K. 1987. Construction, maintenance and water control structures of tidal impoundments in South Carolina. Pages 139-166 *in*: W. R. Whitman and W. H. Meredith. eds. Waterfowl and Wetlands Symposium: Proc .

elevation of managed tidal wetland embankments typically is only slightly higher than the flooded water level of the interior managed wetlands, rising sea level poses a significant threat to their existence, and therefore the sustainability of these habitats for the benefit of migratory waterfowl and other managed tidal wetland species.

Equally important to the management of these wetlands is the salinity of the water used to facilitate water manipulations. At Samworth and Donnelley, freshwater has been the norm and the vegetation communities within the wetlands do not tolerate significant salinity. Even at Yawkey and Santee Coastal Reserve where embankments front on the ocean, relatively low-salinity riverine water has been available for water management purposes. Wetland management scenarios for these wetlands target a range of moderate salinities. As sea level rises and saltwater travels farther inland, fresh water near or at the coast will not occur. Saltwater management strategies will shift to hyper saline; brackish water management strategies will shift to saline; and freshwater management strategies will shift to brackish. These shifting salinity profiles will require DNR to adapt in order to effectively manage wetlands located directly on the coast.

3.1.1.10 DNR Response and Recommendations

Care must be given to ensure current regulatory mechanisms continue to protect this special kind of wetland as well as all other wetlands. Equally important is the need to be certain that the wetland protection regulations embrace an adaptive approach, when necessary, to benefit society and continue to protect all natural resource wetland attributes.

DNR should routinely monitor and maintain dikes, monitor water levels and salinities within and outside the wetlands. Embankments should be raised as needed and water control structures should be maintained and replaced as required. Adaptive relocation of water control structures may be necessary in order to adjust to changing riverine salinity profiles. Adaptive management of these wetlands, based upon water levels and salinities, is critical. Inland expansion or replacement of managed wetlands, by retreat, should be considered as properties become available.

3.1.2 Potential Effects Related to Changes in Water

3.1.2.1 Water Quantity

Water-supply issues are becoming increasingly critical.[94] With more demands on all water resources, it is essential to develop a comprehensive statewide conservation policy that balances human and natural resource needs. Without detailed information about capacity, long-term trends and their relation to the climate and the water budget,

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Symp. On Waterfowl and Wetland Manage. In the Coastal Zone of the Atlantic Flyway. Delaware Dept. of Natural Resour. and Environ. Control. Dover, DE. 522 pp.

[94] Bates, B. C., Z. W. Kundzewicz, S. Wu and J. P. Palutikof, *eds.* 2008: Climate change and water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp. http://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf. Last accessed July 2010.

an efficient and effective water plan will be difficult to implement. Water issues involve both surface and ground waters and include a myriad of factors that must be considered including availability, quality, recharge areas, source-area protection and storage. The primary interest is in fresh water, but at times salt water is an issue, in particular salt-water intrusion into coastal drinking-water wells as well as salt water moving up stream systems from estuaries.[95]

Surface water is monitored primarily by the United States Geological Survey (USGS), but additional information in critical areas would be helpful. Stream gauges provide water quantity information and also are used to monitor flood conditions and issue flood alerts by other agencies. At present, the ground-water monitoring system does not sufficiently cover the state, and a detailed, county-based ground-water monitoring program is needed to determine the availability and sustainability of ground water.

3.1.2.2 DNR Response and Recommendations

An effective policy for water management begins with a fundamental understanding of the behavior and processes that govern water movement and storage. Therefore, the most significant step to improve the understanding of South Carolina water supply is to increase monitoring capability of both surface- and ground-water sources, establish baseline measures of in-stream flow, better understand recharge and define recharge areas, develop databases to compile accumulated results and provide reliable information to assist in management decisions. Accurate assessment of ground-water availability can come only from long-term monitoring and a thorough understanding of the geologic architecture of the aquifers and their confining layers. This type of detailed work includes stratigraphic, subsurface geologic mapping and hydrogeologic studies. Results of these studies and others would reside in an integrated geologic, geophysical and hydrologic database that would benefit not only DNR, but all groups interested in surface- and ground-water issues.

Comprehensive basin-wide water planning should be done for each of the sub-basins in the state. These plans should include a detailed assessment of our ground- and surface-water resources, an assessment of ground- and surface-water use by water-use category, a water-demand analysis for each of the water-use categories, and a comprehensive water plan incorporating water-supply and water-demand management strategies to meet future demands and sustain the resource.

River-basin hydrologic models are needed for each of the sub-basins in South Carolina to predict where and when water shortages will occur and to evaluate the effects that changes in temperature and precipitation will have on surface-water supply. Ground-water flow models are needed in the coastal plain to predict the effects that withdrawals will have on aquifers. These models can be used to evaluate the effects that changes in precipitation and ground-water recharge rates have on our water supply.

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[95] Ranjan, S.P., Kazama, S. and Sawamoto, M. 2006. Effects of climate and land use changes on groundwater resources in coastal aquifers, J. Environ. Manage. 80(1):25-35.

A monitoring network is needed to study interactions between shallow ground water and surface water. The network could also be used to assess antecedent drought and flood conditions, and could be used as a barometer of drought conditions. This network could assist in understanding the relationships between base flow, ground-water levels and changes in precipitation.

3.1.2.3 Water Quality

In addition to affecting water quantity, climate change also will affect water quality.[96] Although DNR does not regulate water quality, the nature of how contaminants enter the water system is a direct function of the physical condition of the environment, including subsurface geology and land-use practices. The LWC can provide important technological and educational assistance in these areas.

3.1.2.4 DNR Response and Recommendations

Support is needed to adequately investigate of the state's subsurface geology. Prior knowledge of subsurface geology is important when planning for industry and development. The impact of accidental spills and remediation of hazardous-waste contamination can be reduced with proper planning. The availability of water, or lack thereof, is highly influenced in parts of the state by subsurface geology. The potential for geologic hazards, fault zones, also needs to be clearly defined. A comprehensive drilling program will help to establish the subsurface framework that influences ground water flow as well as earthquakes.

An expanded surface-water monitoring system also is needed. Monitoring should include water quality parameters such as water temperature, dissolved oxygen, pH, salinity and fecal coliforms. When combined with stream-flow data, this information can yield important information relative to how drought and flooding events impact water quality. These data could be used to augment the South Carolina Department of Health and Environmental Control (DHEC) monitoring system and to provide technical assistance to local governments and other stakeholders involved in land use planning.

A ground-water monitoring network along the coast should be established to measure salt-water intrusion. Strategically located wells in each aquifer should be continuously monitored for water level, temperature and specific conductance.

3.1.2.5 Potential Effects of Changes in Rainfall and Riverine Flow

Estuarine systems are among the most productive ecosystems on Earth and may be among the most sensitive to impacts of climate change as a result of changes in sea level and variation in rainfall that may shift salinity profiles and changes in biotic

[96] IPCC. 2007.

composition.[97] Shifts in salinity profiles in the estuarine system will depend entirely upon freshwater input and rainfall.[98] The projections for rainfall in South Carolina under a warming climate are unknown and require DNR to plan for a range of contingencies. The past decade has been dominated by drought conditions with accompanying shifts in the distribution of species within estuaries. Changes in biotic composition and the prevalence and seasonal distribution of diseased organisms must be expected, but little data exist to predict possible ramifications.

Salinity profiles in estuaries are expected to change as a result of both sea-level rise and changes in precipitation patterns. The former will shift the salinity regimes up estuaries; however the impact of the latter is unknown, as current models do not provide a clear direction to anticipated rainfall in South Carolina over the next few decades.[99] While estuarine species are renowned for their ability to tolerate salinity shifts over a tidal cycle, many have optimal ranges and move in the system according to prevailing conditions.

The worst scenario for sea-level rise could result in a landward shift in salinity resulting from sea-level rise accompanied by drought. This scenario would compress the available habitat, due in part to coastal development, likely resulting in reduced salt-marsh habitat in the optimal salinity ranges. Reduction of the spatial area covered by the salt marsh would reduce abundance and reproduction of estuarine species, as well as affect the entire ecosystem.

Another apparent consequence of extended droughts is drying out and dieback of saltwater marshes. The severe drought in 1999-2002 is thought primarily to have been responsible for salt marsh diebacks along the East Coast and Gulf of Mexico.[100] Studies in the Gulf of Mexico suggest that the drought caused low pH levels which resulted in greater bioavailability of metals which may have been responsible for *Spartina* mortality. On the South Carolina coast, both marsh meadows and marsh fringing tidal creek channels died in 2002.[101] It also is possible that low ground water levels resulting from drought may be related to salt marsh die offs. Salt marsh dieback has obvious implications including a reduction in primary productivity and increased vulnerability to predators of juvenile fishes and invertebrates.[102]

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[97] Michener, W., E. Blood, K. Bildstein, M. Brinson, and L. Gardner. 1997. Climate change, hurricanes and tropical storms and rising sea level in coastal wetlands. Ecological Applications. 7(3):770-801.

[98] Meynecke J., S. Lee, N. Duke andJ. Warnken. 2006. Effect of rainfall as a component of climate change on estuarine fish production in Queensland, Australia. Estuarine, Coastal and Shelf Sci. 69:491-504

[99] IPCC. 2007.

[100] Alber, M., E. Swenson, S. Adamowicz and I. Mendelssohn. 2008. Salt Marsh Dieback: An overview of recent events in the US. Estuarine, Coastal and Shelf Science. 80:201-211.

[101] D. Whitaker, personal observation. Dec 2002.

[102] Minelo, T. and R. Zimmerman. 1985. Differential selection for vegetative structure between juvenile brown shrimp (*Penaeus aztecus*) and white shrimp (*Peneus setiferus*), and implications for predator–prey relationships. Estuarine Coastal Shelf Sci. 20:707–716.

3.1.2.6 DNR Response and Recommendations

Field studies are needed to clearly document the effect and consequences that drought has on the salt marsh and its sensitive ecosystems. These studies would focus on determining the causes of salt marsh dieback and its impacts on primary and secondary productivity.

Accompanying hydrological studies are needed to determine the ambient conditions of coastal ground water and how ground-water levels and water chemistry are influenced by tidal fluctuations, sea-level change and drought. Field-based studies also are needed on the potential ecological and physiological impacts on mollusks, crustaceans and fish resulting from shifting salinity profiles and ocean acidification. Other studies of the migration and dispersal of estuarine species, especially those near the southern limits of their range, are needed.

Support is needed to develop predictive models that project expected sea-level rise, accompanied by a broad range of rainfall and hydrological scenarios. GIS mapping and mathematical modeling of estuarine water salinities as related to changes in river flow and local drought also are needed. This information would define affected marine species that will be forced farther inland than present or whose populations could be negatively impacted by reduced optimal nursery habitat. Mitigation plans could be established and implemented once information is available.

