Southeast Regional Climate Hub Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies

Photo credit: USDA Forest Service, Southern Research Station

Authors: Steven McNulty, Southeast Hub Director; Sarah Wiener, Southeast Hub Coordinator; Emrys Treasure, Southeast Hub; Jennifer Moore Myers, Southeast Hub; Hamid Farahani, Southeast Hub, Lisa Fouladbash, Southeast Hub, David Marshall, Southeast Hub; Rachel F. Steele, National Climate Hubs Coordinator, Washington, DC

Southeast Hub
920 Main Campus Drive, Suite 300
Raleigh, NC 27606

Contributors: Our thanks to Darren Hickman, Natural Resources Conservation Service; Jeff Porter, Natural Resources Conservation Service; Sharon Hestvik, Risk Management Agency; Rick Dantzler, Farm Services Agency; Wendy Hall and Marlene Cole, Animal Plant Health Inspection Service; Juliette Bochicchio, Rural Development; David Meriwether, and Kier Klepzig, USDA Forest Service.

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Letter from Steven McNulty, Southeast Regional Climate Hub Director

Climate-related variability in rainfall, temperature, and extreme weather (e.g., drought, flood, unseasonal frost) pose significant challenges to working land (i.e., range, forest, and agricultural) managers across the southeastern United States. These and other unpredictable stressors are exacerbated by increasing human pressures to natural landscapes, including urbanization, population growth, and land use change. The USDA established the Southeast Regional Climate Hub (SERCH) to better understand and address this combination of environmental and human pressures across the Southeast through a combination of research, outreach, and extension to land managers. The mission of SERCH is "to increase working land resilience to climate related stress across the southeastern U.S., serving as the leading source of adaptation tools and information in support of State and Federal extension, and private consultants who directly work with land managers."

Southeast Climate Hub Director: Dr. Steven McNulty, Photo Credit: Gene Pinder

The SERCH footprint covers eleven States: Alabama, Arkansas, Georgia, Florida, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia. These States have a rich agricultural and forestry history dating back before the origins of the United States. The importance of southeastern forestry and agriculture (e.g., lumber, cotton, peanuts, tobacco) has been integral to the development of the U.S. economy and expanded into the 20th century (e.g., citrus, poultry, swine). Even as the southeastern agricultural, forestry, and rangeland sectors continue to expand, they face pressures from population growth and land fragmentation, which are becoming ever-increasing challenges. In combination with these human pressures, climate change is likely to exacerbate adverse effects on these industries.

Although the southeastern United States has not experienced as significant warming as other regions of the country over the past century, temperatures are expected to increase in coming years, with detrimental effects on crop production. Concomitant effects of climate change on rainfall distribution and water availability place additional pressure on crop production, which is likely to be intensified by the increasing rate of urbanization and population growth pressures on arable lands. The southeastern United States also outranks the rest of the country in billion-dollar disaster events related to climate change (Figure 3). For example, the 2007 drought resulted in a $1.3 billion field crop loss across the region. This estimate does not include the loss of livestock due to insufficient hay production, which exceeded 50 percent in some States, including Alabama. The livestock industry is also vulnerable to climate variability through effects on crop production for feedstock, as expected reductions in corn yield will result in higher feed prices. The forest industry is being affected by climate variability including reduced forest growth, increased potential for insect outbreaks such as the southern pine beetle, greater wildfire risk, and more intense rain events leading to greater soil erosion and stream sedimentation. Producers are struggling to adapt to increasing climate variability, which affects day-to-day management decisions, productivity, and profit. SERCH will help land managers understand and address unexpected changes in weather and stress interactions.

The sizeable task of both developing and conveying adaptation tools and information to the hundreds of thousands of working land owners across the southeastern United States is made possible by the longstanding relationships with State extension agents, Federal staff (e.g., NRCS, ARS, Forest Service), and private consultants. For more than a century, farmers, ranchers, and foresters have turned to these individuals for trusted information and advice specific to their individual management needs. Though Federal staff, extension agents, and private consultants face the complexities of changing demographics, land use change, urbanization, and climate variability in maintaining working lands, they are also the key to ensuring future sustainability of southeastern lands through their longstanding experience and knowledge of working lands and relationships with land managers. SERCH will therefore focus on "training the trainer," or sharing adaptation tools and information with land management consultants who will in turn distribute these products to landowners and managers. Additionally, SERCH will conduct webinars and lectures and develop bulletins and news briefings to bring timely information directly to the land manager across both geographic and cultural boundaries. SERCH plans to conduct extensive survey research. SERCH will also serve as a conduit for conveying the needs of land managers back to Washington program offices by working with land managers to assess their actual needs. The role of SERCH is to work with extension services, NRCS, and private consultants, because these individuals have direct knowledge of the gaps in knowledge or knowledge transfer to land managers. SERCH uses the connections with land manager consultants to learn and share this information with the policymakers and Federal research and grant funding agencies to more efficiently and successfully use funds for the sustainability of southeastern working lands.

Through this combination of direct and indirect knowledge transfer to land managers, SERCH will significantly strengthen our capacity to increase the resiliency of working lands and to better adapt to 21st century stress. This document outlines the type of risks that southeastern agriculture and forestry currently face and, in some cases, options to address these risks. Finally, this document looks forward to providing direction on the priority needs of Southeast working land managers and an outline of how SERCH will address those needs.

Steven McNulty
SERCH Director

1. Introduction

From the mountainous areas of the Ozarks and southern Appalachians to the coastal plains of the Carolinas, Georgia, and Florida, and from the temperate climate of Kentucky and Tennessee to the subtropical climate of southern Florida, the wide range of environments across the southeastern United States provide the basis for the region's long and rich cultural and economic history.

1.1 Description of the Region and Key Resources

Forestry and agriculture play important roles across the region, covering much of the landscape (Figure 1), which is divided into nine ecoprovinces (Figure 2). Much of the history of the region has been centered on agriculture. Cotton, peanuts, and citrus have long been considered southeastern staple commodities, but the range of agricultural products has expanded in recent decades to include new crops such as rice. Concerns over endangered species and sustainability in the Pacific Northwest have led to a greater dependency on Southeast timber and pulp wood supplies, even as the Southeast became the most rapidly growing region in the United States. A concern over the decreasing supply of groundwater in the West is causing more discussion on the need to convert more southeastern agricultural lands into irrigated corn and wheat.

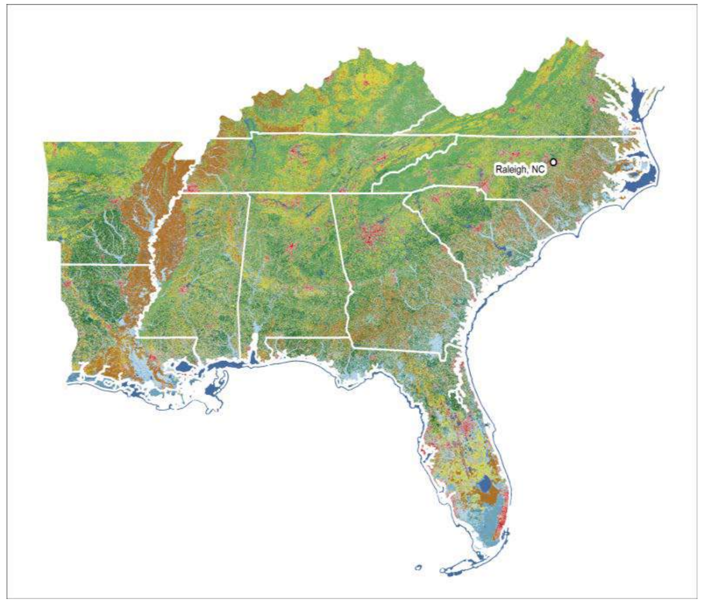

Figure 1: Southeast Climate Hub. Brown, cultivated; tan, grassland; green, forest; red, developed; blue, water.

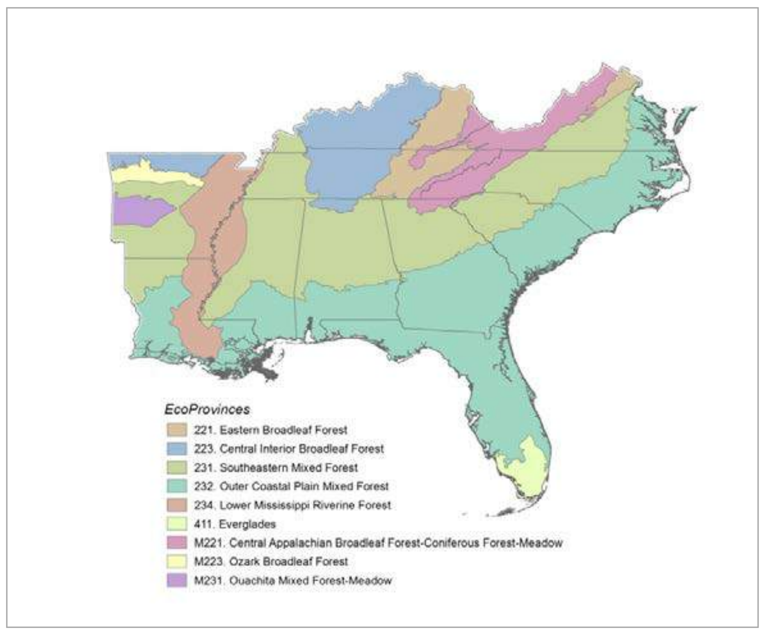

Figure 2: Ecoprovinces of the Southeast Climate Hub

1.2 Demographics and Land Uses

The Southeast is one of the most demographically diverse regions in the United States. Although much of the region is classified as rural, urbanized areas are expanding. Aside from metropolitan centers such as Atlanta, Richmond, and Miami, other metropolitan areas are growing together (e.g., North Carolina's Research Triangle). As urbanization continues the value of land around these areas increases to the point at which forestry and agricultural land use cannot compete with land conversion for urban or suburban use.

In addition to land fragmentation associated with conversion of agricultural and forest lands to non-food or fiber production, changing demographics are affecting land use management, particularly forestry. Although the forest may still be intact, its maintenance may no longer be possible due to difficulties in establishing a common management goal across multiple ownerships.

1.3 General Climate Conditions, Extremes, and Past Effects

The climate conditions of the southeastern United States vary from warm to hot, and from dry to wet. Although anecdotal records date back to the colonial period, region-wide weather records are nonexistent prior to the Civil War and scant until the 1880s. Therefore, the chronology of past region-wide climate effects is relatively short. Additionally, before the 1950s, the road network across the region was sparse and often poorly maintained. The lack of infrastructure significantly magnified extreme weather and climate events. For example, before the 1950s, wildfire forest loss routinely exceeded 7 million acres each year. However, since the road system in the Southeast has expanded and been upgraded, wildfire-caused forest loss rarely exceeds 0.5 million acres per year. The reduction in wildfire loss is not so much a function of climate, but an ability of land managers to access and extinguish the fire.

Conversely, hurricane-related damage has increased markedly during the past 20 years. The number and intensity of hurricanes has not changed, but the amount of coastal construction, and therefore susceptibility to hurricane-force winds and coastal flooding, has increased by several orders of magnitude.

Although the Southeast warmed slightly during the 20th century, some portions of the region (i.e., Alabama and Mississippi) have been cooling. Air temperature is just one component of climate change. Another is precipitation timing and intensity. Across the region, the number of intense (i.e., >2 inches of precipitation within a 24-hour period) precipitation events increased by 22 percent during the 20th century. Higher intensity rainfall leads to greater flooding and soil erosion, which in turn leads to lower agricultural productivity. Much of the sediment generated from soil erosion eventually drains into the Mississippi River and then the Gulf of Mexico. Soil organic matter and fertilizer in the sediment is a major cause of the annual hypoxia zone in the Gulf that is devoid of oxygen, aquatic life, and fishery opportunities. An assessment of dollar-related weather and climate events indicates that the Southeast leads the United States in billion-dollar disasters (Figure 3).

Did you know…?