3.1.3 Potential Effects of Temperature Rise

3.1.3.1 Temporal and Spatial Shifts in Habitat and Life Histories

Shifting climate can cause changes in the spatial distribution of habitat and/or temporal aspects of life history. Shifts in habitat can occur in patches across the landscape, or the geographic range of species can shift. Temporal shifts in life history of species also are likely to occur in response to warmer or cooler temperatures, changes in precipitation, changes in vegetation or shifting seasons. For example, species' reproductive cycles can occur earlier or later in the year (budding has been observed to be occurring earlier for some plant species), become shorter or longer in duration, or occur earlier or later in age. Species at the edges of their range or in marginal habitats need to be able to migrate or disperse to adjust to changing habitat conditions.

Striped bass (*Morone saxatilis*) occurring in lakes that thermally stratify, such as lakes Murray and Thurmond, may experience increased incidence of mortality due to the vertical compression of oxygenated habitat. This could lead to population shifts away from striped bass toward species more tolerant of habitat compression such as hybrid striped bass (*Morone saxatilis* x *Morone chrysops*).[103]

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[103] Brandt, S. B.; Gerken, M.; Hartman, K. J.; Demers, E. 2009. Effects of hypoxia on food consumption and growth of juvenile striped bass (*Morone saxatilis*). J. Exp. Marine Biol. Ecol. 381: S143-S149 .

3.1.3.2 DNR Response and Recommendations

A comprehensive strategy and long-term monitoring program is needed to assess spatial and temporal impacts to organisms, particularly for sensitive, rare or vulnerable species. Knowledge of life history and range for species is needed to develop effective management strategies to protect wildlife and freshwater and marine fishes and their habitat.

3.1.3.3 Population and Ecosystem Effects

Changes in climatic conditions have been linked with ecosystem-wide regime shifts resulting in major changes in species diversity and interactions at all trophic levels.[104] Climate change also has been associated with a northward shift in the distribution of many marine fish species across the Northern Atlantic, the Northwest Pacific and the Bering Sea.[105] [106] The evidence supporting climate-related shifts in distribution and abundance in the southeastern United States is limited since the issue has not been explicitly examined. The potential effects are profound, especially if economically important species are impacted, or if unexpected shifts occur that affect the biodiversity, stability or resilience of ecosystems.

Temperature has a direct effect on the physiology and survival of aquatic species. For example, temperature directly affects their physical growth and maturity, since the majority of aquatic species is poikilotherms, or cold blooded, and has metabolic rates that fluctuate with environmental temperature. Such changes can affect the rate of energy transfer between trophic levels, influence productivity and the function of the marine ecosystem as a whole. Survival can be directly affected by a species' upper and lower temperature tolerances. Overwinter mortality caused by freezes can have major impacts on the abundance of some species, such as spotted seatrout.[107] Conversely, other species utilizing habitats near their thermal maximum, for instance striped bass (*Morone saxatilis*) utilizing coastal waters, may be negatively impacted by high temperatures in the summer.

The abundance and annual commercial landings of brown shrimp (*Farfantepenaeus aztecus)* appear to have declined steadily in South Carolina over the last 2 decades concurrent with increasingly warm winters. Although no cause and effect has been definitively identified, it is hypothesized that the species' recruitment mechanism requires relatively cold winters. On the other hand, the white shrimp (*Litopenaeus*

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[104] Beaugrand G. 2009. Decadal changes in climate and ecosystems in the North Atlantic Ocean and adjacent seas. Deep Sea Research Part II: Topical Studies in Oceanography. 56:656-673.

[105] Grebmeier, J., J. Overland, S. Moore, E. Farley, E. Carmack, L. Cooper, K. Frey, J. Helle, F. McLaughlin and S. McNutt. 2006: A major ecosystem shift in the northern Bering Sea. Science, 311(5766):1461-1464.

[106] ter Hofstede, R., J. Hiddink, and A. Rijnsdorp. 2010. Regional warming changes fish species richness in the eastern North Atlantic Ocean. Mar. Ecol. Prog. Serv. 414:1-9.

[107] South Carolina Department of Natural Resources. 2007. State of South Carolina's coastal resources: Spotted seatrout. http://www.dnr.sc.gov/marine/mrri/pubs/yr2007/seatrout07.pdf. Last accessed Dec 2010.

setiferus), is a subtropical species that may benefit from warmer winters and may expand its range farther north.[108]

Shifting water temperatures in the nearshore and shelf-break can lead to a shift in the distribution of both larval and adult fish. Increasing water temperatures could lead to shifts in areas of maximal abundance and overall species range for species such as red snapper (*Lutjanus campechanus*), red grouper (*Epinephelus morio*), gag (*Mycteroperca microlepis*) and scamp (*Mycteroperca phenax*). Anecdotal evidence suggests that shifts in some species' ranges may have occurred already off South Carolina.[109]

Strong year classes of Atlantic croaker (*Micropogonias undulatus*) populations along the mid-Atlantic coast have been positively related to warmer-than-normal winters.[110] Presumably, a higher frequency of warmer winters could modify the relative abundance for other important species and could result in significant shifting of ecological relationships including trophic structure, food webs and others. A long-term study in Narragansett Bay has documented a progressive shift in the marine community from vertebrates to invertebrates and, especially since 1980, from benthic to pelagic species.[111] Populations of small, short-lived forage species of fish, in particular, can change rapidly in response to climate variation, which can affect the growth and survival of other fish, mammals[112] and birds[113] that consume them.

Some diadromous species are near the southern end of their ranges in South Carolina. Many of these species already are stressed by summer conditions including high temperatures and, in some cases, low dissolved oxygen and anthropogenic impacts.[114] Finfish examples include the shortnose sturgeon (*Acipenser brevirostrum*), federally listed as endangered, and the Atlantic sturgeon (*Acipenser oxyrinchus*), a species of concern that was recently petitioned for listing as endangered. Both of these fish previously were of great economic, nutritional and cultural value to the state.[115] Climate change could exacerbate management problems for these and other species including shad species and river herring (*Alosa spp.*), or even in some cases, limit or eliminate their occurrence in South Carolina. Recruitment failure may occur in severe drought conditions as a consequence of dewatering of gravel bars and absence of the

[108] D. Whitaker, personal observation.

[109] J. Ballenger, MRRI, DNR. Personal communication

[110] J. Hare and K. Able. 2007. Mechanistic links between climate and fisheries along the east coast of the United States: explaining population outbursts of Atlantic croaker (Micropogonias undulatus) Fish. Oceanogr. 16(1):31–45,

[111] Collie, J., A. Wood, and P. Jeffries. 2008 Long-term shifts in the species composition of a coastal fish community Can. J. Fish. Aquat. Sci. 65:1352–1365.

[112] McLeod, et al. 2007. Linking sand eel consumption and the likelihood of starvation in harbour porpoises in the Scottish North Sea: could climate change mean more starving porpoises? Biol. Lett. 3:185-188.

[113] Frederiksen, et al. 2004. Scale-dependent climate signals drive breeding phenology of three seabird species. Global Change Biol, 10:1214-1221.

[114] Jenkins, W.E., T.I.J. Smith, L.D. Heyward and D. M. Knott. 1995. Tolerance of shortnose sturgeon, *Acipenser brevirostrum*, juveniles to different salinity and dissolved oxygen concentrations. Proc. Southeast. Assoc. Fish and Wildl. Agencies. 47:476-484.

[115] Leland, J. 1968. A survey of the sturgeon fishery of South Carolina. Contribution from Bears Bluff Laboratories. No. 41. 27 pp.

seasonally elevated flows which serve as a cue for spawning migration. Results of preliminary modeling investigations suggest that local extinction can occur rapidly.[116]

Freshwater fish species also are likely to be affected by changes in temperature regimes. Eastern brook trout (*Salvelinus fontinalis*) are the most sensitive to temperature of the 3 trout species that occur in South Carolina. They require colder water than rainbow (*Oncorhynchus mykiss*) and brown (*Salmo trutta*) trout. DNR has monitored temperatures in brook trout streams on the Sumter National Forest and Jocassee Gorges streams. Currently, maximum summer temperatures in South Carolina brook trout streams routinely reach 68-70°F (20-21°C) during the hottest summer periods. Brook trout typically do not occur in streams where maximum temperatures exceed 70°F (21°C). Any increase in stream temperature as a result of climate change likely would result in the loss of the species in South Carolina.

Smallmouth bass (*Micropterus dolomieu*) are a popular temperature-dependant coolwater sport fish that are managed in a number of South Carolina waters. For example, if waters were to warm in the Broad River, this recreationally valuable fishery could become jeopardized.

No studies of the response of nongame fishes to projected climate change in South Carolina or the southeastern United States have been published, but research elsewhere has predicted decline in distribution of cool and cold-water fishes.[117] In South Carolina, likelihood of extirpation from the state is high for the suite of fishes that are endemic to the southern Appalachian highlands, as these populations which are restricted to the upper reaches of the Savannah and Saluda drainages are relics from historic stream capture from the Tennessee River system. It also is possible that other upland-endemic species noted in the CWCS as sensitive to environmental change could decline in abundance and distribution with climate change.

Even if the overall distribution of fish species or their center of abundances is unchanged due to warming water temperatures, climatic changes could affect fish populations in other ways. Blue catfish (*Ictalurus furcatus*) are a nongame species that was introduced to the state's waters decades ago. No adverse effects to other aquatic species have been documented as a result of this introduction, and a popular fishery has developed for blue catfish. However, increased average water temperatures could result in increased competition between blue catfish and other species for spawning resources. Blue catfish spawn in temperatures ranging from 70-84°F (21-29°C). A typical spawning could shift from May to April could occur if temperatures rise. Native catfish, which usually do not compete for resources with blue catfish, may compete for spawning sites. This competition could be more pronounced if climate change altered seasonal durations, creating a shorter spring and a more prolonged summer.

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[116] J. Hightower, USGS, Raleigh, NC. Personal communication.

[117] Lyons, J, J.S. Stewart and M. Mitro. 2010. Predicted effects of climate warming on the distribution of 50 stream fishes in Wisconsin, U.S.A. Journal of Fish Biology 77: 1867-1898.

Additionally, climatic changes could alter the timing of the spring phytoplankton blooms – affecting zooplankton populations that many larval and juvenile fish species depend on as prey during this critical period of development. Conversely, climatic changes could directly affect the maturation of fishes, causing a shift in the spawning season. In any case, this could lead to a mismatch in the temporal period for which prey are available to larval and juvenile fish species in any given year, leading to more sporadic recruitment events and a higher probability of recruitment failure in any given year. This effect is often referred to as the Cushing match-mismatch hypothesis.[118]

Evidence is emerging that variations in annual oceanographic events affect the phytoplankton distribution of productivity.[119] For example, studies in other areas indicate that the intensity and timing of seasonal upwelling events have shifted compared to previous decades. This can have major effects on coastal ecosystems and may change the species composition of phytoplankton.[120] For example, the relative proportion of dinoflagellates, which tend to prefer warmer and more stratified water columns, may increase with respect to diatoms.[121]

It is unknown if a longer growing season would affect South Carolina oysters (*Crassostrea virginica*), but it might be due to effects on species composition and abundance of phytoplankton.

Seasonal inshore-offshore and latitudinal distributions, timing of migration and duration of nesting season of loggerhead sea turtles appear to be greatly influenced by water temperature.[122] Satellite-tagged juvenile loggerhead sea turtles have been shown to demonstrate inshore-offshore movement coincidental with water temperatures of 17°C.[123] It also has been demonstrated that warmer sea-surface temperatures in at least some locations lead to earlier onset and longer duration of nesting seasons.[124] It is not known to what degree extended warm weather seasons may alter these life history dynamics, and what the consequences of these environmental changes could have on the recovery of this threatened species. Additionally, sea turtle sex ratios are known to be determined by incubation temperatures in the nest, with warmer

[118] Cushing, D.H. 1990. Plankton production and year-class strength in fish-populations – an update of the match mismatch hypothesis. Advances in Marine Biology 26:249-293.

[119] Hays, G., A. Richardson and C. Robinson. 2005. Climate change and marine plankton. Trends in Ecology and Evolution. 20(6):337-344.

[120] Barth, J. B. Menge, J. Lubchenco, F. Chan, J. Bane, A. Kirincich, M. McManus, K. Nielsen, S. Pierce and L. Washburn. 2007. Delayed upwelling alters nearshore coastal ocean ecosystems in the northern California current. Proc. of the Nat. Acad. of Sci. 104(10):3719-3724.

[121] Monterey Bay Aquarium Research Institute. 2006. Seeing the Future in the Stratified Sea. 2006 Annual Rept. http://www.mbari.org/news/publications/ar/chapters/06_timeseries.pdf. Last accessed Dec 2010.

[122] Bjorndal, K.A., A.B. Meylan and B.J. Turner. 1983. Sea turtle nesting at Melbourne Beach, Florida, I. Size, growth and reproductive biology. Biological Conservation, 26:65-77.

[123] Arendt, M., J. Byrd, A. Segars, P. Maier, J. Schwenter, D. Burgess, J. Boynton, D. Whitaker, L. Liguori, L. Parker, D. Owens and G. Blanvillain. 2009. Examination of local movement and migratory behavior of sea turtles during spring and summer along the Atlantic coast off the southeastern United States. SC DNR, Univ. GA and College of Charleston, Final Report to NOAA Fisheries, Contract Number NA03NMF4720281, 177 pp.

[124] Hawkes, L.A., A.C. Broderick, M.H. Godfrey and B.J. Godley. 2007. Investigating the potential impacts of climate change on a marine turtle population. Global Change Biology, 13(5): 923-932.

temperatures resulting in sex ratios skewed to females.[125] It is conceivable that climate change could cause additional bias in sea turtle sex ratios, and males might become the limiting resource. In a worst-case scenario, a warming local climate could lead to the elimination of male offspring production altogether.[126]

3.1.3.4 DNR Response and Recommendations

Continuation of long-term surveys and archiving, integrating and analyzing the data they produce are essential to understanding climate-related impacts on the state's wildlife and freshwater and marine fisheries resources.

Abundant data exist to explore climate-related issues in databases compiled by MRD, other DNR sections and other organizations including NOAA and the University of South Carolina Baruch Marine Research Institute (BMRI) but funds for analyses are lacking. The MRD databases archive information from numerous ongoing, long-term (10-30 year) biological surveys that cover a variety of key habitats, ranging from small estuarine creeks to offshore deep waters. Examples include an electrofishing survey of upper estuarine habitats, a trammel net survey of lower estuarine marshfront, an estuarine crustacean trawl survey, a coastal trawl survey, a coastal shark and adult red drum longline survey and an offshore live bottom survey. These surveys often complement one another because many species spend different parts of their life cycle in different habitats. Two of the surveys, which are federal programs administered and conducted by MRD staff, cover the entire South Atlantic Bight (SAB) from North Carolina to Florida. They include the Southeast Area Monitoring and Assessment Program (SEAMAP), which began a shallow water trawl survey of the near-coastal SAB in 1986, and the Marine Resources Monitoring, Assessment and Prediction (MARMAP) program, which began research further offshore in 1973 and primarily covers live bottom habitat.

In addition to the various fishery-independent surveys mentioned above, the OFM compiles fishery-dependent databases that record harvest rates of recreationally and commercially important species such as shrimps, crabs, oysters and fish.

Continued support of these long-term surveys is critical for understanding climate-related changes in the marine system, and for predicting potential future scenarios for South Carolina's marine resources. The value of the surveys derives from the time periods covered and the use of standardized collection methodology enabling meaningful, comparable data across years. Support for the collection of additional important biotic and abiotic data, such as fish and crustacean community structure and densities, life history information, temperature and salinity is essential. Existing programs currently provide data for regional stock assessments, but lack resources for critical analyses and modeling of existing data to support climate change studies.

[125] Mrosovsky, N, and C.L. Yntema. 1980. Temperature dependence of sexual differentiation in sea turtles: implications for conservation practices. Biological Conservation 18:271-28

[126] Blanvillain, G., L. Wood, A. Meylan. and P. Meylan. 2008. Sex ratio prediction of juvenile hawksbill sea turtles from South Florida, USA. Herpetological Conservation and Biology 3(1):21-27.

In order to assess the impacts of climate change on freshwater fisheries, a model simulation is needed for various scenarios of climate change using stream assessment data recently collected across the state to provide an objective evaluation of risk to native upland fish species.

Monitoring of penaeid shrimp, crab, fish and oyster populations should continue with fishery-dependent and fishery-independent methods. Efforts should be made to determine relationships between climate change and population dynamics of important species, for instance the impact of warmer winters on brown shrimp recruitment.

Data from other sources are also available, such as the long-term monitoring projects conducted by the BMRI. The integration of data across surveys, across DNR sections and across other research institutes would be a powerful method of detecting long-term biological trends associated with climate change. To facilitate this, it would be useful to compile an easily accessible list of all data sources within the DNR as a whole to integrate marine, freshwater and climate data sources, as well as other organizations within the state that collect long-term data. Comparison of these data with information available from other regions along the Atlantic and Gulf coasts would be useful in order to detect regional patterns.

There is a need to compile and analyze water temperature records from multiple locations to determine if temperatures have increased significantly in the last decade along the Gulf of Mexico and South Atlantic Coast as related to nearshore loggerhead sea turtle foraging grounds. Also needed is repeated examination of the sex ratios in loggerhead sea turtle nests with respect to spatial and temporal variability. At-sea monitoring of sea turtles with trawls should be continued to document overall population trends of juveniles and adults.

Agencies and local communities should continue education and eradication campaigns to eliminate beach vitex, an invasive plant that restricts nest building by sea turtles.

Populations of diadromous species should be evaluated in all major coastal rivers to estimate populations and monitor trends.

3.1.3.5 Harmful algal blooms (HABs)

HABs are caused by certain species of microscopic photosynthetic algae (phytoplankton). They cause a wide range of detrimental effects that are species-specific. Examples include shading and destruction of estuarine grass habitat, shellfish poisoning and toxin production that can bioaccumulate up the food chain and induce sickness and death in wildlife and humans. There has been an increase in reported HAB events over recent decades,[127] partly because of improved monitoring, but also

[127] Anderson, D.M. 2004. The growing problem of harmful algae: Tiny plants pose potent threat to those who live in and eat from the sea. Woods Hole Oceanographic Institution. http://www.whoi.edu/page.do?pid=11913&tid=282&cid=2483. Last accessed Jan 2011.

because of increased aquatic nutrient loading from run-off, alteration in land use patterns and the introduction of exotic HAB species. Climate change may further affect the timing and intensity of HAB events, but the overall relationships among climate change and other factors affecting the HAB prevalence remain unclear. For example, blooms of toxic cyanobacteria and raphidophytes are common in South Carolina. These blooms can cause mass fish kills and often are associated with increased levels of certain nutrients, particularly nitrogen;[128] [129] however, the timing and duration of blooms may be augmented by climate change.

3.1.3.6 DNR Response and Recommendations

The South Carolina Algal Ecology Laboratory has been jointly operated by USC and DNR over the last decade. Additional collaborations exist with the National Ocean Services, Charleston Laboratory. The monitoring and research performed by these collaborative efforts should be encouraged. Examples of relevant questions concerning HABs and climate change include:

1. Does climate change lead to longer summer growing seasons, and if so, then how would HAB taxa that tend to be more responsive to warmer temperatures respond? How might these co-vary with land use patterns?
2. Would harmful blooms simply persist for longer timeframes under predicted climate change scenarios?
3. Or, would phytoplankton blooms eventually exhaust their supply of nutrients, die off, and subsequent microbial respirations adversely affect water oxygen levels, thus inducing hypoxia?

3.1.3.7 Hypoxia and Dead Zones

Increasing temperatures can reduce oxygen levels in coastal waters through a variety of mechanisms such as a decrease in the solubility of oxygen, an increase in productivity and stratification of the water column. Hypoxia-related events have been well-documented in other coastal regions after, for example, extended phytoplankton blooms including in the Gulf of Mexico and Long Island Sound in New York.[130] Hypoxia often is related to increased nutrient run-off coupled with a stratified water column. These combined processes often promote proliferation of phytoplankton biomass, including that of HAB species. Cessation of blooms is typically coupled with increased oxygen consumption by bacteria, and in extreme cases, this oxygen consumption causes hypoxic conditions or dead zones, where oxygen concentrations fall below levels supporting life. These hypoxic regions impact benthic or demersal species and can result in considerable losses to fisheries. The incidences of dead zones are increasing worldwide and are believed to be, in part, a result of increasing global temperatures

[128] Chorus I, Bartram J (1999) Toxic cyanobacteria in water. World Health Organization, London.