- The Southeast is the single largest producer of United States timber
- Timber is the largest valued crop in the southeastern United States
- Hogs and poultry are major commodities, and almost all the nation's peanuts, tobacco, and sweet potatoes come from the Southeast (National Agricultural Statistics Service, 2014a)

Photo Credit: NRCS

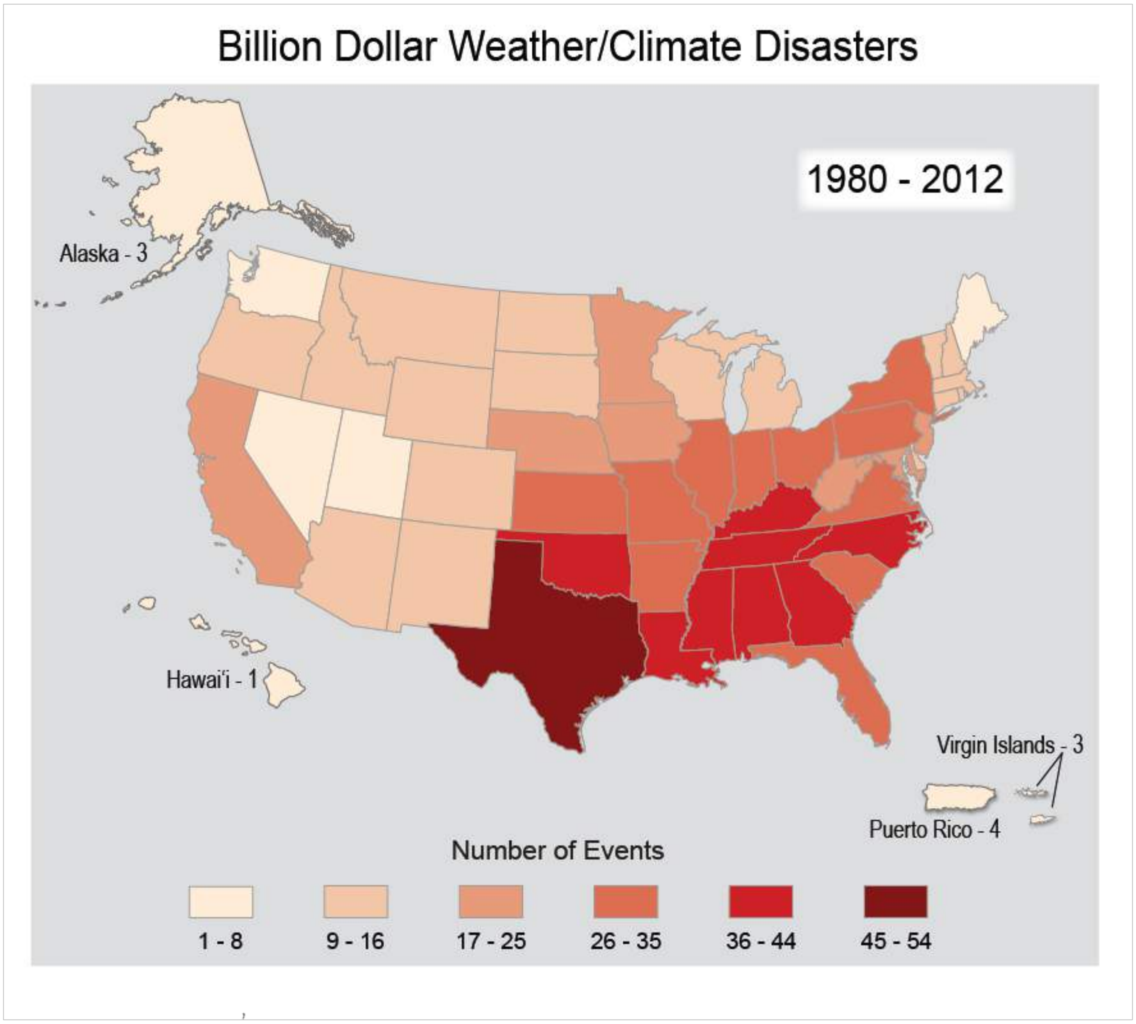

Figure 3: Number of times each State has been affected by weather and climate events over the past 30 years resulting in more than $1 billion in damages. The primary disaster type for coastal states is hurricanes, whereas interior and northern States in the Southeast also experience sizeable numbers of tornadoes and winter storms. For a list of events and the affected states, see: http://www.ncdc.noaa.gov/billions/events.94. Figure and caption source: (Carter et al., 2014).

1.4 Summary of National Climate Assessment and Regional Climate Scenarios

Sea level rise, hurricanes, extreme heat, and decreased water availability are the major stressors outlined by the National Climate Assessment for the Southeast (Carter et al., 2014). The number of days with daytime temperatures above 95°F is expected to increase across the region, with extreme increases in the southern part of the region by as much as 50 days per year, and summer temperatures increasing substantially (Figure 4). Additionally, the number of nights below freezing is expected to decrease, with extreme decreases in the northern part of the region by up to 20 days per year (Figure 5). Coastal states are vulnerable to sea level rise, with the coasts of Louisiana and Mississippi demonstrating the highest vulnerabilities. Summer precipitation is expected to fluctuate, with both increases and decreases in precipitation varying across the region (Figure 6).

Climate projections and impact models will help land managers anticipate and prepare for potential future change. However, climate projections are complex, and making creditable interpretations of their results is a challenge in an applied context. SERCH will work with partners to provide useful and credible climate projection summaries that are based on the best available evolving science and models. For example, the State Climate Office of North Carolina is developing climate projection visualization products under the NIFA-funded PINEMAP project to provide climate projections and other impact model results through an online decision support system. Figure 4, Figure 5, and Figure 6[1] present preliminary climate projection results for the region based on Multivariate Adaptive Constructed Analogs (MACA)-generated climate projections used in the decision support system. These figures are provided to illustrate cutting-edge data presentation techniques that respect climate data best practices.

- Figure 4: Summer average temperatures are projected to increase across the region, with relatively little difference between emissions scenarios by mid-century (2040–2059).
- Figure 5: The number of days per year with minimum temperatures <32°F is projected to decrease, especially across the northern extent of the region.
- Figure 6: Summer average precipitation projections range from drier to wetter, with decreasing model agreement into the future. By the end of the century (2080–2099), the mean projected change shows drying along the Gulf coast and in Florida.

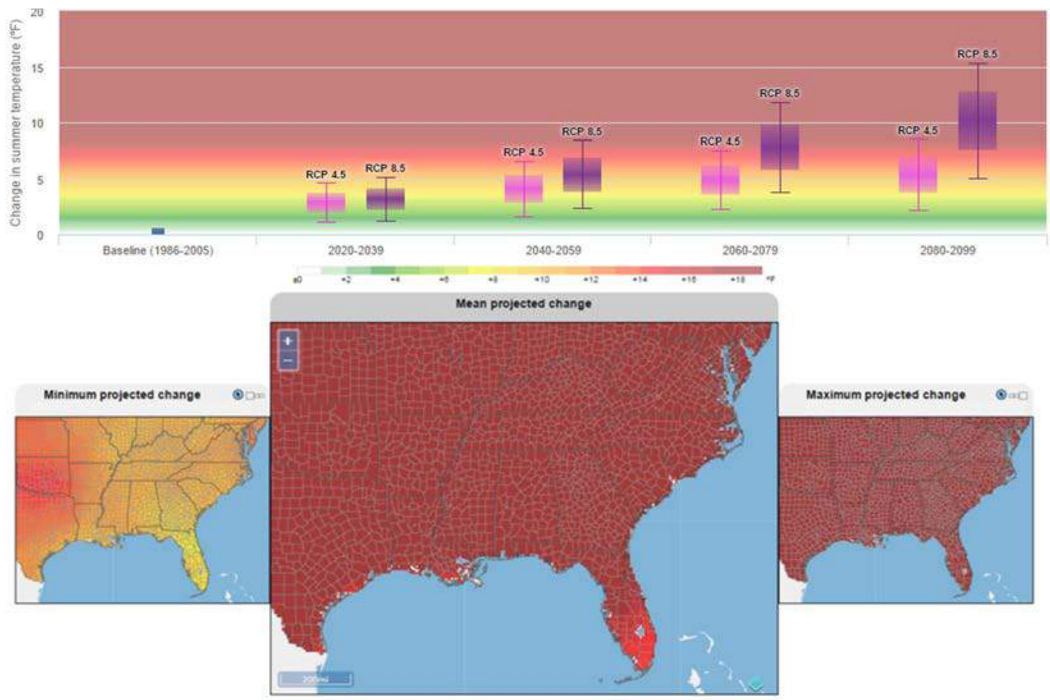

Figure 4: Projected change in summer average temperatures. Top: a box-and-whisker plot shows the change over time by emissions scenario. Bottom: spatial distribution of change for 2080–2099 for the intense warming scenario (RCP 8.5) with consideration of model spread (minimum, mean, maximum). Figures are preliminary and provided by the State Climate Office of North Carolina.

[1] Climate forcings in the MACAv2-LIVNEH were drawn from a statistical downscaling of global climate model (GCM) data from the Coupled Model Intercomparison Project 5 (CMIP5, (Taylor et al., 2012)) utilizing a modification of the Multivariate Adaptive Constructed Analogs (MACA, (Abatzoglou & Brown, 2012)) method with the Livneh (2013) observational dataset as training data.

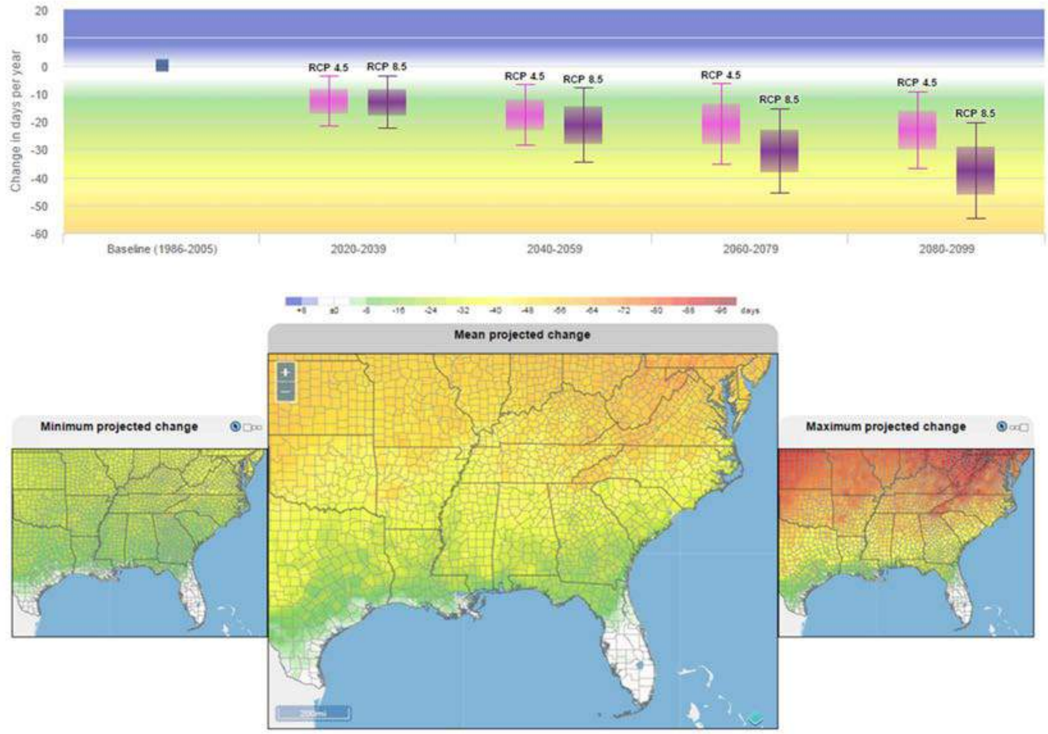

Figure 5: Projected change in the number of days per year with minimum temperatures <32°F. Top: box-and-whisker plot shows change over time by emissions scenario. Bottom: spatial distribution of change for 2080–2099 for the intense warming scenario (RCP 8.5) with consideration of model spread (minimum, mean, maximum). Figures are preliminary and provided by the State Climate Office of North Carolina.

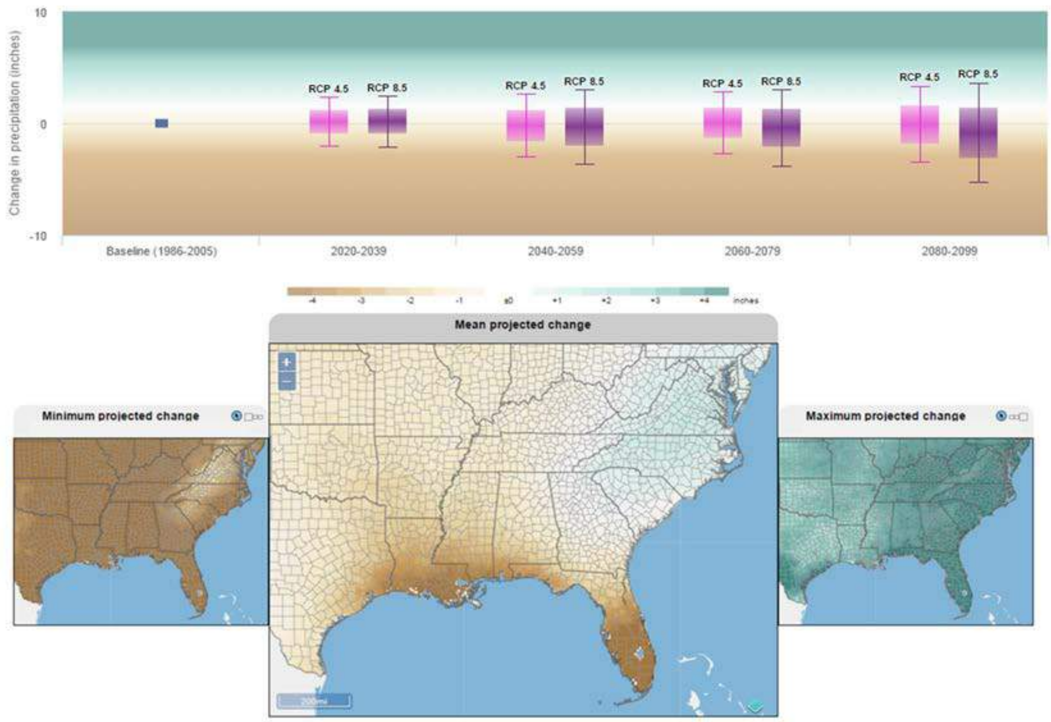

Figure 6: Projected change in average summer precipitation. Top: box-and-whisker plot shows change over time by emissions scenario. Bottom: spatial distribution of change for 2080–2099 for the intense warming scenario (RCP 8.5) with consideration of model spread (minimum, mean, maximum). Figures are preliminary and provided by the State Climate Office of North Carolina.

Temperature

Unlike other regions within the United States—or even the world—the Southeast did not exhibit an overall warming trend in surface temperature in the 20th century (Kunkel et al., 2013). Following a relatively cool period during the 1960s and 1970s, temperatures in the Southeast have steadily increased with the most recent decade (2001−2010) being the warmest on record. Table 1 provides an overview of the trends in temperature anomaly and precipitation anomaly for each season and year over the 1895−2011 time frame. A majority of the anomalies were not significant (at the 95% confidence level), except for precipitation trends in the summer being lower and higher in the fall (Kunkel et al., 2013).

Table 1: Trends in precipitation anomaly (inches/decade, 1895–2011) for each season as well as the year as a whole.

Season	Precipitation (inches/decade)[a]
Winter	NS
Spring	NS
Summer	−0.10
Fall	+0.27
Annual	NS

[a] NS, not significant. Only values statistically significant at the 95% confidence level are displayed.

Source: Kunkel (2013) based on a new gridded version of COOP data from the National Climatic Data Center, the CDDv2 data set for the northeastern United States.

Precipitation

Interannual precipitation variability has increased over the past several decades across much of the Southeast. More exceptionally, wet and dry summers have been compared with the middle of the 20th century. Annual precipitation has increased annually in the summer particularly along the northern Gulf coast (Kunkel et al., 2013).

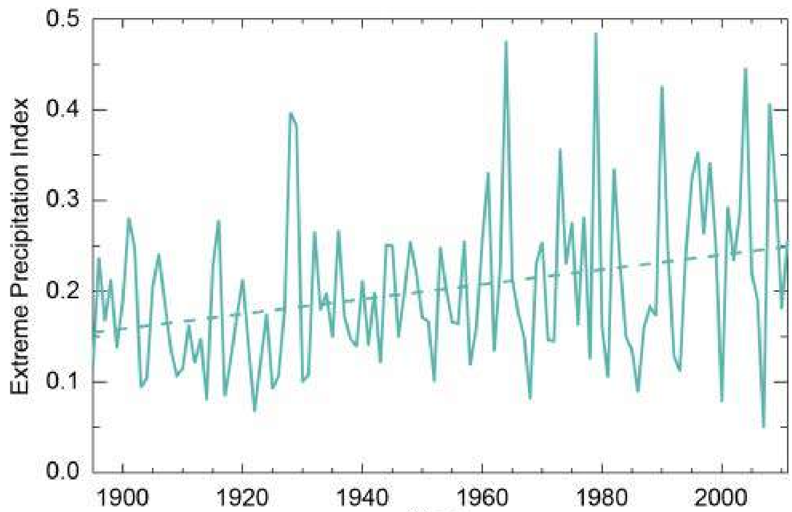

Figure 7: Mean annual extreme precipitation index for the Southeast U.S. Occurrence of 1-day, 1-in 5-year events. Source: (Kunkel et al., 2013)

Extremes

Extremely hot days in the Southeast have either decreased or stayed the same while the number of warm summer nights has increased. Extremely cold days have decreased, and year-to-year precipitation variability has increased over the last several decades. Extreme precipitation events have been increasing, particularly over the past two decades (Kunkel et al., 2013).

Expected Changes

Models indicate annual mean temperature increases across the Southeast for all future time periods and emission scenarios.[2] Model simulations also predict an increase in the number of hot days (maximum temperatures of more than 95°F) and an increase in the length of the freeze-free season ranging from 20 to 30 days by mid-century. Days with minimum temperatures below 10°F are expected to disappear by mid-century (Kunkel et al., 2013). Average annual precipitation in the Southeast is projected to increase with the greatest increases occurring in the winter. The number of wet days (precipitation exceeding 1

[2] These National Climate Assessment projections are assuming an “IPCC A2 scenario,” which is defined as “a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in the other storylines” (Intergovernmental Panel on Climate Change, 2000). See Kunkel (2013) for more detail.

inch) is projected to increase throughout the Southeast, particularly across the Appalachian mountains (Kunkel et al., 2013).

2. Regional Agriculture's Sensitivity to Climate Change and Adaptation Strategies

The major crops grown (on the basis of dollar value in 2014) in the Southeast can be collated into five groups: summer annual row crops; winter annual row crops; fruits and nuts; vegetables; and specialty crops. Figure 8 shows crops by number of acres and number of farms per State. The climate vulnerability of the major crops in the Southeast is directly tied to their duration in the field, where the crops are grown.

2.1 Cropping Systems Overview of Risks, Vulnerabilities, and General Adaptation Strategies

Crops are grown at all times throughout the year in the southeastern United States. This diversity of row crops, fruits, nuts, vegetables, and specialty crops occurs throughout the year, and as a result, climate variability has an effect on production, regardless of the season. Figure 8 shows the distribution of crops across the Southeast by State.

Most of the southeastern United States row crops, fruits and nuts, vegetables, and specialty crops are affected by a rise of atmospheric carbon dioxide (CO_2) concentration, increased temperature, increased ozone (O_3), and temporal and spatial changes in rainfall (Walthall et al., 2012). Rising temperatures could reduce yields and harm the yield of many crops due to the already high growing season temperatures characteristic of the Southeast. Approximately 85 percent of all plants use the C_3 method of carbon fixation, including important southeastern crops such as rice, soybeans, peanuts, cotton, tobacco, pines, and most deciduous trees. Generally, C_3 plants are found in cooler temperate climates, and their photosynthetic pathway becomes less efficient as air temperature rises or water becomes limiting. These plants are particularly susceptible to drought and heat increases associated with climate change compared with plants that use the C_4 method of carbon-fixation evolved in warmer climates. Although fewer in number, C_4 plants are commercially important (e.g., corn, sugar cane, sorghum) and are better adapted for the increasing climate variability within the Southeast.

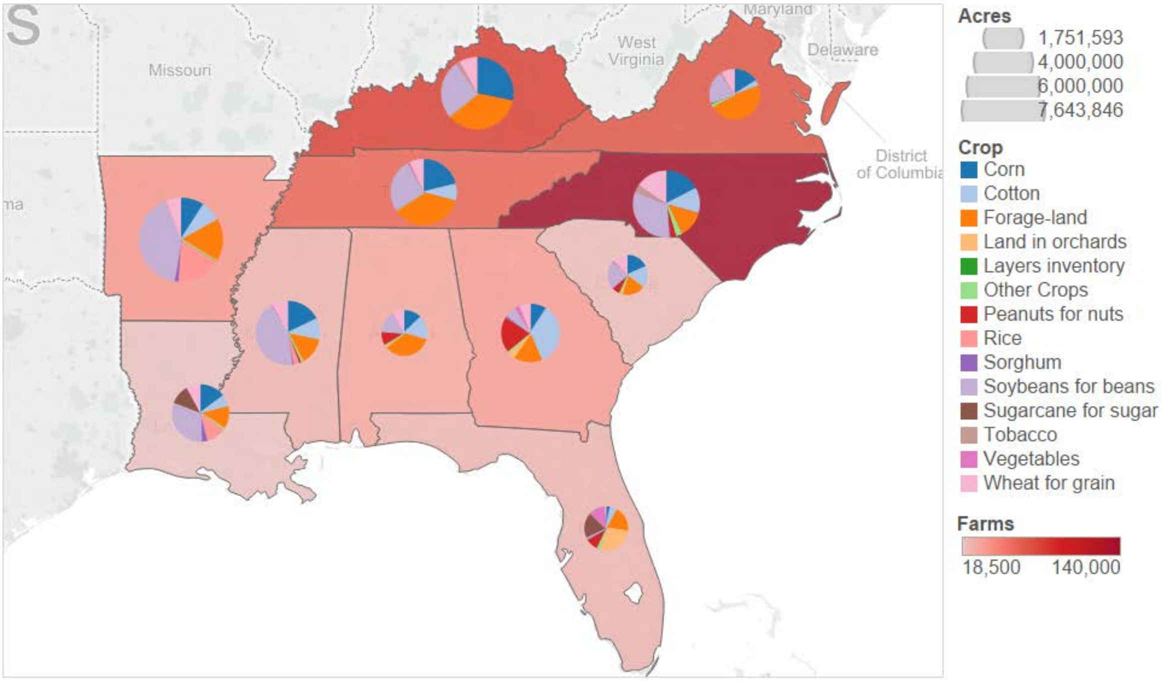

Figure 8: Distribution of crop production across the Southeast. The fill color of each state represents the total number of farms in that state. The pie chart color shows the number of acres by crop. The pie chart size shows the total number of acres in production. This data set was obtained from the National Agricultural Statistics Service (2014c) State-Level Census. The State-level data sets can be found at http://www.nass.usda.gov/Statistics_by_State/.

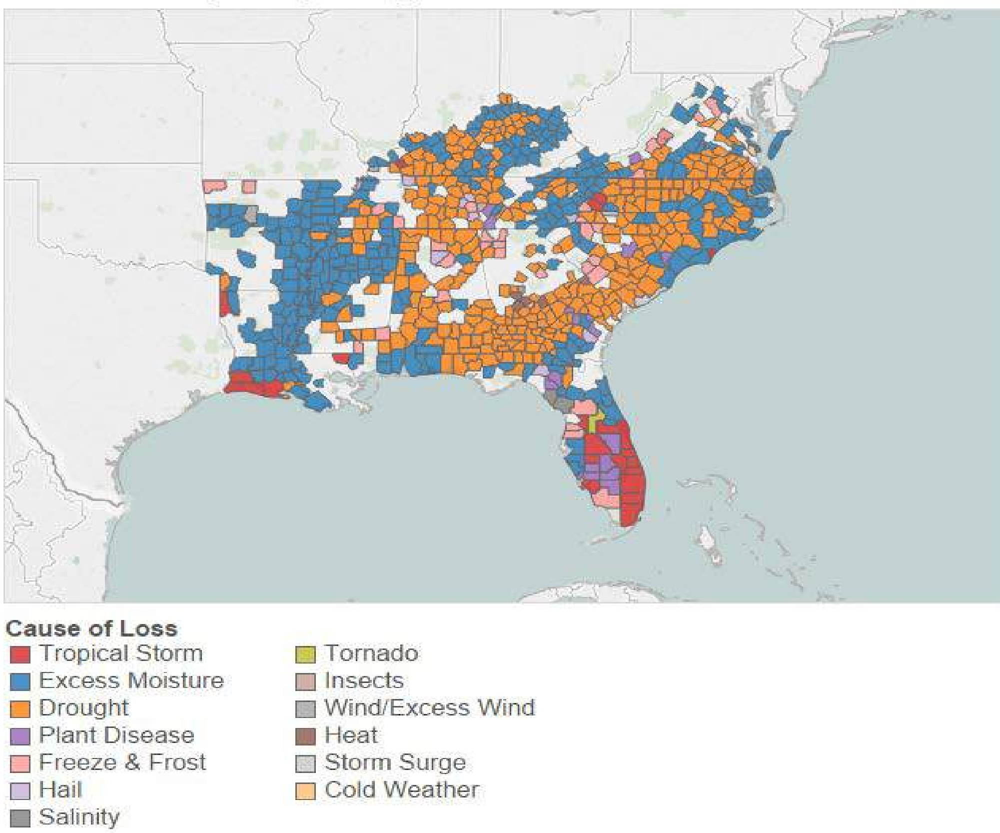

Figure 9: Maximum cause of crop loss by county for 2000–2009 based on USDA Risk Management Agency Data (http://www.rma.usda.gov/data/cause.html).

Regardless of whether a plant uses a C_3, C_4, or even rarer CAM photosynthetic pathway, all plants will be affected by changing climate and climate effects. Altered rainfall patterns will increase the occurrence and severity of extreme events, including flooding, drought, sea level rise, and salinization, which will impair many of these crops through altered water availability and soil conditions. Many of these crops will also face greater pest and weed pressures due to changes in temperature and rainfall patterns, which can provide greater opportunities for pest breeding and longer frost-free seasons. Figure 9 shows causes for crop loss by county across the southeastern United States from 2000 to 2009.

In addition, pollination processes may be adversely affected by climate change due to changes in phenology, flowering times, and effects to pollinators, which is a particular concern because 75 percent of the world's leading food crops are pollinated by animals (i.e., bees, butterflies, moths, birds, bats, beetles and other insects, (Klein et al., 2007). Ground-level O_3 concentrations have a direct, negative effect on crops grown in the southeastern United States (Fiscus et al., 2005) because O_3 causes a loss of photosynthetic capacity, which results in suppressed yield (Wilkinson et al., 2012). Although confined in the past to principally urban centers, O_3 concentrations have increased across the region and have become included as a climate variability factor that requires attention (Fuhrer & Booker, 2003). Recent evidence suggests that elevated O_3 renders wheat more susceptible to rust diseases (Mashaheet et al., 2014). This has tremendous implications for crop production and for the ability of plant pathogens to devastate crops because of an increase in O_3. Crops grown in the southeastern United States that are most sensitive to elevated O_3 are wheat, cotton, soybeans, potatoes, rice, corn, and grapes (Mills et al., 2007). Recent research has shown that higher O_3 levels can significantly reduce the distance over which bees can locate flowering plants. Higher air temperature is a major factor in O_3 production. Therefore, climate warming could adversely affect crop production in multiple ways. Vulnerabilities and adaptive management strategies for specific major crops are discussed below in detail. This information is also summarized in Table 2.

Table 2: Climate change vulnerabilities, effects, and adaptation options by crop.