[129] Downing TG, Meyer C, Gehringer MM, Venter M (2005) Microcystin content of *Microcystis aeruginosa* is modulated by nitrogen uptake rate relative to specific growth rate or carbon fixation rate. Environ Toxicol 20:257-262

[130] Diaz, R.J. and R. Rosenberg. 2008. Marine ecosystems spreading dead zones and consequences for marine ecosystems. Science. 321:926-929.

promoting greater water stratification.[131] The phenomenon can be exacerbated by nutrient-laden freshwater runoff related to increasing impervious surfaces from coastal development and changes in rainfall patterns. Numerous dead zone events have occurred in South Carolina during the last 2 decades, but most have been confined to small estuarine creeks and were of short duration. In 2004 and in 2009, relatively large events occurred in coastal waters just off Horry County in Long Bay.[132] Preliminary studies indicate these events were caused by persistent southwest winds resulting in upwelling near the coast, thence causing the unusual effect of trapping nutrient-laden water near the beaches, leading to hypoxia. Climate-related changes in ocean and wind circulation patterns could result in a greater frequency of coastal hypoxia. [133]

3.1.3.8 DNR Response and Recommendations

The relationship between climate change, land use and phytoplankton bloom timing and intensity is virtually unstudied for coastal South Carolina, but should be an important focus of future research. Agencies and universities should continue to form partnerships to monitor coastal hypoxia. Permanent nearshore monitoring stations strategically located along the coast should be maintained to monitor physical and chemical aspects of coastal waters. Efforts should be made to develop mathematical models that can explain hypoxia events, including the oceanographic conditions that give rise to them. Anthropogenic causes of hypoxia should be addressed and corrected where possible.

3.1.3.9 Potential Effects of Ocean Acidification

Increasing ocean acidification apparently related to increasing CO_2 levels in the Earth's atmosphere raises concerns about the future of reef-building corals and other species that incorporate calcium carbonate into their skeletons including mollusks, crustaceans and some plankton.[134] While South Carolina does not have shallow-water coral reefs, the impact of ocean acidification on oysters and other species is of concern. It is expected that ocean pH will fall to about 7.8 over the next 300 years and this is within the range known to impact oyster growth. However, pH in estuaries typically ranges between 7.0-7.9, with the lower values known to impact a variety of physiological and

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[131] Kelling, R, and H. Garcia. 2002. The change in oceanic O2 inventory associated with recent global warming. Proc. Nat. Acad. Sci. 99(12):7848-7853.

[132] Sanger, D. , D. Hernandez, S. Libes, G. Voulgaris, B. Davis, E. Smith, R. Shuford, D. Porter, E. Koepfler and J.H. Bennett. 2010. A case history of the science and management collaboration in understanding hypoxia events in Long Bay, South Carolina, USA. J. Environmental Manage. 46:340-350.

[133] Gregg, R.M. L.J. Hansen, K.M. Feifel, J.L. Hitt, J. M. Kershner, A.Score, and J. R. Hoffman The State of Marine and Coastal Adaptation in North America: A Synthesis of Emerging Ideas. Eco. Adapt. Bainbridge Island, WA. http://www.cakex.org/sites/default/files/EcoAdapt%20Synthesis%20Report%20January%202011.pdf. Last accessed May 2011.

[134] Orr, J.,, V. Fabry, O. Aumont, L. Bopp, S. Doney, R. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R. Najjar, G. Plattner, K. Rodgers, C. Sabine, J. Sarmiento, R. Schlitzer, R. D. Slater, I. Totterdell, M. Weirig, Y. Yamanaka and A. Yool. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature. 437:681-686.

immune functions in oysters.[135] Further deceases in pH could result from increasing ocean acidification, acid rain and increasing development in the coast zone. The effects of low pH are amplified at higher temperatures. Whether the expected increases in ocean acidity, atmospheric CO_2 and temperature pose serious threats to oysters and other estuarine species is difficult to assess as the issue has not been well studied. Similar concerns exist for many crustaceans, as the molting process involves calcium demineralization and re-mineralization of the exoskeleton and this is influenced by both internal pH as well as external pH. Increased acidification also could impact phytoplankton bloom dynamics and regional primary productivity.

3.1.3.10 DNR Response and Recommendations

Agency and university researchers should cooperatively monitor pH in coastal waters. Support is needed for research on the potential ecological and physiological impacts of shifting salinity profiles and ocean acidification on mollusks, crustaceans and fishes.

3.1.4 Potential Effects Related to Changes in Terrestrial and Aquatic Habitats

3.1.4.1 Habitat Fragmentation

Habitat decline, shifting climate regime, increasing development, particularly in coastal areas, and rising sea level represent constraints and barriers to dispersal and migration of fish, wildlife and plant species.[136] Maintaining migratory corridors is essential for the ability of wildlife and fishes to find suitable habitat and for population maintenance. Over the past several decades, habitats within South Carolina have become increasingly fragmented. Natural areas have been developed and roads have been created or widened throughout much of the state. This development has disrupted traditional corridors and resulted in pockets of wildlife habitat that are isolated from one another. Dams and other barriers have fragmented entire river systems and impede migration of diadromous and freshwater fish as well as many invertebrate species. As climate changes, further habitat fragmentation will restrict movement of animals, limiting or preventing the critical ability to migrate to more favorable habitats.

3.1.4.2 DNR Response and Recommendations

The South Carolina Heritage Trust Program was created in 1976 to help stem the tide of habitat loss by protecting critical endangered species sites through acquisition and other means. Enabling legislation directed DNR, in concert with other state agencies, to set aside a portion of the state's rich natural and cultural heritage in a system of heritage preserves to be protected for the benefit of present and future generations (Sec. 51-17-20, 1976 *S.C. Code of Laws*).[137] Support for the Heritage Trust and other habitat

[135] Gazeau, F., C. Quiblier, J. Jansen, J.P. Gattuso, J. Middelburg and C Heip. 2007. Impact of elevated CO2 on shellfish calcification. Geophysical Research Lett. 34 :L07603, doi:10.1029/2006GL028554.

[136] P. Opdam and D. Wascher. 2003. Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. Biological Conservation 117:285–297. http://research.eeescience.utoledo.edu/lees/Teaching/EEES4760_07/Opdam.PDF Last accessed Sept 2010.

[137] http://www.scstatehouse.gov/code/statmast.htm. Last accessed Sept 2010.

protection programs is needed to identify, create and preserve important conservation corridors to allow migration and movement of affected species. In addition, the agency will need to investigate ways to partner with other agencies and non-governmental organizations to develop and maintain adequate migration corridors.

3.1.4.3 Loss and Alteration of Habitats

Temperature changes likely are to result in changes in vegetative structure of wildlife habitats throughout the state. In the event local temperatures warm, higher elevation habitats could suffer; cooling temperatures could affect lowcountry habitats. More rapid and extreme temperature fluctuations could stress populations and restrict thermal refugia. These changes could result in habitat loss and a change in both vegetative and animal community structure. Two examples of important freshwater fisheries at increased risk are trout (subfamily *Salmoninae*) and striped bass. Habitat loss not only affects the area in which the species can live, it also affects food availability and availability of suitable nesting/breeding areas. Impacts associated with temperature changes most likely will be greater in the higher elevations of the state.

Precipitation changes will affect both surface and groundwater levels and will result in impacts to both terrestrial and aquatic systems.[138] Wildlife depends on a variety of water sources within the state. All animals require water within their habitats, some more than others. Changes in wetland systems will affect many species of birds (particularly waterfowl), reptiles and amphibians that depend on these areas for foraging and breeding habitats. Isolated freshwater wetlands, small streams and seepage wetlands are critical to the survival of many of these species. Small wetlands and the species associated with them may be excellent indicators for the effects of climate change on larger systems.

Freshwater aquatic systems are susceptible to changes in precipitation. Streams, rivers, lakes and ponds are dependent upon both precipitation and groundwater recharge to maintain flow and water levels. Changes in surface and groundwater levels can affect the species assemblages and migration in freshwaters throughout the state.

3.1.4.4 DNR Response and Recommendations

There is the need to gather plant and animal baseline data for terrestrial and aquatic habitats and monitor the rate of change in both vegetative and animal community structures. The agency should use the information collected to determine appropriate management options in response to climate change and adapt management activities as climate changes occur in response to the changing habitat needs of wildlife and fish species. DNR should use these data to develop predictive models of the effects of temperature changes.

Monitoring the rate of water level and flow change in all surface waters and groundwater systems is vital to terrestrial as well as aquatic habitats. DNR should use the

[138] IPCC. 2007.

information collected to determine appropriate management options in response to climate change and adapt its management activities as climate changes occur in response to the evolving habitat needs of wildlife and fish species. The agency should use data collected to develop models that can assist in predicting water level and flow change and work with other entities to ensure adequate water levels and flow rates for wildlife and fish.

3.1.4.5 Habitat Impacts Related to New and Alternative Energy

As the nation strives to locate and utilize alternative, cleaner and more carbon-neutral sources of energy, it is important to understand that such sources may result in additional impacts to wildlife, fish and their habitats. Increased demand for biofuels can result in decreased wildlife habitat as forests and conservation areas are converted to production areas. Wind power, both on- and off-shore, can result in increased mortality to birds and bats. Hydropower can result in reduced flow in rivers and restrict movements of freshwater and diadromous fish as well as cause direct impacts through turbine impingement. Impacts to natural resources may be mitigated during planning, permitting and licensing for alternative energy projects.

3.1.4.6 DNR Response and Recommendations

The agency should work with all stakeholders including utilities, other agencies, NGOs, legislators, government planners and other experts as alternative energy sources are developed, licensed and brought on line to ensure natural resource needs are addressed during planning.

3.2 Potential Biological Effects Resulting from a Changing Climate

3.2.1 Species and Habitat Data

3.2.1.1 Insufficient Data for Species and Habitat

Although very detailed distribution and life history data exist for some harvestable species within the state and for a limited number of special status species (threatened and endangered species), these types of data are lacking for the majority of wildlife and freshwater fish. Without information about the distribution and abundance of species and their habitat requirements, reproductive abilities and longevity, it will be very difficult to understand and respond to impacts associated with climate change.

DNR has developed a plan to identify species of greatest conservation need in the state through its *South Carolina Comprehensive Wildlife Conservation Strategy* (CWCS) which includes recommendations to address threats to these species and their habitats.[139] A total of 1,240 species is identified in the CWCS, including marine species. Because these species currently are considered at risk, any additional impacts

[139] Kohlsaat, T., L. Quattro and J. Rinehart. 2005. South Carolina Comprehensive Wildlife Conservation Strategy. SC Dept. Nat. Resour. http://www.dnr.sc.gov/cwcs/index.html. Last accessed Sept 2010.

associated with climate change will exacerbate current threats; data needs identified for those species in the CWCS should be addressed as we manage for climate change.