Crop	Vulnerabilities (positive or negative)	Effect	Adaptation
Summer Annual Crops			
Cotton	1. Higher temperatures (−) 2. Moisture deficit stress (−) 3. Flooding events (−) 4. Elevated CO_2 (+)	1. Decreased seed set, reduced boll size, fewer seeds per boll, and fewer fibers per seed 2. Fewer bolls and reduced fiber quality 3. Yield losses	1. Genetic breeding , altered planting timing, changing distribution 2. Irrigation 3. Flood prevention
Corn	1. Excess water (−) 2. Insufficient water (−) 3. Higher temperatures(−)	1. Impaired growth or death during early growth 2. Growth and yield reduction if during grain filling 3. Yield losses (8.3% per 1°C increase)	1. Flood prevention 2. Irrigation 3. Altered cultivation practices
Soybean	1. Higher temperatures (−) 2. Pests, diseases (−) 3. Elevated CO_2 (+)	1. Yield loss (−1.3% per 1°C increase) 2. Some may become more severe 3. Growth increase, improved soil water use	1. Changing planting timing and distribution
Rice	1. Higher temperatures (−) 2. Elevated CO_2 (+,−) 3. Inadequate Water (−) 4. Flooding (−)	1. Daytime >33°C, then disrupted reproduction; cooler nighttime temps.	1. Using different cultivars, changing planting times, genetic breeding

Crop	Vulnerabilities (positive or negative)	Effect	Adaptation
	5. Pests, disease, and weeds (−) 6. Sea level rise (−)	2. reduced yield 3. Potential for increased yields; indirect effects on development and yield warrant study 4. Competing water demands 5. Loss of crop 6. Increased intensity; weed competition 7. Salinization in soil and water → threatens quality	2. (None) 3. Improved water management systems (e.g., intermittent irrigation); breeding cultivars tolerant to water changes 4. Flood prevention 5. Pest resistant varieties; crop diversification
Winter Annual Crops			
Wheat	1. Higher temperatures (−) 2. Water loss (−) 3. Excess water (−) 4. Altered rainfall patterns (−) 5. Ozone (−) 6. Pests, diseases, weeds (−) 7. Elevated CO_2 (+)	1. Impair reproduction, reduce growth, productivity and yield 2. Decreased yields 3. Decreased yields, or death 4. Pre-harvest sprouting → reduced quality 5. Reduced yields 6. Increased pests and diseases 7. May increase photosynthesis	1. Genetic breeding, changing planting dates, planting different cultivars, moving distribution northward 2. Irrigation 3. Flood prevention
Minor Grains (Barley, Oats, Rye)	1. Higher temperatures (−) 2. Climate variability (−) 3. Elevated CO_2 (+,−) 4. Drought (−)	1. More variable yields (increase or decrease, depending on severity of and interaction between stressors)	1. Selective plant breeding
Fruit Crops			
Citrus	1. Higher temperatures (−) 2. Elevated CO_2 (+)	1. Induce fruit abscission, shorten pollination period, increase fruit drop 2. Alter stomatal conductance and leaf transpiration; increase canopy photosynthesis, leaf water use efficiency, biomass, and yield	1. Breed newly adapted cultivars
Strawberries	1. Drought (−) 2. Excessive water (−)	1. Reduced leaf area, root development, berry size, and yield 2. Decreased yield, total leaf area, sugar content, and weight	1. Irrigation 2. Flood prevention
Vegetable Crops			
Peanuts	1. Higher temperature (−) 2. Higher ozone (−)	1. Poor peanut health 2. Reduced N_2 fixation, suppressed yields	1. Plant breeding for cultivars adapted to high heat stress

Summer Annual Crops

Summer annual row crops include cotton, soybeans, corn, rice, and grain sorghum. Together, these five crops are grown on approximately 27.6 million acres in the Southeast, with a value of just under $8.3

billion. Cotton, soybeans, and corn are grown throughout the region. Nelson et al. (2014) showed that models of future climate varied widely, and that agricultural production, cropland area, trade, and commodity prices also show a large amount of volatility and uncertainty. The combination of environmental and economic volatility makes southeastern land managers especially vulnerable to business losses.

Corn and rice are quite sensitive to excessive high temperatures during flowering and ripening. Even if the climate variability is relatively small, the timing of this change and the cumulative effect of temperature increases could negatively affect corn and rice within the region (Sanchez et al., 2014).

Cotton

The United States is the third largest exporter of cotton (after China and India). Cotton makes up 35 percent of global fiber use and is the principal fiber crop in the United States (Economic Research Service, 2014a). Cotton contributes $25 billion to the United States economy and supports 200,000 jobs across the industry (Economic Research Service, 2014a). In 2014, cotton production used 10.8 million acres nationally (Economic Research Service, 2014a). Within the Southeast, cotton production uses 6.2 million acres and produces $2.9 billion in revenue annually.

Vulnerabilities

Cotton will likely be affected by higher temperatures, elevated CO_2 levels, moisture deficit stress, and flooding related to altered rainfall distribution. The ideal temperature range for cotton is from 68° to 86°F (Reddy et al., 1991). Higher temperatures will likely negatively affect the growth, development, and yield of cotton, especially if heat stress occurs during the flowering phase. Cotton reproduction is sensitive to high temperatures because heat stress can alter pollination patterns, thus reducing fertilization (Walthall et al., 2012) and threatening crop productivity (Oosterhuis & Snider, 2011; Snider et al., 2010). Warming temperatures can also alter photosynthesis and respiration leading to reduced boll size, fewer seeds per boll, and fewer fibers per seed (Arevalo et al., 2008). Elevated CO_2 levels may enhance photosynthesis as the use of CO_2 increases relative to the amount of water used to produce the seed (Reddy, Hodges, et al., 1995; Reddy et al., 1997; Reddy, Reddy, et al., 1995). However, increased photosynthesis does not necessarily equate to improved lint quality (Reddy et al., 1999). Cotton may also be affected by altered rainfall distribution, which, in combination with higher temperatures and plant evapotranspiration water use, may result in moisture deficit stress, further reducing boll production, and fiber quality (Ball et al., 1994; Pettigrew, 2004; Turner et al., 1986). Finally, increased flooding events could result in more frequent complete yield loss (Bange et al., 2004).

Adaptation

Several potential management options exist to help cotton adapt to climate vulnerabilities, including genetic breeding to improve the plant's use of water or to tolerate higher air temperatures (Allen & Aleman, 2011). Adaptive management practices may include the initiation of field irrigation through traditional center-pivot systems or more water-efficient drip irrigation. Improved technologies in subsurface drip irrigation, low-energy precision application (LEPA) irrigation, and furrow-dikes may be viable options for helping producers improve water use efficiency (Bordovsky et al., 1992; Sorensen et al., 2011). Where production lands are prone to flooding, land-forming procedures may be adopted on fields to promote runoff and reduce flooding (Walthall et al., 2012). The longer growing season of cotton provides some level of flexibility in planting. Farmers can plant cotton earlier in the season to reduce exposure to high temperatures during the reproductive phase, which has led to higher yields in the Mississippi Delta (Pettigrew, 2002). Cotton might also be planted farther north where temperatures are currently too cool to grow cotton but may become warmer in coming years and decades (Walthall et al., 2012).

Corn

As the primary feed crop for livestock production, a source of food, and an ingredient in industrial products and ethanol, corn is a significant crop in the United States (Economic Research Service, 2015a). Corn is grown on 80 million acres (Economic Research Service, 2015a) with a value of $52.3 billion, primarily in the Midwest, and in rotation with soy. Nearly 6 million acres of corn are produced across the Southeast, accounting for nearly $1.5 billion in revenue. Approximately 20 percent of the United States corn crop is exported (Economic Research Service, 2015a).

Vulnerabilities

Corn production is vulnerable to changes in water and temperature from climate variability. Too much or too little water can reduce corn growth depending on timing of the occurrence. For example, impaired growth or death may result if corn receives excess water during the early growth stages (Hatfield & Prueger, 2011). Comparatively, a deficit in soil water during the grain filling period can also reduce growth and lower yields (Hatfield & Prueger, 2011). Corn is also sensitive to warming temperatures, with an estimated 4.6 percent decrease in yield per each 1°F increase in average growing season temperature (Lobell & Field, 2007). Air temperatures in the Southeast are already near or exceeding the optimal for corn production (Hatfield et al., 2011), and further increases in growing season temperature will likely reduce corn yields. A yield decrease of 1.7 percent is estimated for each 1°F increase in air temperature (Hatfield et al., 2011). Yields are expected to decline by mid-century, with predicted increases in both domestic and international food prices (Hatfield et al., 2014).

Adaptation

Many of the same adaptive management actions used to increase the resiliency of cotton can also be applied to corn, including irrigation, flood prevention, and alterations in cultivation practices. In addition to these traditional methods for increasing productivity, increasingly climate variability is causing a re-evaluation of production goals. Historically, increasing the density and fertilization of corn would likely lead to higher yields per acre. However, under the increasing variability associated with climate change, the potential for drought-related reductions in yield increase significantly with traditional planting practices. Therefore, new planting strategies are in development, including honeycomb planting, whereby gaps are purposefully left in planted rows to allow soil areas where water demand by corn is reduced (Tokatlidis, 2013). These unplanted areas are meant to serve as mini water reservoirs where water can diffuse from unplanted soil into planted soil during periods of drought. Although the overall yield using this planting method will likely be less compared with traditional planting techniques, the resiliency of the total yield will be higher. The premise that more is not always better in terms of productivity and crop survival under a changing climate in an area that will likely continue to evolve for other agricultural and forest crops (McNulty et al., 2014).

Soybean

Soybean is an important economic crop; more than 83 million acres were harvested in 2014 (Economic Research Service, 2015b), 80 percent of which occurs in the Midwest. In the Southeast, soybeans cover 11.3 million acres and produce $2.6 billion in crop revenue. Soybean is an important export crop with soybean oilseed exports producing $20 billion annually (Economic Research Service, 2014b).

Vulnerabilities

Soybeans are often grown in rotation with corn, both of which are expected to suffer yield losses with warming temperatures in the Southeast, where already high growing-season temperatures are expected to increase further (Kucharik & Serbin, 2008; Lobell & Field, 2007). Soybean yields are predicted to decrease with warming temperatures by a predicted 0.7 percent decrease in yield per 1°F temperature increase (Lobell & Field, 2007). Atmospheric CO_2 enters the plant more easily as atmospheric concentrations increase. The faster that CO_2 can enter the plant (through stomates), the less plant water is lost through the stomatal opening, which allows CO_2 to enter. Therefore, the water use efficiency (i.e., the amount of carbon gained divided by the amount of water lost) increases with increasing atmospheric CO_2 concentration. The increased water use efficiency may potentially help mitigate the water deficit that may accompany warming temperatures as evapotranspiration increases with air temperature and thus more quickly depletes soil water (Leakey et al., 2006). Studies have shown that elevated CO_2 levels between 550 and 585 ppm cause an increase in soybean growth by 15 to 16 percent (Morgan, 2005). It is difficult to predict how complex interacting factors of warming temperatures, elevated CO_2, water changes, and indirect effects on pests and diseases will influence soybeans in a world of changing climate. For example, elevated CO_2 in the Midwest led to a decrease in browny mildew disease but an increase in brown spot severity (Eastburn et al., 2010).

Adaptation

Similar to the crops above, changes in cultivation practices such as timing of planting and distribution of plants may help mitigate the yield losses from higher temperatures. Irrigation and improved water use efficiency can help ameliorate water stress and droughts that are likely to occur. Soybeans are also a crop highly suited for no-till agriculture. Unlike conventional disking/harrowing/plowing that exposes large volumes of soil to open air, no-till agriculture minimizes the amount of soil disturbance. There are many benefits to this farming practice, including greater weed control and accumulation of soil organic matter (Six et al., 1998). Organic matter has excellent water-holding capacity and can act as a buffer to drought by increasing the amount of water held by the soil and available for plant uptake. Additionally, carbon sequestered as organic matter is removed from the atmosphere, therefore helping to reduce the rate of climate change.

Rice

Rice is an important food source for half of the world’s people, and it is projected that rice production will need to increase globally by about 1 percent each year to support projected increases in the global population (Livezey & Foreman, 2004; Rosegrant et al., 1995). The United States is the fourth-largest rice exporter in the world, thus it is important to understand how climate change will affect rice production and to develop adaptive strategies to mitigate those effects (Livezey & Foreman, 2004). U.S. rice production is predominantly located in the Mississippi River Delta region, occupying around 2.5 million acres and producing more than 180 million cwt of rice across the region, with Arkansas producing the most (118 million cwt, (Economic Research Service, 2015a)).

Vulnerabilities

Because reproductive processes are disrupted at temperatures exceeding 91°F, rice is likely to be adversely affected by warming temperatures (Satake & Yoshida, 1976), and yield is expected to be reduced by higher nighttime temperatures (Mohammed & Tarpley, 2009). Plants, including rice, are always active, even at night. After the sun sets, plants continue to respire. As nighttime air temperatures increase, so does nighttime respiration, and as respiration increases, the amount of stored carbon decreases. Lost carbon cannot be used to produce the rice seed and is expelled into the atmosphere. Peng et al. (2004) found that rice yield decreased by 10 percent for every 1.5°F in nighttime air temperature.

Elevated CO_2 levels may lead to higher rice yields (e.g., (Baker et al., 1992)), although indirect effects on development and yield warrant further study on specific cultivars (Kim et al., 2003; Kim et al., 1996; Moya et al., 1998). Although rice is grown in different environments, irrigated (paddy) rice is the most common and could be negatively affected by inadequate water supplies. In the United States, 80 percent of rice is grown in the Mississippi Alluvial Plain, with the most intense practices in the Grand Prairie region of the Mississippi River Delta. Intensive extraction from the water aquifer for agriculture there is causing a reduction in the groundwater table (ASWCC, 1997), competing with drinking water availability, and threatening depletion of the groundwater supply (ASWCC, 1997). Rice is also threatened by prolonged flooding. In 2011, 25,000 hectares of planted rice were lost due to flooding of the

Mississippi River (Walthall et al., 2012). Sea level rise also threatens to impair water quality for rice production by increasing salinization. This is especially a concern in Mississippi, because approximately 200,000 acres of U.S. rice production are located along the Gulf coast (Walthall et al., 2012). Warming temperatures are also likely to increase the range of pests (Huang & Khanna, 2010). Changes in rainfall and water availability are likely to increase the intensity of certain diseases, including brown spot and blast (Walthall et al., 2012). Rising CO_2 levels also are likely to increase weed competition, which could reduce yields (Ziska, 2010).