In addition to those species identified in the CWCS, other wildlife and fish species are likely to experience impacts related to climate change. Habitat for local, migrating and wintering waterfowl, neotropical migrant birds, reptiles and amphibians as well as a number of freshwater fish species is particularly vulnerable to climate change impacts.

3.2.1.2 DNR Response and Recommendations

The agency should continue to collect baseline data for wildlife and fishes in South Carolina. Data collection projects should include abundance, distribution and life history studies. Data should be utilized to determine appropriate management options in response to climate change. Habitat management activities must be adaptive as climate changes occur in response to the changing needs of wildlife and fish species. DNR should use data collected to develop models that can assist in predicting species response to climate change.

3.2.1.3 Habitat Data and Characterization

As with information about wildlife and fish species in South Carolina, there is a lack of data concerning the historic and current condition of habitats. Without current or past baseline data, it will be very difficult to assess the vulnerability of habitats and to determine the rate of habitat loss. In addition to the need for baseline data, it will be critical to identify the climate change effects on wildlife and fish habitat.

3.2.1.4 DNR Response and Recommendations

DNR should collect baseline data on the condition of wildlife and fish habitat in South Carolina. This information should be used to determine appropriate management options in response to climate change. The agency should adjust management activities as climate changes occur in response to the changing habitat needs of wildlife and fish species. Data collected can be utilized to develop models that can assist in predicting habitat response to climate change.

3.2.2 Endangered, Threatened or Species of Concern

3.2.2.1 Declining Habitat for Endangered, Threatened or Species of Concern

Habitat loss is the most important factor contributing to species decline. Climate change may exacerbate habitat decline, particularly for rare or sensitive species such as amphibians. Nuisance and exotic species invasions, changes in plant and animal community structure and changes in abiotic factors such as hydrology, soil moisture and climate are areas of great concern relative to rare or sensitive species conservation.

3.2.2.2 DNR Response and Recommendations

DNR maintains and manages the South Carolina Rare, Threatened and Endangered Species Inventory. Much of the data in the Inventory is submitted to DNR by citizens and academic institutions, so data acquisition is driven by individual submissions rather than a comprehensive plan or strategy. Additional support for comprehensive and long-term monitoring of rare and sensitive plant and animal species is needed. This should involve development of a more modern inventory system with significant IT support. The current database should be screened and standardized with other systems in the region.

An improved monitoring strategy can provide vital data to guide conservation and habitat management activities. Again, there is opportunity to partner under the umbrella of existing and future conservation efforts. Potential conservation activities include translocation of species where appropriate, rare plant species propagation and identification and protection of important habitat. The management of natural resources will become increasingly difficult and complicated as climate change advances. The Conservation Section within the LWC can provide needed leadership and technical expertise to local, regional and statewide conservation and planning efforts.

3.2.3 Invasive Species

3.2.3.1 Potential for Introduction of Invasive Species

Increased temperatures, changes in rainfall and other environmental factors affected by climate shifts or change can create ideal conditions for proliferation of invasive plant and animal species, including parasites and pathogens. An increase in the number and diversity of native and non-indigenous invasive plant and animal species has been documented in South Carolina terrestrial, freshwater and marine habitats. Some of these species may have been released accidently or by well-meaning citizens, but others are likely migrating northward from more tropical climates as a result of warming temperatures. Regardless of the manner in which they have become established, these species already are impacting native animals and their habitats. As climate changes, an increasing number of exotic species likely will migrate to South Carolina. Habitats can be destroyed as resources are over-utilized. Invasive and non-indigenous species have the potential to outcompete native species for food and other resources.

Impacts of invasive species are second only to habitat loss for the significant decline and extirpation of both endangered and common species. The current environmental, economic and health costs of invasive species could exceed $138 billion per year in the United States, more than all other natural disasters combined. In 2006 alone, the United States spent $1.2 billion combating invasive species. That total does not even consider the numerous hours and dollars spent at regional, state and private levels to combat invasive species.[140]

[140] Pimental, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs associated with non-indigenous species in the United States. Biosci. 50(1):53-65.

Invasive species can completely overtake unique, sensitive and important habitats, such as those protected on lands dedicated as DNR Heritage Preserves, and out compete other established natives, forcing them into endangered, threatened or species of concern status. Stressed vegetation is vulnerable to attack by non-indigenous parasites and pathogens. The identification and acquisition of land for preserves often is based on the presence of unique native floral or faunal populations; however, if climate change alters local conditions in ways that allow invasive species to proliferate, the value of conservation lands as habitat for native species can become compromised.

Tilapia is a warmwater non-indigenous group of fish that extensively are stocked under permit in the state to control algae in private ponds. With few notable thermal refuges excluded, tilapia will die from cold stress in a typical South Carolina winter when water temperatures drop below 50°F (10°C). Historically, south coastal South Carolina water temperatures routinely drop to 45-50°F (7-10°C) during the winter. In the event that waters were to warm in the state, the potential for tilapia to overwinter is possible. Tilapia currently overwinters in Florida and has become an invasive species and a major management problem. If tilapia were to routinely overwinter in South Carolina it would result in direct competition with native and existing species for space, food, habitat and spawning areas, which could drastically alter natural fish communities.

The destruction that non-indigenous peacock bass (*Cichla* spp.) can cause to native fish communities is well documented.[141] In Florida, these fish currently are widespread, but, fortunately, these fish are very temperature dependant and do not typically survive in waters cooler than 60°F (16°C). Given current South Carolina winter low temperatures, tilapia is much more of an eminent threat than peacock bass. However, if winter temperatures increase, peacock bass could become a threat in South Carolina. Other invasive fish that are common in Florida and, like peacock bass, could become established in South Carolina, include various cichlids, pleco (*Hypostomus plecostomus*), Asian swamp eel (*Monopterus albus)*, walking catfish (*Clarias batrachus*), various piranha and oscar (*Astronotus ocellatus*). All of these fish could, like tilapia, compete with native species for habitat, food and spawning resources.

Despite the increased frequency of occurrence, and in some cases the establishment in South Carolina, of subtropical and tropical flora and fauna, including invertebrate fauna, with historic ranges once restricted to latitudes south of Cape Canaveral, little has been done to determine the impact of these species on the natural ecosystems of our state, or to assess whether or not their arrival and dispersal has been enhanced or accelerated by climate changes. Recently it has been demonstrated that changes in seasonal maxima and minima of water temperature may be more important than changes in means.[142] Examples of marine invertebrates that have extended their ranges northward include two millennia Andrew C. Kemp, Benjamin P. Hortona,,

[141]Pelicice, F.M. and A.A. Agostinho. 2009. Fish fauna destruction after the introduction of a non-native predator (*Cichla kelberi*) in a neotropical reservoir. Biol Invasions. 10.1007/s10530-008-9358-3.

[142] Stachowicz, J, J Terwin, R Whitlatc, and R. Osman. 2002. Linking climate change and biological invasions: Ocean warming facilitates nonindigenous species invasions. Proc. Natl. Acad. Sci. 99(24):15497-15500.

Jeffrey P. Donnellyc, Michael E. Mannd,species of callinectid crabs similar to native blue crabs (*Callinectes bocourti* and *C. exasperatus*); the spiny hands crab (*Charybdis hellerii*); the blue land crab (*Cardisoma guanhumi*); the green porcelain crab (*Petrolisthes armatus*); two pulmonate snails (*Creedonia succinea* and *Microtralia ovula*); an intertidal littorinid snail (*Echinolittorina placida*); the Asian green mussel and the charrua mussel (*Perna viridis* and *Mytella charruana*); the Asian tiger shrimp (*Penaeus monodon*); two acorn barnacles (*Megabalanus coccopoma* and *M. tintinnabulum*); and a caprellid amphipod (*Caprella scaura*).[143] In addition, lionfish (*Pterois volitans*) have colonized the southeastern United States from Florida to North Carolina over the past decade.[144] These represent some of the most recently discovered arrivals, although others are certain to arrive in the future. Invasive species can be extremely problematic because they may competitively displace existing species or cause radical habitat changes that affect entire populations or ecosystems. For example, beach vitex (*Vitex rotundifolia),* an introduced exotic plant from Hawaii, recently has taken over sand dune areas on some beachfronts in northern Georgetown and Horry counties. Its aggressive growth and impenetrable roots quickly cover dunes, making them unsuitable for loggerhead sea turtle nesting.[145] Species such as *Phragmites australis*, *Hydrilla verticillata* and *Eichhornia crassipes* are aquatic plants with similar impacts to brackish and freshwater areas in the United States where they create monocultures outcompeting native species and drastically altering the ecology of entire ecosystems. Another example is the nematode *Anguillicoloides crassus*, a parasitic worm originally located only in Asian eels (*Anquilla japonica*). The first record of *A. crassus* in wild-caught American eels (*Anguilla rostrata*) was from Winyah Bay in 1996,[146] having been introduced by the transport of live Asian eels. The parasite is much more detrimental to the health of American eels than its natural host, and it may exacerbate problems in this already declining species by interacting with other sources of stress, such as climate change. (Martin Vermeere, and Stefan Rahmstorff www.pnas.org/cgi/doi/10.1073/pnas.1015619108)

The recent range expansions of native North American mammals, specifically coyotes (*Canis latrans*), into South Carolina raise questions about the role climate change has played or may play in this phenomenon. Obviously, ranges have expanded and contracted over time but, more recently, it has become clear that transport and release by humans have placed animals and plants in new areas, and these species have occupied available habitats. In many cases they then compete directly with native species, to their detriment. The principal of natural range expansion is difficult to detect and describe and naturalization is difficult to determine.

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143 South Carolina aquatic invasive species management plan. Prepared in coordination with the South Carolina Aquatic Invasive Species Task Force by the South Carolina Department of Natural Resources. September 2008. 94 pp.

144 Albins, M. and M. Hixon. 2008. Invasive Indo-Pacific lionfish *Pterois volitans* reduce recruitment of Atlantic coral-reef fishes. Mar Ecol. Prog. Ser. 367:233–238.

145 Murphy, S. and D. Griffin. 2005. Loggerhead turtle - *Caretta caretta.* 2006. http://www.dnr.sc.gov/cwcs/pdf/Loggerheadturtle.pdf. Last accessed Dec 2010.

146 Fries, L.T., D.J. Williams and S.K. Johnson. 1996. Occurrence of *Anguillicola crassus*, an exotic parasitic swim bladder nematode of eels, in the SE United States. Trans. Am Fish. Soc. 125:794-797.

Recently, the armadillo (*Dasypus novemcinctus*) expanded its range into South Carolina from points south and west, and the federally endangered wood stork (*Mycteria americana*), that historically nested in Florida, now nests in significant numbers in this state. The available literature does not describe climate change as a factor in this expansion. Habitat loss and alteration for nesting and foraging are most often described as the major factors for range expansion of the wood stork.