Adaptation

Adaptation strategies include using different cultivars, changing planting times and crop rotations, genetic breeding, and using different soil treatment technologies. Planting dates can be adjusted to reduce exposure to high temperatures during the reproductive processes, including flowering. Different cultivars that shed pollen earlier in the day may also be planted (Walthall et al., 2012). Breeding has been suggested to include adaptive traits such as heat tolerance, pest resistance, and water extremes (drought and flooding) (Wassmann et al., 2009). New water management methods will need to be developed to reduce the amount of groundwater usage associated with rice irrigation; especially as human extraction of groundwater continues to increase, to prevent depletion of groundwater sources and water conflicts. One potential technique for minimizing water use is intermittent irrigation, which has a 50 percent reduction in water application without adverse effects to production (Massey et al., 2003).

Winter Annual Row Crops

Winter annual row crops include winter cereal grains, barley, oats, rye, and wheat. Together, these five crops are grown across approximately 700,000 acres in the southeastern United States with a value of about $4.5 billion. Among the winter grains, wheat is the most widely planted, with approximately 25 percent of the Southeast acreage being in North Carolina. Oats are used primarily as a grazing and forage crop in Alabama and Georgia but are also grown as grain for animal feed in the Carolinas and Virginia. Barley traditionally has been used as a grain for animal feed, but since 2013, higher-valued barley for use as malt in the brewing and distilling industries has led to greater acreage being planted particularly in Virginia and North Carolina. Rye acreage is primarily limited to Georgia. Organically grown grain was grown on about 25,000 acres in 2010, and that increased to about 100,000 acres in 2013, particularly in the Carolinas, Georgia, and Virginia.

In an analysis of climate change and crop insurance, Beach et al. (2010) projected increased yields for barley, oats, and rye (along with hay and red winter wheat) (Walthall et al., 2012). However, grain crop yields, including those of oats, wheat, and field corn, might drop if higher summer temperatures affect critical stages of development (Frumhoff et al., 2007). Selective plant breeding in coarse grains such as barley has increased global production, but farming systems that rely on such technological improvements can be more sensitive to climatic variability (Adams et al., 1998).

Wheat

Wheat is the most widely grown and consumed staple food crop in the world and accounts for one-fifth of the global food supply. The demand for wheat is projected to increase by 60 percent by 2050, or by roughly 1.1 billion metric tons. Climate change and harmful variability can negatively affect this cornerstone crop. The primary market class of wheat grown in the Southeast is soft red winter. However, improved varieties of hard red and hard white wheat have resulted in 100-fold increases in acreage of these market classes in Kentucky, North Carolina, South Carolina, and Virginia.

Vulnerabilities

Wheat is vulnerable to warming temperatures and heat stress, elevated CO_2, and changes in water availability, ozone, pests, diseases, and weeds. The optimal temperature range for wheat seedling development is 68° to 86°F (Porter & Gawith, 1999). Warming temperatures and heat stress can impair reproduction (Zinn et al., 2010). With exposure to high temperatures (above 90°F), a decrease in grain yield and biomass occurs at harvest (Ferris et al., 1998). Yields are expected to decrease with drought and water loss. For example, in rainfall-limited conditions, wheat will respond by decreasing the number of grains produced per plant, but the size of each grain will be larger. In addition, drought will speed up the maturity process in wheat by an average of 12 days, resulting in shorter time for grain-filling and lower yield (Yang et al., 2014). Excess water is also a problem, because water-logging can reduce wheat yields by 20 to 50 percent (Collaku & Harrison, 2002), and sustained flooding can cause complete crop loss. Elevated ozone is also likely to reduce wheat yields (Heagle, 1989). Recent evidence suggests that elevated ozone renders wheat more susceptible to rust diseases (Mashaheet et al., 2014). Pests, diseases, and weeds, each of which may increase with warming temperatures, affect wheat. Pests often benefit from longer growing seasons, which provide an extended breeding period. Higher temperatures may also increase overwintering of wheat diseases such as stem rust, which prefers warmer temperatures (Garrett et al., 2006; Walthall et al., 2012), although this depends on the interaction of other factors.

Adaptation

Adaptation strategies to these vulnerabilities include genetic breeding to propagate adaptive varieties, and changing planting dates, cultivars, crop distribution, irrigation, and flood prevention measures. Wheat breeding is a long-standing and reasonably well understood practice, and it may be possible to breed adaptive varieties and cultivars such as those with modified flowering times (Walthall et al., 2012). Producers may also adapt to these climate vulnerabilities by altering their agricultural practices, by planting different cultivars, or altering the timing of planting. Wheat, unlike many other commercial crops, is largely self-pollinating. Therefore, early planting of wheat is less likely to encounter imbalances between flower maturity and pollinator arrival. This would require guidance on risk assessment, especially from frost damage, with other issues such as pests, diseases, and weeds addressed as necessary (Walthall et al., 2012). Irrigation and flood prevention may be used to address changes in water access. Finally, a more long-term adaptation may include altering the geographical distribution of wheat crops by planting them farther north to avoid extreme temperatures. Ortiz et al. (2008) suggested that the spring wheat belt might shift more than 10 degrees latitude northward into western Canada by 2050. As suggested by Walthall et al. (2012), the southern United States might become more suitable for winter-sown spring wheat.

Fruit Crops: Citrus, Apples, Grapes, and Strawberries

Citrus is the primary fruit crop in the Southeast, occupying approximately 476,000 acres across Florida, with a production value of more than $1.3 billion (National Agricultural Statistics Service, 2014b). Apples, peaches, pecans, and grapes make up the remaining major fruits and nuts, with apples ranging in production across the more northern states of the Southeast and pecans concentrated mainly in Georgia and Mississippi. Grapes are grown for jellies and jams, but also for wine, particularly in Virginia and North Carolina.

General fruit vulnerabilities

These perennial crops' productivity is effected by several factors including air temperature, water availability, air pollutants (e.g., ozone, nitrogen, sulfur deposition), and elevated CO_2. Although elevated CO_2 increases growth rate and yield if sufficient water and nutrients are available to support the increased growth potential (Kimball et al., 2007), productivity could be reduced by heat stress and nutrient deficiencies (Adam et al., 2004). High light intensity and quality are needed for optimal biomass production and fruit quality (Dokoozlian & Kliewer, 1996; Jackson, 1980). An increase in cloud cover associated with increased atmospheric water vapor could reduce solar radiation and therefore reduce fruit tree productivity.

Citrus

Excessively high air temperatures can induce fruit drop (Rosenzweig et al., 1996) and shorten the pollination period, whereas lower air temperatures lengthen the pollination period (Iglesias et al., 2007). The optimum range for fruit development is 72° to 81°F, with temperatures greater than 86°F increasing fruit drop (Iglesias et al., 2007). Citrus does not generally need chilling (Walthall et al., 2012). A doubling of CO_2 would have a number of effects on citrus, including increasing canopy photosynthesis (Brakke & Allen, 1995), leaf water use efficiency (Adam et al., 2004), biomass (Allen & Vu, 2009), and in a number of studies, yield increases (Idso & Kimball, 1997; Walthall et al., 2012). Therefore, an increase in atmospheric CO_2 may appear to be highly beneficial to citrus production. However, as a heat-trapping gas, atmospheric CO_2 also contributes to atmospheric warming and atmospheric instability (e.g., intensive rain events and droughts, higher growing temperatures). These negative effects could offset the CO_2 growth benefits and cause farmers to use adaptive management practices such as irrigation.

Apples

In the Southeast, warmer temperatures could cause considerable damage to apple trees throughout their life cycle (Walthall et al., 2012). Apple trees are susceptible to damage from abnormal temperatures. High temperatures in June and July and extreme cold in the winter can kill buds, whereas winter warming periods can de-acclimate buds and increase their susceptibility to winter damage. Additionally, high air temperatures can reduce fruit size. A doubling of atmospheric CO_2 could reduce leaf transpiration of apple trees by 27 to 33 percent, increase the crop's water use by 13 to 16 percent, and increase biomass by 81 percent (Chen et al., 2001, 2002). Under a warming climate scenario, increased water use efficiency by apple trees may increase yields, but that could be offset by rising air temperatures and potential drought. Irrigation may be needed to assure that sufficient soil moisture is maintained for apple production.

Grapes

A chill accumulation of 90 to 1,400 chill units is required for grapes, with bud break at 39°F and leaf appearance at 45°F (Reginato et al., 2010). Grapes generally grow best at air temperature ranging from 57° to 68°F, and air temperatures greater than 97°F reduce production (Walthall et al., 2012). Additionally, greater variation in maturity and a reduction of fruit acidity have been found with higher temperatures (Jones et al., 2005). A doubling of CO_2 would increase leaf water use efficiency by 69 percent, whereas biomass and yield were shown to increase in the range of 40 to 50 percent (Bindi et al., 2001; Moutinho-Pereira et al., 2009). However, these projected changes do not include the likely higher amount of evapotranspiration that would be associated with higher air temperature due to elevated atmospheric CO_2. Indirectly, the wine industry may also be affected through the quality of the barrels used to age wine. Oak is the most common species used for barrel making, and projected increases in oak growth could produce weaker barrels and more frequent cask failure (Tate, 2001).

Adaptation

The quality of a grape is highly dependent on air temperature and is therefore quite sensitive to climate change and variability. Night harvesting now often occurs in hotter regions to maintain freshness, resulting in a fruitier product. Other adaptation measures focus on minimizing the amount of heat that the grapevines receive during the growing season. Techniques such as planting rows at angles to maximize self-shading, planting rows closer together, and using mulches to maintain soil water moisture are increasingly used as air temperatures increase (Mozell & Thach, 2014). Research is also underway to develop more drought- and salt-tolerant varieties of grapes.

Strawberries

Strawberries are an important early spring crop across the Southeast but are sensitive to a number of environmental factors. A lack of soil water can reduce leaf area, root development, berry size, and yield (Bordonaba & Terry, 2010; Klamkowski & Treder, 2008). However, excessive water also decreases fruit yield, sugar content, and weight (Casierra-Posada, 2007). Additionally, early frosts can destroy a crop.

Drip irrigation can address soil water limitations but offers no protection against early frosts. Center-pivot irrigation can address both soil water limitations and frost, but at a cost of additional water and energy use.

Adaptation

A major source of adaptation will be the production of new cultivars, either through breeding or molecular technology (Kean, 2010). One such focus of new cultivars could be to breed varieties that have photoperiod-induced dormancy, as opposed to temperature-induced dormancy, to adapt to warmer winters (Walthall et al., 2012). Higher air temperature effects on productivity losses can be adaptively managed through the use of reflective particle films to reduce canopy and fruit temperature (Glenn, 2009). Many lower-technology tools are already in use, including crop load adjustment, canopy pruning, and training to reduce unwanted solar radiation, and irrigation.

Vegetable Crops: Potatoes and Peanuts

A wide array of vegetable root crops are grown in the Southeast, but the majority of the acreage consists of peanuts, potatoes, and sweet potatoes. Although peanuts are often considered a nut crop, they are in reality a vegetable, similar to other members of the Fabaceae or bean family. Six of the eleven States in the southeastern region produce peanuts. North Carolina has the largest acreage of sweet potatoes, and this has been increasing since 2010. Taken together, these three vegetables are grown on more than 1 million acres, with a production value of just approximately $1 billion.

Vulnerabilities

Potatoes are susceptible to yield reductions during droughts and periods of high temperature, particularly when coupled with high wind speeds (Wolf, 2002). Both high ozone and high temperatures have negative effects on peanuts. Current levels of ozone reduce nitrogen (N_2) fixation (Tu et al., 2009) and suppress peanut yields (Booker et al., 2009; Grantz & Vu, 2009). Higher ozone has also been correlated with higher instances of spider mites (Heagle et al., 1994). High temperatures can also generally have a negative effect on peanut health (Wassmann et al., 2009). Likewise, sweet potatoes are subject to a number of pest species including the sweet potato borer, wireworms, aphids, mites, and white grubs, among others. The interaction of changing air temperature and insect predator-prey relationships are not fully understood.

Adaptation

Plant breeding can result in varieties that are adapted to high heat and drought stress, whereas irrigation can alleviate water shortages (Hijmans, 2003). Another important aspect of crop success is postharvest transport. Potatoes are can begin to rot very quickly when the temperature and humidity are high, which is predicted in a warming world. New and more extensive refrigeration equipment will be needed to maintain potato quality between field and market (Haverkort & Verhagen, 2008).

General Adaptation Strategies: Crop Diversification

Although every crop may have adaptation strategies that are specifically designed to maintain the quantity or quality of the product, some strategies are appropriate for many types of crops. Crop diversification is one strategy that could be more universally applied to address negative climate change effects (Lin, 2011). Crop diversification is the intercropping of multiple species together in space or time (e.g., rotations) on a farming landscape that provides beneficial functions to improve system productivity and ecological integrity. Crop diversification can improve resilience to pest and disease outbreaks by supporting greater biodiversity in the farming system and by increasing the number and types of beneficial organisms that can prey on harmful species (Lin, 2011). In comparison to mono-cropping, crop diversification increases genetic diversity and can help reduce vulnerability to adverse weather, pest, and disease events (Roberts, 2008). Intercropping can lead to better soil structure and soil organic matter, better nutrient cycling, and better water retention, which can help mitigate the severity of drought or rainfall variations. For example, incorporating trees or shrubs as buffers in an ecosystem can help reduce flooding and erosion while also providing shade to reduce heat stress associated with climate change to surrounding vegetation. Cover crops can also reduce soil erosion from strong rainfall events (Segura et al., 2014), although increasing soil organic matter through the added decomposition of fine roots and leaves generally leads to better soil water retention and greater resilience against droughts (Dabney et al., 2001). Having a more diversified selection of crops can also help buffer producers against crop failures or market fluctuations in the price of a single crop such as corn. Guidance is needed to educate producers on best practices for intercropping in their specific region, within the local contexts of ecology, labor, short- and long-term climactic conditions, and economic investments and returns.

2.2 Livestock Systems Overview of Risks, Vulnerabilities, and General Adaptation Strategies

Beef cows, milk cows, hogs, pigs, layers, broilers, and other forms of poultry account for a majority of livestock in the Southeast. North Carolina produces the most hogs and pigs in the Nation, mostly on large-scale, confined operations. Table 3 shows the quantity of livestock and poultry in the Southeast, and Figure 10 delineates those numbers by State for beef cows, milk cows, and hogs and pigs.

Table 3: Livestock and poultry farms and population in the Southeast (National Agricultural Statistics Service, 2014a)

Livestock and Poultry	Farms	Animals (100,000)
Beef cows	214,000	70
Milk cows	6,000	5
Hogs and pigs	12,000	107
Layers	47,000	825
Broilers and other poultry	14,000	60,553

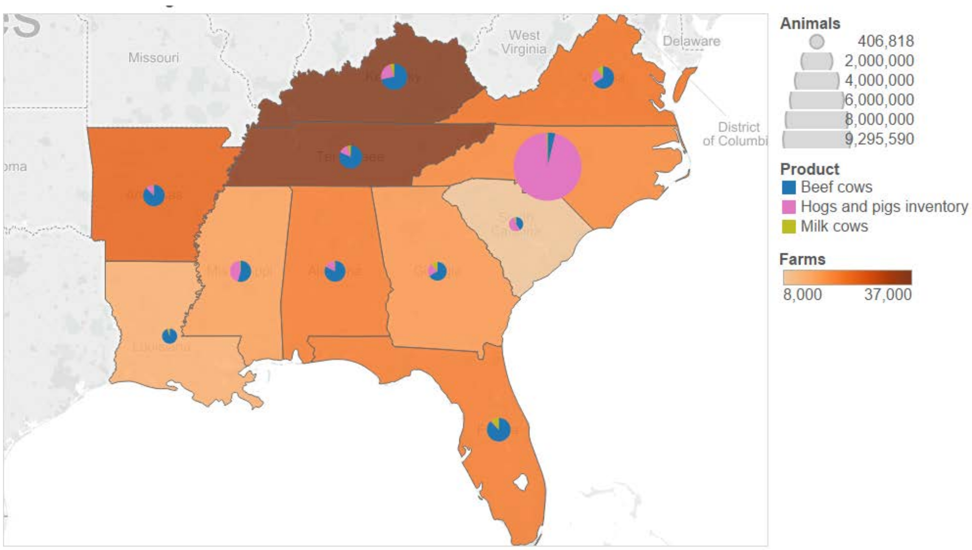

Figure 10: Beef cows, milk cows, cattle, and pigs in southeastern States. The fill color of each State shows the total number of farms in that state. The pie chart color shows the number of animals by product. The pie chart shows the total number of animals produced. This data set was obtained from the National Agricultural Statistics Service 2012 State-Level Census (2014c). The State-level data sets can be found at http://www.nass.usda.gov/Statistics_by_State/.

Changing climatic conditions will affect animal agriculture in four primary ways: 1) feed-grain production, availability, and price; 2) pastures and forage crop production and quality; 3) animal health, growth, and reproduction; and 4) disease and pest distributions (Rötter & Van de Geijn, 1999).

The projections of extreme heat events in the Southeast will likely create major challenges for animal agriculture. The challenges are expected to differ between pastured (or unconfined) versus housed (or confined) animal operations. Livestock production systems that provide partial or total shelter (e.g., poultry and swine, and to some extent dairy operations) reduce the risk and vulnerability associated with extreme heat. Although housing animals indoors helps minimize the effect of heat waves, management and energy costs will increase for confined-production enterprises and may require modification of shelter and more water used for cooling (Melillo et al., 2014).

Livestock production is becoming an increasingly intensive industry (Pielke, 2013). Cheap feed and energy coupled with manageable disease control are all critical to industry success. Severe storms could cause power failures leading to catastrophic livestock loss, as well as lagoon treatment and shelter flooding. Increasing climate variability could also negatively affect feed grain production and costs. The higher demand for grain to make biofuels could also increase overall grain prices.

The effects of climate change on livestock are likely to be variable based on a number of factors such as the magnitude of temperature increase, water availability, and animal feed prices. Dairy cows are particularly sensitive to heat stress, with optimal temperature for milk production between 40° and 75°F. Beef cattle and poultry industries will likely be affected both through direct effects on production and indirectly through changes in grain prices, pasture productivity, or costs for cooling. Cooling costs could be difficult to estimate due the fluctuating price of fossil fuels. Significant effects on beef cattle survival occur with continuous temperatures above 90°F, especially with increasing humidity.

Water availability is expected to become a major issue in southeastern livestock-intensive operations such as poultry production.[3] Currently, securing water for the purpose of cooling chicken houses is a significant cost in places such as parts of Alabama that have limited groundwater resources for direct pumping.

Farmers and ranchers will need to become more resilient to climate variability (including more frequent droughts, heat, frost, and high winds) and climate change by adopting locally relevant adaptation measures (Ingram et al., 2013). The planning and implementation of conservation practices has typically occurred under an assumption of a relatively stable climate. However, farming operations will need to become more financially and managerially flexible to adapt to potential changes in temperature, precipitation, and other meteorological elements, as well as the direct effects of changes in atmospheric greenhouse gases.

In general, intensively managed livestock systems have more potential for adaptation than crop systems, and some of these adaptations may be enabled by the use of alternative energy sources on farm (Fraisse et al., 2009). Vulnerabilities and adaptation strategies are emphasized for the dominant Southeast livestock commodities within the categories of confined, pastured, and aquaculture.

In the discussion that follows (and in Table 4), vulnerabilities and adaptation strategies are re-emphasized for the dominant Southeast livestock commodities within the categories of confined, pastured, and aquaculture. Because of many similarities in vulnerabilities and adaptation strategies across the eastern United States, which includes the Northeast and the Southeast regions, interested readers are also referred to livestock assessments by the Northeast Hub from which we share below some elements equally appropriate to the Southeast.

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[3] Univ. of Georgia Cooperative Extension; http://www.caes.uga.edu/applications/gafaces/?public=viewStory&pk_id=4194

Table 4: Summary of climate change vulnerabilities, effects, and adaptation strategies for livestock in the Southeast

Poultry & Eggs: NC, GA, AR, AL, MS, KY, LA, SC, VA[1]

Vulnerability:	Heat stress; extreme precipitation; flooding; pathogens and parasites.
Effect:	Higher energy costs; reduced egg production; lower meat quality; susceptibility to disease.
Adaptation[2]:	Expand ventilation and cooling systems (R,E,N); improve energy efficiency (R,E,N); alter design and/or location to avoid flood damage (R,E,N); closely manage field crops (R,E,N); improve disease monitoring and ability to quarantine (R,E); breed heat-resistant chickens (R); adopt new feeds.

Beef cattle (also horses, sheep, and goats): TN, FL, AL, AR, GA, KY, LA, MS, VA, NC, SC[1]

Vulnerability:	Heat stress; extreme precipitation; drought; warmer winters; disease.
Effect:	Diminished weight gains; lower quality pasture; greater susceptibility to health problems.
Adaptation[2]:	Increase shade (E,N); identify heat-resistant breeds (R); manage pasture (R,E,N); disease monitoring and quarantining (R,E).

Dairy: FL, GA, KY, TN, VA[1]

Vulnerability:	Heat stress; drought; warmer winters; pathogens and parasites.
Effect:	Reduced milk productivity; lower birthing rates; greater susceptibility to health problems; higher energy costs.
Adaptation[2]:	Expand cost-effective ventilation and cooling systems (R,E,N); adjust feeding management (R,E,N); breed genetically resistant cattle (R).

Pigs and Hogs: NC, SC, VA, TN, MS, GA, AR, AL[1]

Vulnerability:	Heat stress; extreme precipitation; drought; warmer winters; disease.
Effect:	Diminished weight gains; greater susceptibility to health problems; higher energy costs.
Adaptation[2]:	Identify heat-resistant breeds (R); disease monitoring and quarantining (R,E); enhanced energy efficiency (R,E,N).

Fish & Shellfish Aquaculture: MS, LA, AL, FL[1]

Vulnerability:	Warmer sea temperatures; increased carbon dioxide in water; sea level rise; extreme precipitation.
Effect:	Less than optimal physical functioning and reproduction; vulnerability to disease; damaged habitats; algae blooms/red tide.
Adaptation[2]:	Improve monitoring of species populations, disease, and ecosystem health (R); identify disease-resistant shellfish strains (R); relocate infrastructure (R,E); ecosystem management (R,E).

[1] Primary States affected (listed in the order of the importance of the subject commodity in the State).
[2] R, E, and N designate which of the Research (R), Extension (E), or NRCS (N) activity will be necessary to help producers adopt each adaptation strategy.

Confined Operations

Confined operations include those facilities that meet the animal feeding operation definition of animals that are confined for at least 45 days in a 12-month period with no grass or other vegetation in the confinement area during the normal growing season.

Poultry

Poultry is the primary confined livestock operation in the Southeast. For poultry and egg operations, heat stress presents the most problematic climate vulnerability, although the consequences of this are mitigated because chickens and turkeys are frequently raised in climate-controlled housing facilities. Maintaining a cool temperature for broiler hens provides the optimal conditions for their health, growth, and disease resistance. With projected warming temperatures in the Southeast, poultry farmers seeking to regulate temperatures within their facilities will likely experience higher cooling costs. Better ventilation systems coupled with more frequent use may also result in higher maintenance costs (Division of Energy and Climate, 2014). Energy expenditure is the second highest expense for contract poultry producers. Installation of energy-efficient equipment will result in annual energy cost savings. The equipment may be eligible for Federal assistance such as through the USDA NRCS Environmental Quality Incentives

Program (EQIP), grants, loans through the USDA Rural Energy for America Program (REAP) Section 9007 of the Farm Bill, and utility company incentives.

The poultry industry is generally connected with the corn and soybean industries through poultry feed. Therefore, stresses to field crops may have secondary effects on the poultry industry in the form of higher feed prices (Coale et al., 2011; Division of Energy and Climate, 2014). High wind speeds and precipitation from tornados and hurricanes can have devastating effects on confined poultry or livestock if facilities are destroyed, resulting in long periods without production and considerable animal mortality (Ingram et al., 2013).

As discussed by Pielke (2013), adaptation mechanisms for the poultry industry (summarized in Table 4) include adoption of new feeds, use of genetics to breed birds that are more heat tolerant and pest resistant, adoption of management protocols to avoid pest and disease risks, and changes to animal housing to accommodate heat loads and environmental pressures. Higher temperatures may also present new disease threats to chickens (Coale et al., 2011). Disease threats may be confronted through better abilities in monitoring and quarantining (Coale et al., 2011). Researchers are also investigating chicken breeds with enhanced resistance to heat stress.

Dairy

Dairy cattle are mostly kept in free-stall barns with open sides and are generally more exposed than poultry and swine, and thus more vulnerable to heat stress. Because heat stress poses the most perilous threat to the dairy industry in the Southeast, many of the identified adaptation strategies focus on enhancing cooling systems. Under greater warming, more susceptibility to illnesses may also result, especially as pathogens and parasites have more opportunity to multiply with warmer winter conditions. More intense rainfall can contribute to greater amounts of polluted runoff from dairy operations. This can increase the potential for discharges from waste storage facilities. Considerations should be made to enlarge existing waste storage facilities and adjust current design parameters to include additional storage to account for more intense rainfall and runoff events and cooling systems.

Wolfe et al. (2011) found that shifts in feeding strategies can help keep cows cool during heat stress, including feeding cows easily digestible forages, adding supplements to encourage digestion and replace minerals lost through sweating and panting, ensuring that feeding occurs during cooler parts of the day, and making sure that cows have sufficient access to water. Long-term adaptation may include cross-breeding with more heat-tolerant breeds and furthering research on heat tolerance in known milking breeds (Fraisse et al., 2009).

Pastured Operations

Rising temperatures are expected to cause heat stress on livestock such as beef cattle, horses, sheep, and goats that are raised outdoors during summer months. Animals respond to extreme temperature events by altering their metabolic rates and behavior. Meat animals are managed for a high rate of weight gain, which increases their potential risk when exposed to high temperatures. Temperature-induced stress can disrupt performance, production, and fertility, limiting the ability of animals to produce meat, milk, or eggs. This is more pronounced with increasing duration (i.e., the number of days) of extreme heat than by increases in average temperature. Exposure to high temperature can be costly to producers, as was the case in 2011, when heat-related production losses exceeded $1 billion (Melillo et al., 2014). Elevated humidity and wind velocity exacerbates the effect of high temperatures on animal health and performance (Harris et al., 2003).

In 2007, farmers across much of the Southeast experienced crop and forage losses due to drought. Regional pastures could not produce enough grass for livestock, resulting in a higher demand for corn for feed and a sharp rise in corn prices. Many farmers sold their livestock to avoid the additional feed costs. The increase of livestock on the market initially lowered meat prices, but the long-term decrease in available livestock resulted in long-term price increases. To ensure quality pasture, farmers may manage these lands for drought through expanded irrigation and by incorporating drought-resistant forage varieties. If farmers have difficulty producing their own feed for their livestock animals, they will likely pursue feed on the market, perhaps at higher prices due to anticipated shortages and diminished quality (Nash & Galford, 2014).

The cattle pasture industry has adapted slowly to suit local environmental conditions such as water and forage availability. Ingram et al. (2013) presented several management options that ranchers could use to adapt to climate change. Some of these include the use of species-rich mixtures, legumes, and better adapted forage species and cultivars in forage lands. Additionally, changing grazing frequency to favor the maintenance of highly digestible plant species and to increase tolerance to drought stress will improve resilience of pasture lands. The use of intercropping with legumes and use of C_3 and C_4 species of feed crop mixes, along with integrated control options to reduce the spread and effects of gastrointestinal parasites (especially in ruminant production systems) also increases ecosystem sustainability. Provisions for more shade or water in extensive grazing systems and development of better technologies will reduce heat stress effects in confined systems. Another useful adaptation option is changing livestock and poultry breed selection to favor animals that are more tolerant of local conditions. Livestock managers could also benefit from development of methods to warn producers when temperature heat indexes are nearing threshold levels so that they can take action to avoid losses.