Of greater threat are species currently located in Florida and South Georgia that come from more temperate parts of the world but have been historically limited to ranges south of South Carolina by cold winters. Significant climate change could allow northward and eastward range expansion in these species that would be detrimental to native species. Plants, birds, reptiles (especially large constrictors), amphibians and a few mammals are now reproducing in areas south of South Carolina. Inventory and monitoring is essential to determine and describe any changes in range of these exotic species.

3.2.3.2 DNR Response and Recommendations

DNR should continue monitoring wildlife and fish populations and their habitats for evidence of new invasive and non-indigenous species. Through existing programs within DNR, South Carolina needs to consistently fund and expand control activities to eliminate or reduce concentrations of those species where possible. DNR and others should seek to strengthen State laws regulating importation and transportation of non-native species and to implement the action items delineated under the goals and objectives of the South Carolina Aquatic Invasive Species Management Plan.

DNR is a partner in the South Carolina Aquatic Invasive Species Task Force and, through the Aquatic Nuisance Species Program, collaborates with the South Carolina Aquatic Plant Management Council to annually develop a South Carolina Aquatic Plant Management Plan. DNR also is active on regional levels with the Gulf States and South Atlantic Panel and on state levels with the South Carolina Exotic Plant Pest Council. Similar strategies to address nuisance and exotic species, particularly on conservation lands should be expanded within the state. Support is needed to develop and implement a comprehensive, prioritized monitoring strategy for the early detection of non-indigenous species. DNR also should seek to partner and collaborate with others working in this area.

Support of taxonomic expertise is an important component of any successful invasive species monitoring program. The Southeastern Regional Taxonomic Center (SERTC), located in the MRRI, has developed a curated collection of marine and estuarine animals from the SAB and maintains a searchable library of regionally relevant peer-reviewed taxonomic literature. Through collaborations with other labs and museums, SERTC has collected and preserved representative specimens from numerous habitats throughout the southeastern United States, documenting northern range extensions along the Atlantic Coast. Continued funding for this program needs to be secured. The

Center played an important role in developing the management plan for South Carolina aquatic invasive species.[147]

Prevention may be the best adaptive strategy to minimize the impact of invasive species. Enforcement of existing statutes related to intentional importation of non-indigenous species, such as apple snails (family *Ampullariidae*), is essential. Enforcement mechanisms should be strengthened; however, a review of all statutes and regulations regarding importation of non-indigenous organisms is recommended, with the legislative goal of a consolidated, comprehensive state law to minimize intentional and accidental introduction. A rapid response plan to eradicate, contain or control invasive species also is an essential tool to curtail the spread of invasive species.

3.2.4 **Potential for Increased Incidence of Pathogens**

3.2.4.1 Increased Incidence of Pathogens

Climate warming has been linked with a general increase in pathogens, which may have negative effects on host populations.[148]

The oyster disease Dermo (*Perkinsus marinus*) has been determined to be ubiquitous in South Carolina oysters although infection intensities are relatively low.[149] Infection intensities have consistently been relatively low, perhaps because Palmetto State oysters are almost exclusively intertidal and exposed to high summer temperatures that may inhibit the disease.[150] Another oyster disease, MSX (*Haplosporidium nelson*) has been infrequently detected in South Carolina and it is not known how climate change may affect the prevalence of this pathogen.

An apparent outbreak of disease caused by the hemolymph-infecting dinoflagellate *Hematodinium* in the late 1990s in Georgia reportedly led to substantial mortalities in blue crabs and other crustaceans. It is believed that the outbreak was initiated by a prolonged drought that resulted in higher salinities in estuaries, thus favoring the growth of *Hematodinium*.[151] In many South Carolina estuaries, blue crabs can escape to lower salinity refuges, but in the northern part of the state these refuges may not be available. Knowledge of the dynamics of hosts and pathogens in the marine environment is limited, but where disease outbreaks occur, they often are associated with unusual

[147] South Carolina Department of Natural Resources. 2008. South Carolina aquatic invasive species management plan. http://www.dnr.sc.gov/invasiveweeds/aisfiles/SCAISplan.pdf. Last accessed Dec 2010.
[148] Harvell et al. 2002. Climate warming and disease risks in terrestrial and marine biota. Science 296: 2158-2162. Hereafter Harvell et al. 2002.
[149] Bobo, Y., D. Richardson, L. Coen and V. Burrell. 1997. A report on the protozoan pathogens *Perkinsus marinus* (Dermo) and *Haplosporidium nelson* (MSX) in South Carolina shellfish populations. SC DNR Mar. Res. Div. Tech. Rept. No. 86. 50 pp.
[150] Bushek, D. 1997. Chlorine tolerance of the eastern oyster pathogen, *Perkinsus marinus*: Standards for sterilization and quarantine. Grant # P/M-2A, SC Sea Grant Consortium Final Rept.
[151] *Hematodinium* Continues - No Let-Up in Sight. 2002. The Georgia Blue Crab Journal. http://crd.dnr.state.ga.us/assets/documents/BlueCrabNewsletterapr02.pdf. Last accessed Dec 2010.

climatic events.[152] The potential for outbreaks of new pathogens is high because of the expectation of greater variation in climate over the next few decades and invasion of species carrying non-native pathogens.

Large-scale disease mortality in wild penaeid shrimp has not been observed in South Carolina; however, disease and mortality in nonnative shrimps in aquaculture farms within the state has been documented. Cultured shrimp are vulnerable to a number of viruses with susceptibility varying among species, but thus far, no known mortality has occurred in the wild populations of South Carolina. Because pathogenic viruses are known to exist and shrimp are more vulnerable when exposed to multiple stresses, including high temperature and salinity, additional stresses caused by climate change may have a negative effect on wild populations.[153] [154] A pathogen that is known to affect wild shrimp is the black gill (brown gill) syndrome. This condition is caused by an apostome (protozoan) that attaches to shrimp gills and causes melanization, or a darkening of the chitinized exoskeleton. This disease typically is most common when coastal waters are warmest in August and September.[155] Although no directly related mortality has been documented, it is clear that shrimp stamina, ability to escape predators and probably resistance to disease are compromised by the condition. The lowest incidence of the disease since 1999 occurred in 2001 following a relatively cold winter. These apparent relationships to water temperature may suggest that warmer winters and summers associated with climate change may amplify the disease.

Changes in temperature regimes may result in an increase in wildlife and fish diseases that are adapted to warmer conditions. Warmer temperatures can increase the potential for invasion by new pathogens, or increase risk of more serious invasions by existing pathogens. Not only could such pathogens affect wildlife and fish, effects to native vegetation could alter habitats and make them unsuitable for native species. Sudden oak death and the hemlock wooly adelgid infestations are already changing the landscape of some of South Carolina forests, making them potentially more vulnerable to invasion.

3.2.4.2 DNR Response and Recommendations

A proactive program monitoring the health of aquatic animals is not feasible. The potential pathogen pool is large and resources and tools are limited. The most adaptive approach is vigilance for potential pathogens and collaboration with the Clemson Veterinary Diagnostic Center. Advances in molecular technologies have developed a broad range of diagnostic tools that allow scientists to assess thousands of known pathogens in a single assay. It is not known if similar tools for other species are available. Efforts to monitor interstate movement of potentially infected animals should

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[152] Harvell et al. 2002.

[153] Zein-Eldin, Z. and M. Renaud. 1986. Inshore environmental effects on brown shrimp, *Penaeus aztecus,* and white Shrimp, *P. setiferus,* populations in Coastal waters, particularly of Texas. Mar. Fish. Rev. 48(3):9-19.

[154] Zhan, W., Y. Wang, J. Fryer, K. Yu, H. Fukuda and Q. Meng. 1998. White spot syndrome virus infection of cultured shrimp in China, J. of Aquatic Animal Health 10:405-410.

[155] Whitaker, D., J. Powers, B. Gooch, N. West and A. Von Harten. 2009. Cooperative research in South Carolina – SC DNR Final Report to National Marine Fisheries Service NOAA, Grant Number NA04NMF4720306. p 45-49.

be continued and enhanced. Research should continue for the development of diagnostics, particularly field tests that can be used to identify pathogens.

Continued support is needed to monitor wildlife and fish populations and their habitats for evidence of new disease and parasite infestations. DNR should maintain and strengthen regional and national contacts and interactions related to disease and parasite challenges, including participation in the Southeastern Cooperative Wildlife Disease Study.

3.3 Impacts to Commercial and Recreational Fishing and Hunting and Other Public Uses of Natural Resources Resulting from a Changing Climate

3.3.1 Potential for Changes in Recreational and Commercial Opportunity

Wildlife and fish populations likely are to be altered as climate change occurs. Such changes may result in reduced commercial and recreational hunting and fishing opportunities of some species, although opportunities may increase with others. As populations are monitored, it may become necessary to alter seasons or bag limits on some species. It will be important to keep the public notified of changes as they occur in order to reduce the potential for conflict between human and natural resource needs and values.

3.3.2 DNR Response and Recommendations

Long-term monitoring of harvested species should be conducted in order to detect temporal and spatial changes in numbers and prevent unsustainable population declines. Research is needed to model and understand the relationship between climate change and population dynamics of important species. Outreach and education are required so that South Carolina residents, city and county officials and legislators understand changes in natural resources resulting from climate change. Strategies and policies are needed to establish compromises that balance needs of the resource with human needs and uses.

3.4 Natural Resources Education and Outreach Needed as a Result of a Changing Climate

3.4.1 Needs for Climate Change Impacts Education and Outreach

Climate change potentially will cause significant alterations to the nature and structure of habitats and species distributions in the southeastern United States including South Carolina. Coastal communities, in particular, will become increasingly vulnerable to a wide range of hazards including hurricanes, shoreline erosion, flooding and storm surge. The impact of these hazards is compounded by coastal development as coastal population increases and coastal ecosystems are degraded. A resilient community understands the potential impacts of these hazards and prepares itself to respond with timely and holistic management strategies. This gives communities the ability to recover after hazard events and adapt to future conditions.

3.4.2 DNR Response and Recommendations

A critical element of the DNR response to climate change is to increase public awareness of the potential adverse, and positive, effects resulting from these changes. Agency efforts at outreach and education are threefold:

1. DNR should strengthen and increase partnerships with other agencies and organizations involved in climate change research and policy and planning. For example, the Southeast Natural Resource Leadership Group (SENRL), an interagency collaboration established to improve communication on natural resource issues, has recognized the need for natural resource agencies to proactively guide policy, management and socioeconomic decision making regarding climate change.[156] The DNR should seek opportunities to participate in national and local networks such as the SENRL and the recently established Southeastern Climate Science Center. National and local networks are a rich source of information, ideas, research and funding opportunities. Participation in such efforts can greatly increase the efficiency and effectiveness of a state climate change response plan.
2. DNR must assist local communities in planning for change and providing coastal resiliency to reduce overall vulnerability of economic and ecological systems to climate variations. The agency's education programs can help inform decision making in the state regarding climate change by strengthening regional and local partnerships for improved community response. Communities will need assistance planning for their response to potential hazards by considering institutional capacity, land development patterns and natural resource conservation. DNR alone cannot respond to the needs of these communities; however, DNR regularly works with partners that can provide access to information and tools designed to help communities identify critical linkages and understand how decisions impact their community and the environment. By strengthening regional and local partnerships, DNR can help respond to the needs of communities by linking them with the information they require.
3. DNR will play an important role in communicating information on climate change to citizens of South Carolina. Through partnerships with educators and policy makers, DNR research and management staff can work with these groups to translate scientific information into action. The agency will use the World Wide Web to publish reports, news articles and other information involving climate change as well as to provide a mechanism for public comment and input into the process. By involving the public in the research process, DNR will build buy-in from the community and capacity at the local level to respond adaptively to future conditions. The importance of resilient communities will increase as the impacts of climate change are felt. In addition, substantial

[156] Southeast Natural Resource Leadership Group. 2008. Meeting notes. 14 pp.

efforts should be made by agency staff to publish their research data and analysis in peer-reviewed scientific journals.

Climate change is a global concern with potentially significant impacts to South Carolina. To understand and assess the impacts to the human and natural resource populations of this state will involve the cooperative efforts of many agencies, scientists and planners as well as the local community. Education of the state's citizens on the negative and positive impacts of climate change is an essential component of this process. Each of these outreach initiatives is critical to improving the state's capabilities to respond and adapt to climate change. Through regional, state and national partnerships, DNR can help communities protect themselves and the important natural resources surrounding them.

3.5 Technologies Needed to Mitigate and Protect Natural Resources as a Result of a Changing Climate

3.5.1 Technologies Needed to Monitor Physical and Biological Change

Understanding and monitoring climate change impacts on the state's natural resources will require the enhancement of the agency's technology infrastructure, database and analysis and modeling capabilities. Various DNR programs have collected natural resource data for the state, and these historic and recent data are maintained in disparate database systems. For example, the South Carolina Climate Office records hourly and daily temperature, precipitation, storm event and other meteorological data from numerous weather stations throughout the state. These data are stored in Oracle and are used by staff in regional drought analysis and monitoring studies. Similarly, the South Carolina Geological Survey and the USGS established cooperative programs to record surface and ground water and lithologic data from various river/stream gauges and well monitoring stations. These data primarily are maintained in Oracle with some tables residing in Microsoft Access. WFFD maintains numerous fisheries, wildlife, botanical and other habitat-related databases in a variety of mainframe, server and PC-based database management systems.

MRD has a variety of long-term data sets containing both physical and biological data. For example, MRRI maintains several long-term fishery and water-quality databases that are relevant to evaluating the effects of climate change on those resources. These include: the MARMAP fishery independent monitoring program of offshore (deepwater) reef fish that extends back 20+ years and the SEAMAP fishery independent monitoring program of nearshore non-reef finfish and crustacean species that also extends back 20+ years. Both of these programs collect data from Cape Hatteras to Cape Canaveral that includes basic water quality measures and both use standardized sampling programs that facilitate long-term trends analysis. MRRI also maintains a 10-year database of juvenile loggerhead sea turtle distribution and density that extends from about Winyah Bay south to and including the northern portion of Florida.

To facilitate inshore monitoring, the MRRI conducted a standardized trammel netting program to assess the composition and abundance of the state's recreational finfish species for 20+ years, and another standardized sampling program to assess the relative abundance and distribution of shrimp and blue crabs that is also 20+ years in duration. The MRRI also participates in several programs to determine and assess environmental measures affecting coastal resources. In cooperation with DHEC, the MRRI has conducted an annual statewide assessment of water quality, sediment quality and biological resources for bottom invertebrate fauna, fish and crustaceans since 1999. The ACE Basin NERR program also has nearly continuous water quality and weather data extending back to 1995 and this program is expected to continue to be maintained in the future.

Mining these various data sets for long-term trends is a critical need, but the data are stored in a variety of formats and in many cases are not in advanced information management systems. Therefore, it is strategically important to develop a comprehensive spatial and tabular database of existing natural resources data and integrate various analytical, statistical and modeling tools to forecast trends and project changes in the distribution of these resources in response to climate change.

DNR also has extensive natural resources spatial data in the agency's geographic information system. These data include statewide soils, wetlands and land use, hydrography, known threatened and endangered species locations, road centerlines, administrative boundaries, contours, digital elevation models, agency owned and/or managed lands and boat ramps, surface and subsurface geology, multi-temporal digital orthophoto quarter quadrangles and Landsat Thematic Mapper satellite imagery. Statewide land cover data was classified from Landsat TM data for the 1985/86, 1992/93, 1997/98, 2002/03 and 2008/09 time periods. These data can be used to provide baseline trends in habitat change and to project potential future impacts from climate change and sea-level rise. Similarly, MRD has developed new oyster maps that provide detailed base imagery and shape files of intertidal shellfish resources. These imagery products also could be used to evaluate changes in wetland vegetation extent and distribution over time which has tremendous potential value in evaluating loss of wetlands and shellfish due to sea-level rise. More recently, the agency initiated a statewide program to develop high resolution elevation data using Light Detection and Ranging (LiDAR) technologies. These data provide digital elevation models with a vertical accuracy of 15.0 to 18.5 cm in open terrain which is essential for sea-level rise and wetland change modeling.

3.5.2.1 DNR Response and Recommendations

In order to meet the agency's long-term needs for responding to climate change impacts in South Carolina, numerous additional strategies and technologies will be required to include:

1. DNR needs to implement a resource inventory and monitoring program to track trends in resource abundance and distributions at the species and landscape

levels as determined to be viable and appropriate to the agency mission. This inventory will require input from all sections and groups, and should expand upon existing data collection and monitoring programs as discussed in Section 3.5.1. Further, it should include the use of various satellite image processing data and tools to systematically assess changes to the vegetative structure and man-made landscape features of the state. Access to accurate, long-term monitoring databases is critical for developing strategies to respond to climate change impacts; therefore, implementation of these comprehensive monitoring programs should be considered a priority.

2. The agency must expand its existing technology infrastructure to support the climate change studies. This includes the implementation of various direct and remotely-sensed measurement platforms to provide *in situ* documentation of sea-level rise, temperature and precipitation, stream flow and other critical data and the integration of all data collected through agency resource inventories in a comprehensive Oracle database. Coupled with various data mining and warehousing technologies, this would enable examination of data for trends and patterns useful for understanding climate change impacts. Further, as these long-term data and information are recorded and analyzed, additional network bandwidth, data storage and computational processing capabilities will be required to support the volume and complexity of scientific, graphic, GIS, imagery and video applications. Additionally, partnerships should be established with other southeastern states and academic institutions to develop a standardized data schema and information delivery platform that will facilitate sharing/exchange of regional data, analysis results and reports.
3. DNR also must develop appropriate data access, scientific analysis (statistical, biometric, image processing, spatial modeling and forecasting, etc.) and resource management decision-support tools to assess the impacts of climate change and develop appropriate management strategies. These tools must include business intelligence and data mining technologies to discover patterns inherent in the data and extensive use of the World Wide Web to disseminate relevant information to the public regarding climate change and its impacts to the state's natural resources. Where available, the agency should implement commercial-off-the-shelf (COTS) solutions that can be augmented with software and applications developed by agency programming staff that address issues specific to natural resources management in South Carolina. For example, the Sea Level Affecting Marshes Model (SLAMM) developed by the United States Fish and Wildlife Service can be adapted from its general visualization modeling application to incorporate high resolution LiDAR elevation and soils data to model potential impacts of sea-level rise on salt and brackish marshes along the coast. Other software tools appropriate to the needs of the DNR are available from various federal and state governments including numerous sea-level rise and biodiversity impact assessment technologies developed by the NOAA Coastal Services Center. These assessment tools should be evaluated for application to the needs of the DNR for determining climate change impacts in the state.

4. Finally, DNR must develop the expertise required to meet the challenges of understanding and addressing the vast array of environmental impacts and natural resource management issues associated with climate change. Staff training in various analytical, modeling and geographic information systems software and associated technologies is essential. Similarly, sponsorship and participation in various regional programmatic workshops and technical committees are critical for developing and maintaining strategic climate change response initiatives.

The creation of long-term monitoring programs, implementation of new technologies and establishment of regional partnerships are essential components of the DNR's response to climate change in South Carolina. The efforts required to accomplish these key objectives may be facilitated by outside funding sources, as many grant opportunities now support or require the development of digital data and implementation of innovative technologies. Additionally, cooperative partnerships facilitate information sharing, which increases the efficiency and effectiveness of programs and opens opportunities for additional funding sources.

4.0 NATURAL RESOURCES LAW ENFORCEMENT DURING AN ERA OF CLIMATE CHANGE

The Law Enforcement Division (LED) is responsible for enforcement of state and federal laws governing hunting, recreational and commercial fishing, recreational boating and other natural resources conservation concerns; promoting safety and developing public support through education and outreach. Additionally, the LED is tasked with assisting other state and federal agencies with varying security missions dealing with non-natural resource issues and events.

Climate change can no longer be considered solely an environmental issue. The physical effects of climate change will have both natural resources impacts as well as socio-economic impacts including the loss of infrastructure, resource scarcity and displacement of life and property. In turn, these impacts could produce security consequences to include civil unrest and instability, presenting new challenges to law enforcement agencies and governments attempting to maintain order and rule of law.[157]

[157] Abbot, C. 2008. An uncertain future: Law enforcement, national security and climate change. Oxford Research Group. http://www.bvsde.paho.org/bvsacd/cd68/uncertain.pdf. Last accessed May 2010.