Higher temperatures coupled with higher precipitation may also increase heat stress-related mortality and the number of mosquitoes and flies, which often are carriers of disease. Extreme precipitation events may also cause hoof health problems for grazing animals. Along with greater precipitation, warmer winter temperatures will likely contribute to wetter and muddier conditions, fostering respiratory infections in cattle (Griffin, 2009).

Aquaculture Operations

About 90 percent of fish and shellfish are harvested through wild fisheries (i.e., commercial fishing), which are mostly concerned with catching, processing, and selling fish. Catfish, perch, salmon, hybrid striped bass, tilapia, and trout account for well over 50 percent of all aquaculture sales. Mollusks, including abalone, clams, mussels, and oysters, and crustaceans such as lobsters and shrimp account for nearly a quarter of all sales, followed by a few percentages of sale attributed to each of baitfish and sport fish.

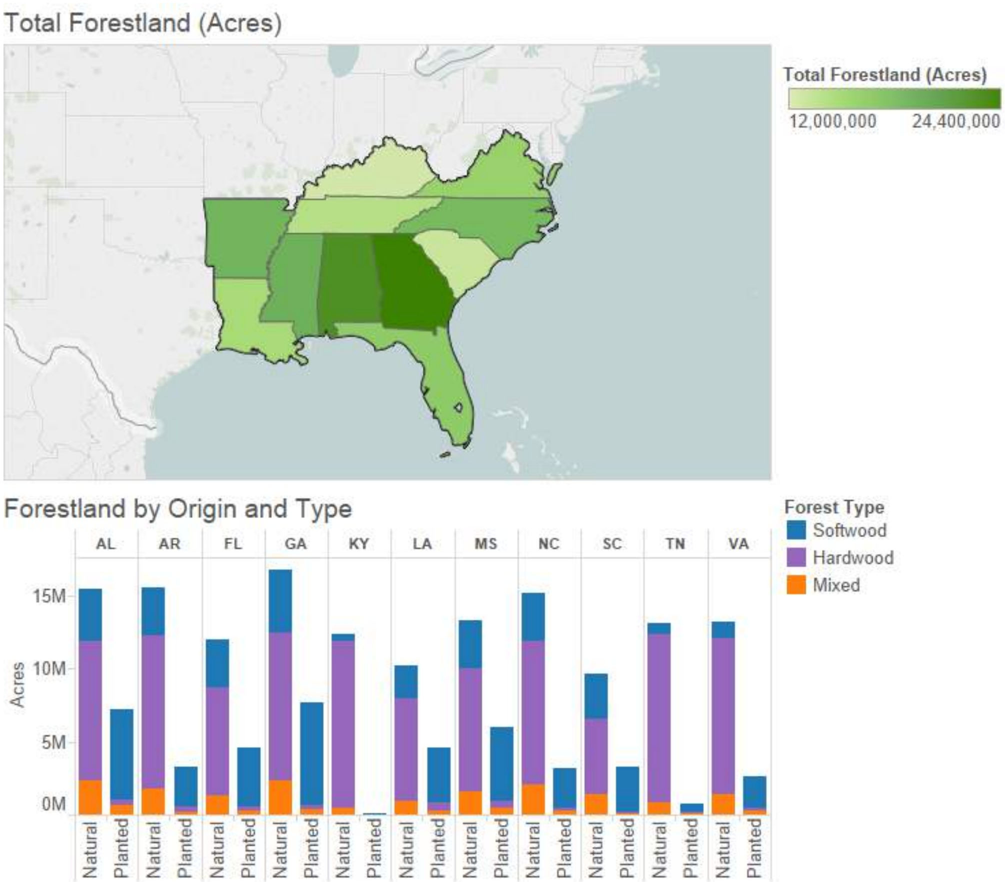
The fishing and fish farm industries are particularly vulnerable to changes in freshwater availability, increases in salinity due to saltwater intrusion into coastal surface and groundwater, water quality declines in coastal areas, and losses of marsh, mangrove, and seagrass habitat. For instance, the large aquaculture industries in Louisiana and Mississippi place high demands on freshwater reserves, particularly groundwater. In most of the Gulf coast States, about 50 percent of aquaculture ponds use groundwater, with Louisiana being 75 percent dependent on groundwater. Higher groundwater salinity levels resulting from more frequent droughts and saltwater intrusion could negatively affect the region’s aquaculture industry. For example, during the 1999–2000 drought, salt contamination of surface and shallow groundwater limited crawfish farming in southwestern Louisiana, leading to economic devastation of many crawfish farmers. In Mississippi, the State's vulnerable aquaculture industry will be under threat as a result of shrinking freshwater supplies, increasing salinization, warmer water temperatures, and contaminated runoff from high precipitation events. Both coastal and freshwater fisheries of the Gulf coast are vulnerable to potential changes in the flow and availability of water.

Other examples of potential climate effects on fisheries and aquaculture include greater levels of illness and death due to greater summer heat stress and decline in dissolved oxygen in stream, lakes, and shallow aquatic habitats leading to fish kills and loss of diversity among aquatic species. Projected increases in temperature are expected to result in more frequent outbreaks of shellfish-borne diseases in coastal waters and altered distribution of native plants and animals. Sea level rise that could flood coastal spawning marshes, warming ocean temperatures and thus causing fish displacement, and increasingly acidic waters resulting in coral decline and mortality are all climate-related effects to the aquaculture industry (Pielke, 2013).

Rising temperatures are a concern for the aquaculture industry, including catfish producers. With higher temperatures, populations of pond microorganisms will grow more rapidly. The larger population of microorganisms will use more oxygen, leaving less for fish species such as catfish. Traditionally, catfish farmers have relied on observing fish at the top of the ponds taking in air as an indicator for the need of pond aeration. The Agricultural Research Service has developed a monitoring system that automatically starts pond aeration when oxygen levels reach a minimum allowed level. This new monitoring system will turn on the aerators as often as needed to add more oxygen to the water, which leads to a significantly increase in catfish growth rates.

3. Forest Systems Overview of Risks, Vulnerabilities, and General Adaptation Strategies

Although natural forests in the Southeast are predominantly hardwood, planted forests are mostly softwood, with a heavy emphasis on loblolly pine (Figure 11). Drought, wildfires, insect and plant invasions, and more intense storms all pose threats to the health and resiliency of southeastern forests. Scientists expect that increases in temperature and changes in rainfall patterns will cause these disturbances to become more common and with greater intensity and duration (McNulty et al., 2013). Forest management approaches can be used to decrease the risk of climate change on forestlands.



Acres of natural and planted forestland for 2013 inventory cycle, derived from Forest Inventory Data Online web-application, version: FIDO 1.5.1.05c. Data source: http://apps.fs.fed.us/fia/fido/customrpt/app.html

Figure 11: Forestland by type and origin across the Southeast in 2013

3.1 Vulnerabilities

Its large land area and broad range of latitudes and elevations provide the southeastern region with exceptional biological diversity, as well as a high degree of vulnerability. There is a strong relationship between increased vulnerability and increased biological or economic loss. This is why the southeastern United States has more natural disasters worth $1 billion or more in damage than anywhere else in the country (see Figure 3). Vulnerabilities are generally considered to be specific by location or affected species. Certain tree species may be vulnerable to a specific type of insect, whereas other species in the same area are not affected. Conversely, a trees species may be highly vulnerable to a specific risk (e.g., wildfire) in one part of the Southeast, but that same species may less vulnerable in another part of the region because wildfire is much less common.

Appalachian Highlands and High-Elevation Forests

Changing temperature and rainfall patterns may threaten the survival of northern hardwood trees in mountain forests. Higher temperatures will allow species from lower elevations to migrate up-slope into higher areas, thereby changing the species mix of current forest communities. Hardwood forests may also experience stress from higher temperatures, allowing pines and other fast-growing species to become more dominant at the expense of slower-growing species such as hickories and oaks. Forest landowners should observe the responses of these species to any stress caused by drought and higher temperatures and may need to thin tree densities to increase water availability for remaining trees or, ultimately, shift management focus away from northern hardwood species. Spruce-fir forests are also at high risk.

Piedmont

Warmer temperatures, along with changes in spring and summer rain, are projected to lead to more periods of drought throughout the Southeast. Forests are more susceptible to damage from pests such as southern pine beetles and Ips bark beetles during droughts. Higher winter temperatures are likely to increase the distribution and intensity of pine beetle outbreaks. Stress from drought and higher temperatures in combination with wide-scale pest outbreaks have the potential to cause broad-scale forest dieback. Planting trees with wider spacing between them and thinning existing stands in combination with competition control can increase the water available to crop trees and help prevent pest and drought-related dieback. Wider tree spacing could also reduce fuel loads and wildfire risk but increase the potential for hurricane caused blow-down (McNulty, 2002).

Coastal Plain

Coastal areas in the Southeast have already experienced an average of 1 inch of sea level rise per decade over the 20th century, a rate that will continue to increase in the future. As saltwater flooding expands, low-lying coastal wet forests could become marshland. Increasing salinity of coastal aquifers from sea level rise may affect forestlands within 3 miles of the coast. Landowners in these coastal areas can better prepare for future changes by planting more salt-tolerant trees. For farther inland areas, sea level rise can lead to higher water tables, meaning landowners may need to consider bedding as part of their site preparation activities.

3.2 Risks

Risks are the cause of ecosystem vulnerability. If there are no risks, then there would be no vulnerability. Therefore, vulnerability can be described as either the sum of all risks, or the vulnerability of a species to a single risk. In turn, risk is a function of both biotic (e.g., species present, life cycle, population size) and abiotic (e.g., climatic conditions, pollutants) attributes. A risk increases as the number of factors associated with a particular risk increase.

Pests and Invasive Species

Invasive and aggressive plant and insect species may increasingly outcompete or negatively affect native species in the future. Winter freezes currently limit many forest pests, but higher temperatures will likely allow these species to increase in number, further threatening woodlands. Destructive insects such as bark beetles will be better able to take advantage of forests stressed by more frequent drought (Ayres & Lombardero, 2000). Certain invasive plant species such as kudzu are expected to increase dramatically as they become able to tolerate a wide range of harsh conditions (Bradley, 2010).

Wildfire

Wildfire frequency is expected to increase across the region. More cloud-to-ground lightning due to warming may increase wildfire ignitions, whereas more frequent droughts will lead to drier fuels that will burn more easily and at hotter temperatures, contributing to more frequent and larger wildfires. Prescribed burning will remain an important tool for reducing fuels on forest lands, but the number of days when burning is prohibited may increase due to dry and windy conditions.

Timber

Increasing concentrations of atmospheric carbon dioxide and fluctuating temperature and precipitation levels will affect timber resources. Higher CO_2 levels generally increase growth rates in trees, but decreased water availability could offset these increased growth rates. Heat stress may also limit the growth of some southern pines and hardwood species. Intensified extreme weather events, such as hurricanes or ice storms, are also expected to lead to increased timber damage or loss.

Water Quantity and Quality

Shifts in rainfall patterns will lead to periods of flooding and drought that can significantly affect our water resources. Increases in heavy downpours and more intense hurricanes can lead to greater erosion and more sedimentation in our waterways. Longer droughts may lead to a decrease in dissolved oxygen content and poor water quality in some areas, as well as a higher demand for water. Sea level rise can increase the potential for saltwater intrusion into coastal freshwater tables.

Wildlife and Fish

Wildlife species will be affected in different ways, depending on their needs and adaptability to change. Higher temperatures may begin to change the region's grass cover from cool to warm season grasses, which could affect wildlife forage quality. Populations of large mammals such as deer and bears may increase with warmer winter temperatures because they will have less need for pre-winter food, which results in a higher winter survival rate. Birds, on the other hand, may decrease in population as vegetation types change and heat stress makes migration more difficult. To adapt, arrival date and nesting times of some common birds may start earlier in the year. However, if the cycles of insect populations become offset, migrating birds that arrive early could starve waiting for insect hatches to begin.

Fish

Warmer air and water temperatures and changes in stream flow will affect the abundance and distribution of fish species. With higher water temperatures, fish communities in northern streams will begin to resemble communities in more southerly locations. Altered stream flow patterns can lead to decreases in water quality and oxygen content. Coldwater species such as trout will be the most vulnerable to population declines with future warming.

Wetlands

Wetlands will be particularly vulnerable to changes in water supply due to changes in temperature and rainfall patterns. Wetland plant and animal communities will be affected by changes in the length of time that the wetlands hold water and by increases in extreme events such as hurricanes. Groundwater-fed wetlands not associated with a river or stream will be most vulnerable to changing climate because temperature and rainfall changes have the potential to lower groundwater table levels. Drier wetlands will be particularly vulnerable to catastrophic fires as thick organic/peat soils dry out.

Biological Diversity

Plants and animals at risk from fluctuating conditions will respond to environmental changes by adapting, moving, or declining. Species with higher genetic variation will be likelier to survive in new conditions and may increase in frequency. Higher temperatures will cause many species to shift ranges, generally moving north or up in elevation. However, in many cases, land use changes will restrict the ability of plants and animals to move into suitable habitat. The species most likely to be negatively affected by climate change will be those that are highly specialized and habitat-restricted. In many cases, invasive exotic species such as cogongrass may have the upper hand in adapting to and surviving the projected changes. Conversely, species that have a preference for a cooler climate, such as red spruce, sugar maple, beech, and hemlock, will likely be extirpated from the southeastern region.