Table 4.1 Anticipated public safety effects related to climate change in South Carolina.[158]

Weather Event	Public Safety Issue	Population Affected	Public Safety Burden
Heat waves	Heat stress	Elderly, socially isolated, poor, those already health impacted	Low to moderate
Increase in mean temperature	Heat stress, increased disease	Outdoor workers, elderly, poor, outdoor recreationalists	Low to moderate
Extreme weather events	Injuries, drowning	Coastal and Lowcountry dwellers, the poor, outdoor recreationalists	Moderate
Severe winter weather	Injuries, hypothermia, drowning,	Elderly, poor, outdoor recreationalists	Moderate
Sea-level rise	Injuries, drowning, water and soil salinization, ecosystem and economic disruption	Coastal and Lowcountry dwellers, outdoor recreationalists	Moderate
Drought, ecosystem migration	Water shortage, low rivers and lakes, boating accidents, food shortage	Elderly, children, poor, outdoor recreationalists, multiple populations	Moderate to high
Floods	Excess water, dam failures, crop losses, livestock loses, loss of pollution containment, loss of human life	Multiple populations	Moderate to high
Severe climate change	Heat stress, drowning, water shortage, limited food availability, human conflict	Multiple populations	High

4.1 Marine Law Enforcement

4.1.1 Marine Law Enforcement Issues

Marine law enforcement primarily is responsible for enforcing recreational and commercial fishing laws, promoting boating safety and investigating boating incidents in the marine environment. DNR officers regularly conduct search and rescue missions in outlying areas and assist other law enforcement agencies in investigations. The LED has officers trained in underwater diving to assist in law enforcement, search and rescue and evidence recovery missions. The Division also utilizes aircraft for law enforcement patrol, search and rescue and other department missions. The LED is called upon to provide homeland security missions related to waterborne activities including, but not limited to, commercial ship escorts and port security.

[158] Balbus, J.M. and M. L. Wilson. 2000. Human health and global climate change: A review of potential impacts in the United States. Washington, DC: Pew Center on Global Climate Change. http://www.pewclimate.org/docUploads/human_health.pdforg/global-warming-in-depth/all_reports/human_health. Last accessed Oct 2010.

As certain species adapt to climate change some will shift ranges creating additional opportunity for commercial and recreational fishing in the marine environment. These shifts in range and availability will be magnified by human population growth and additional resource pressure. Sensitive habitats may be threatened, requiring additional monitoring and patrols to stem illegal activities and overharvests. The need for conservation enforcement will become apparent as this process unfolds. In view of the possible decline of food resources there will be ever increasing pressure to push the boundaries of conservation to meet economic and food supply needs. In the case of a catastrophic event these issues will manifest themselves at the most basic level, where everyday citizens stressed by poor economic and environmental conditions will begin subsistence fishing by harvesting whatever is available to meet daily needs. Law enforcement will be the only line of defense between these individuals and overharvesting of species. Additionally, alternative energy development will usher in a new set of law enforcement issues in order to monitor and protect marine energy development infrastructure.

In addition to resource protection, the LED may be faced with an increasing recreational boating population along our coastline as a result of higher temperatures and possible longer boating seasons. As a result, enforcement of recreational boating may not be readily available if the current trend of reducing officer positions continues.

4.1.2 DNR Response and Recommendations

Funding for an adequate, if not expanding, natural resource law enforcement presence in the marine environment will be necessary. Partnerships with federal and other state and local law enforcement agencies will be required.

4.2 Inland Law Enforcement

4.2.1 Inland Law Enforcement Issues

As in the marine environment, the LED is responsible for enforcing recreational and commercial fishing laws, promoting boating safety and conducting boating incident investigations on inland surface water bodies. DNR officers regularly conduct search and rescue missions in the air and on or under the surface of rivers, lakes and ponds assisting other law enforcement agencies in investigations. The LED performs homeland security missions related to waterborne activities near hydroelectric dams, nuclear facilities and other energy production facilities. Additionally, the LED is tasked with protecting land-based game and non-game species as well as investigation of hunting related incidents.

Climate change may shift ranges of popular species pursued through recreational hunting and fishing, bringing pressures on sensitive species and habitats; such as the threat that warming and drought imposes on aquatic species, for example, trout and anadromous fish. These threats will be magnified by human population growth and additional resource pressures. Sensitive habitats may be threatened, requiring additional monitoring and patrols to stem illegal activities and over harvests.

As within the marine environment, the need for conservation enforcement will be apparent as this process unfolds. With ever increasing pressure to push the boundaries of conservation to meet economic and food supply needs, every day citizens stressed by poor economic and environmental conditions will begin subsistence fishing and hunting by harvesting whatever is available to meet daily needs. Law enforcement will be the only line of defense between these individuals and the overharvesting of species.

Additionally, as higher temperatures and longer seasons become stabilized, the LED will be faced with an ever increasing recreational boating population. As a result, enforcement of recreational boating activity may not be readily available if the current trend of reducing officer positions continues.

4.2.2 DNR Response and Recommendations

Funding for an adequate, if not expanding, natural resource law enforcement presence in inland areas will be necessary. Partnerships with federal and other state and local law enforcement agencies will be required.

4.3 Public Safety

4.3.1 Public Safety Issues

The potential public safety effects of climate change have been extensively reviewed.[159] Many are health and safety related. Principal public safety concerns include those related to severe weather events and heat waves. Indirect concerns, for which data to support projections are less available and uncertainties are greater, include human competition for available resources, population dislocation and civil conflict/unrest. In addition, changes in the patterns of pests, parasites, and pathogens may affect wildlife, agriculture, forests and coastal habitats and can alter ecosystem composition and functions. Climate change may disrupt these life-support systems and carry implications for public safety.

Very few public safety laws and regulations currently have a direct bearing on climate change. However, public safety officials can provide science-based input regarding laws and regulations affecting the environment, natural resources and alternative energy arenas. As policies are codified, there may be roles for state and local public health agencies in enforcing such policies including water quantity and quality regulations as an example.

[159] Frumkin, H., J. Hess, G. Luber, J.Malilay and M. McGeehin. 2008. Climate Change: The Public Health Response. Am. J. Public Health. 98:435-445. http://www.bvsde.paho.org/bvsacd/cd68/HFrumkin2.pdf. Last accessed Sept 2010.

4.3.2 DNR Response and Recommendations

There is widespread scientific consensus that climate is changing and it also is being reported in the public safety arena.[160] Mounting evidence suggests there will be future impacts on public safety, including illnesses and injuries associated with heat stress and exposure. Other future impacts will include incidents related to drought caused by shallow surface waters, severe weather events and floods. Finally there are likely to be public safety impacts to surface- and ground-water supplies. Indirect effects may include the consequences of mass migration and human conflicts over available resources. Addressing these occurrences to public safety will be a pressing challenge for natural resource and other law enforcement agencies. Although the scope and complexity of the challenges may be unprecedented, the conceptual framework for responding will draw on long-standing public safety policy. An effective public safety response to climate change is essential to preventing injuries and illnesses, enhancing preparedness, and reducing risk. Science-based decision-making will help manage uncertainty and optimize environmental outcomes.[161]

As climate change evolves, the role of natural resources law enforcement will be required to adapt. There will be a need for additional emphasis on protecting dwindling resources requiring the need for enhanced conservation enforcement. Also, public ambivalence to natural resources will become apparent as the need for gathering food becomes a priority at an unknown cost to all fish and wildlife resources. In either case, the role of the LED will evolve with a greater focus on resource enforcement or a greater focus on more traditional roles of law enforcement where public safety is the priority. In either instance, the LED, in the face of an ever-changing world, will continue to play an increasing role in traditional public safety.

[160] IPCC. 2007.
[161] IPCC. 2007.

5.0 SUMMARY AND PRIORITY LIST OF CLIMATE CHANGE ISSUES

5.1 Overarching Issues and DNR Recommendations

This first report from DNR sets the foundation for actions needed to address climate change impacts to natural resources in South Carolina. The report identifies the overriding natural resource issues and provides recommended actions to keep South Carolina at the forefront of conserving natural resources during an era of changing climate. These overarching issues include the potential for:

1. Detrimental change in habitat,
2. Detrimental change in abundance and distribution of species,
3. Detrimental change to biodiversity and ecosystem services,
4. Detrimental change on the traditional uses of natural resources including hunting, fishing, other compatible public uses, forestry and agriculture,
5. Detrimental change in the abundance and quality of water, and
6. Detrimental change in sea level.

Specific tasks identified by DNR in order to move forward in an era of climate change while protecting natural resources include:

1. Spatial mapping,
2. Monitoring and establishing baselines on
    a. Living resources,
    b. Non-living resources, and
    c. Climate trends.
3. Habitat acquisition,
4. Adaptation strategies on DNR-titled properties,
5. Integration and analysis of data,
6. Outreach and education,
7. Developing additional partnerships and collaborating with others, and
8. DNR leading by example.

5.2 DNR Leading by Example

DNR is making climate change an integral part of the agency's ongoing mission. A Climate Change Impacts Technical Working Group (CCI-TWG) was formed with representatives from each division. The CCI-TWG reports directly to the Executive Office and was charged with the completion of this comprehensive report addressing the potential impacts of a changing climate to natural resources in South Carolina. The CCI-TWG developed recommendations that will lead to integrating climate change into the DNR organizational culture, its structure and all aspects of its work. These key steps include:

1. Develop an approach that will incorporate climate change into DNR strategic and operational plans and existing structure that can be used as a vehicle for internal and external communication,
2. Ensure that all levels of agency staff are aware of, and appropriate staff engaged in, climate-change initiatives,
3. Update and align DNR actions with regional and national climate-change initiatives as appropriate,
4. Work with stakeholders and partners on fish and wildlife adaptation and mitigation,
5. Prepare an internal and external outreach strategy to communicate climate change issues, and
6. Develop clear and measurable indicators to track the results of DNR climate change efforts.

To accomplish its mission, DNR recommends the following core climate change foci of effort:

1. Policies and Opportunities – focus on grants, legislation, partnerships and strategic planning,
2. Research and Monitoring – focus on standardized monitoring protocols and state-specific data (including gaps) and predictive modeling,
3. Communication and Outreach – focus on the DNR messages and a climate change communication plan,
4. Adaptation – focus on the activities related to unavoidable climate-change impacts on fish and wildlife, and
5. Operations – focus on positioning DNR as a leader by reducing the agency's carbon footprint, improving its energy efficiency and decreasing operational costs by accomplishing the following:
    a. Achieve increased fuel economy through fleet reduction, use of more efficient vehicles as well as implementing efficient wildlife and fisheries management and law enforcement where combustion engines are required,
    b. Achieve increased energy efficiency through obtaining energy audits for agency buildings and adoption of practicable energy audit recommendations,
    c. Implement practicable water efficiency measures for agency buildings, and
    d. Implement paperless internal communications and document management.

DNR is taking a lead role among South Carolina state agencies to advance the scientific understanding of the vulnerability of South Carolina's vital natural resources during an era of changing climate. These actions and advocacy for sound planning should enable the agency, its partners, constituents and all Palmetto State citizens to avoid or minimize the anticipated impacts. The agency will strive to lead by example, work to create ecosystem resiliency and partner with others to preserve and protect South Carolina’s natural resources.