Soil Productivity

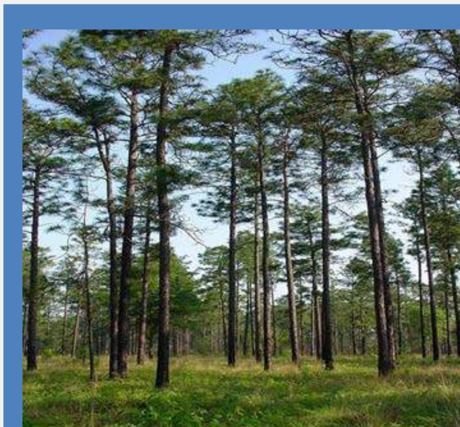
Higher temperatures and intense droughts may lead to greater decomposition of organic matter in soils, which over time, can lead to a higher risk of soil compaction if forestry best management practices (BMPs) are not used during harvests. BMPs are the standard methods in use to achieve the best results while protecting all of the natural resources and reducing nonpoint sources of pollution.

Recreation and Aesthetic Quality

Coldwater fisheries are likely to be heavily effected by warming air and water temperatures. Trout will largely be extirpated from mountain streams. Warmer temperatures will also reduce or extirpate warm-intolerant trees such as sugar maple and beech. These species are currently sporadically located across the southern mountains and provide some of the best fall foliar color. If colorful species are lost, tourism to the areas is likely to decline.

3.3 Adaptation Strategies

Timber management activities provide forest managers and landowners with an opportunity to increase forest resilience or the ability to withstand multiple threats, including drought, invasive species, disease, and wildfire. Improving forest resilience is a sound land management goal that provides multiple benefits and does not have to be costly. By using sound forest management practices that keep projected future conditions in mind, the immediate and long-term health of forest lands can be promoted, and investments against these potential threats can be protected.



Adaptive Management

- More farmers are converting conservation practices such as no-till plowing to maintain soil moisture, reduce pesticide use, and increase yields
- Foresters are changing tree harvest rotation lengths, spacing, and controlled burns to reduce wildfire, drought, and beetle caused forest mortality

Genetics

Genetically diverse and adapted seedlings are important to use. Allocation of proper seed sources to seed zones will ensure resiliency (Erickson et al., 2012). We need to maintain a diverse genetic population because extreme chronic and episodic stress associated with climate variability and change could cause forests and agricultural lands to respond to stress in previously unobserved and therefore unanticipated ways (McNulty et al., 2014).

Thinning

Periodic thinning of woodlands helps to reduce overcrowded conditions that could restrict the growth of dominant trees. Thinning can increase the water available to the remaining trees and reduce stand densities, both of which will help to minimize risk from insects, disease, wildfires, and warmer temperatures. To help minimize stress from changing environmental conditions for the life of the forest, it can be helpful to thin to slightly lower densities than are traditionally recommended (McNulty et al., 2014). Intensified pre-commercial thinning may also be necessary to remove damaged or diseased trees and to increase resources for the remaining trees.

Prescribed Fire

Prescribed fire will remain a valuable management tool in the Southeast to reduce fuel loads and the chance of wildfires and to maintain ecosystem health. However, landowners and managers will need to consider changes in the “spring green-up period” of tree and understory growth as the climate warms. Prescribed fires will need to be carried out during periods that minimize damage to the crop trees and beneficial understory species. Projected changes in temperature, rainfall patterns, and intensity of extreme events (e.g., hurricanes) may shorten the window when prescribed burns may be carried out.

Harvest

As changes in temperature and rainfall patterns affect tree growth, traditionally recommended woodland rotation lengths may need to be altered. If tree growth is significantly affected by these changes, and a different tree variety or species would grow better in those same conditions, then it may be better to harvest the established trees at a shorter rotation length and replant with the better variety. If a different tree variety or species is more resilient to forest threats and changing environmental conditions (e.g., increased hurricane risk), then it may be better to harvest the established trees at a shorter rotation length and replant. However, landowners interested in managing for carbon sequestration may want to consider rotation lengths slightly longer than the optimal length for timber production and financial returns. Additionally, leaving some residual vegetation or woody material onsite following harvests could help keep ground temperatures lower, providing better habitat for some plant and wildlife species. All of these competing factors make the choice of rotation length very complicated.

Site Preparation

Keeping some residual vegetation onsite will help lower soil temperatures and maintain nutrients and soil moisture as temperature and rainfall levels fluctuate. Wider-spaced site preparation (e.g., during bedding) could be used to help minimize future threats. Herbicide prescriptions may also need to be altered as invasive plants become more aggressive and new species move into the region. Prescribed fire will remain an important site preparation tool, but in some instances this may need to be replaced with heavy equipment or herbicide alternatives due to rainfall, air quality, or drought-related controlled burning limitations.

Planting

Tree nurseries that diversify their seedbanks by using either mixes of species or mixes of genetic traits from a single species will help forest owners protect their investment against future threats. Single-aged monocultures from one genetic origin will be the most susceptible to future threats, whereas multi-aged mixed forests consisting of species with varying traits will be the most resilient. Choosing species known to grow in a wide range of conditions and withstand disturbance, including heat and drought stress, will also help maintain forest health. The single decision of "what kind of tree seedlings to plant or regenerate" will have lasting effects on how the forest is managed for decades to come.

Fertilization

Forest productivity could potentially increase with more carbon dioxide in the atmosphere, although lower amounts of rainfall at the same time might limit this growth increase. Higher fertilization rates could allow managers to take advantage of this boost in forest productivity, especially where nitrogen is a limiting factor. However, changes in atmospheric nitrogen concentrations may lead to more nitrogen deposition in some places, and nitrogen levels may need to be monitored before any applications of fertilizer. Too much fertilization could lead to trees with a smaller root area and more canopy growth, causing greater susceptibility to future drought stress.

Tools and Resources

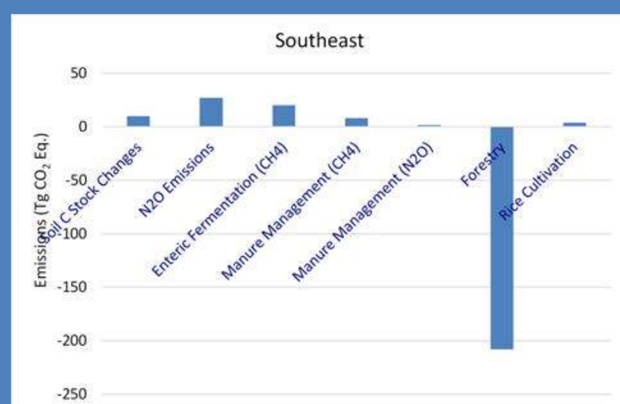
Several tools and resources exist to assist forest managers in adapting to climate change. Two modeling tools that can assist forest managers prepare for changes in climate include Tree Atlas (http://www.fs.fed.us/nrs/atlas/) and ForeCASTS (http://www.forestthreats.org/research/tools/ForeCASTS). The Template for Assessing Climate Change Impacts and Management Options (TACCIMO; http://www.taccimo.info) is a knowledge management system containing the best available science regarding climate change and forest management.

4. Greenhouse Gas (GHG) Emissions Profile from Agriculture and Forests within the Region and Mitigation Opportunities

Agriculture in the Southeast (including crop, animal, and forestry production) has net greenhouse gas (GHG) emissions of approximately −138 teragrams[4] carbon dioxide equivalent (Tg CO_2 eq.) (i.e., a net storage of GHG emissions). In the region, crop-related nitrous oxide (N_2O) emissions are the largest contributor to GHGs at 27 Tg CO_2 eq., followed by methane (CH_4) from enteric fermentation (21 Tg CO_2 eq.), CH_4 and N_2O from manure management (9 Tg CO_2 eq.), and rice cultivation (4 Tg CO_2 eq.). Forestry is the only contributor to net carbon storage at −208 Tg CO_2 eq.[5]

Southeast Region Highlights

- Corn, soybeans, hay, beef cattle, poultry, and swine are the primary agricultural commodities produced in the Southeast.
- The highest source of GHG emissions is N_2O from croplands.
- Changes in carbon storage in 2008 offset GHG emissions resulting in GHG net storage.
- The greatest mitigation potential is available from changes in land retirement management practices.
- Retiring organic soils from cultivation and establishing conservation cover provides a good opportunity for additional carbon sequestration in the region.



4.1 Soil Carbon Stock Changes

Land use and management practices for organic and mineral soil types resulted in net emissions of 9.9 Tg CO_2 eq. in 2008 (see Table 5). Specifically, cropland production changes to mineral soils sequestered 0.5 Tg CO_2 eq. (i.e., sequestering is equivalent to negative emissions), changes in hay production stored 2.0 Tg CO_2 eq., and land removed from agriculture and enrolled in the Conservation Reserve Program (which is managed by the Farm Service Agency) sequestered 0.9 Tg CO_2 eq. (see Table 5). In contrast, agricultural production on organic soils (which have a much higher organic carbon content than mineral soils) resulted in emissions of 12.2 Tg CO_2 eq.

The contribution to changes in the soil stock of carbon depends on the tillage practice. Table 6 shows the number and percent of acres in the Southeast cultivated via various tillage practices by crop type. Management practices that use reduced till or no till can contribute to greater storage of carbon over time depending on site-specific conditions.

[4] A teragram (Tg) is 10^{12} grams, which is equivalent to 10^9 kilograms or 1 million metric tons.
[5] Net carbon storage is the balance between the release and uptake of carbon by an ecosystem. A negative sign indicates that more carbon was sequestered than greenhouse gases were emitted.

Table 5: Estimates of annual soil carbon stock changes by major land use and management type, 2008

Land Uses	Emissions (Tg CO_2 eq.)
Net change, cropland[a]	0.52
Net change, hay	−2.00
Conservation Reserve Program	−0.91
Ag. land on organic soils	12.28
Total[b]	**9.89**

Source: USDA (2011)
[a] Annual cropping systems on mineral soils (e.g., corn, soybean, and wheat).
[b] Total does not include change in soil organic carbon storage on federal lands, including those that were previously under private ownership, and does not include carbon storage due to sewage sludge applications.

Table 6: Number and percent of acres by tillage practice in the Southeast

Crop Type	Acres[a]	No Till[b]	Reduced Till[b]	Conventional Till[b]	Other Conservation Tillage[b]
Corn	4,908,205	57.6%	14.8%	19.7%	7.8%
Cotton	2,852,812	32.8%	11.5%	53.5%	2.2%
Hay	6,424,403	NA	NA	NA	NA
Sorghum	174,735	4.4%	11.2%	71.2%	13.2%
Soybeans	11,234,110	45.0%	10.9%	35.5%	8.5%
Wheat	3,024,945	51.8%	19.4%	7.8%	20.9%

[a] Total acreage is 23,711,006. Source: USDA (2011).
[b] Source: USDA ERS (2011).
NA, not available.

4.2 Nitrous Oxide (N_2O) Emissions

In 2008, N_2O emissions in the Southeast were approximately 26.7 Tg CO_2 eq. Of this, 18.0 Tg CO_2 eq. was emitted from croplands and 8.7 Tg CO_2 eq. was emitted from grasslands.[6] About half of all crop-related N_2O emissions in the Southeast is from the production of soybeans, corn, and hay, and another 37 percent is from non-major crops (National Agricultural Statistics Service, 2014c).

The largest sources of N_2O direct emissions are soybeans and non-major crops (Table 7). The quantity and timing of nitrogen-based fertilizer affect the rate of both direct and indirect N_2O emissions.[7] Table 8 indicates the percent of national acres that did not meet the rate or timing criteria as defined by Ribaudo et al. (2011). Timing criteria is defined in terms of best practices for quantity and timing of fertilizer application. Meeting the best practice rate criterion is defined as applying no more nitrogen (commercial and manure) than 40 percent more than that removed with the crop at harvest, based on the stated yield goal, including any carryover from the previous crop. Meeting the best practice timing criterion is defined as not applying nitrogen in the fall for a crop planted in the spring (Ribaudo et al., 2011). Acreages not meeting the criteria represent opportunities for GHG mitigation.

[6] Including both direct and indirect emissions, Table 7 includes only *direct* emissions from crops.
[7] Direct N_2O emissions are emitted directly from agricultural fields and indirect N_2O emissions are emissions associated with N losses from volatilization of N as ammonia (NH_3), nitrogen oxides (NOx), and leaching and runoff.

Table 7: Direct nitrous oxide (N_2O) emissions by crop type

Crop Type	Direct N_2O Emissions ($Tg\ CO_2$ eq.)	% of Region's Cropland N_2O Emissions
Soybean	3.12	26.2%
Corn	1.68	14.1%
Hay	1.26	10.6%
Cotton	0.95	8.0%
Wheat	0.44	3.7%
Sorghum	0.02	0.2%
Non-major Crops	4.40	37.1%
Total	**11.8**	**100.0%**

Source: USDA, (2011).

Table 8: Percent of national acres not meeting rate and timing criteria

Crop	Not Meeting Rate	Not Meeting Timing
Corn	35%	34%
Sorghum	24%	16%
Soybeans	3%	28%
Wheat	34%	11%

Source: Ribaudo et al. (2011).

4.3 Livestock GHG Profile

Livestock systems in the Southeast focus primarily on the production of swine, beef and dairy cattle, sheep, poultry, goats, and horses. In 2008, the region had more than 1.3 billion poultry, nearly 15 million beef cattle, and more than 12 million swine (U.S. Department of Agriculture, 2011). Nearly 95 percent of the cattle in the region are beef cattle. As with patterns in livestock production across the country, the primary source of GHGs from livestock is from enteric fermentation, digestive processes that result in the production of methane (CH_4) (referred to as enteric CH_4). In 2008, livestock in the Southeast produced 20.6 Tg CO_2 eq. of enteric CH_4.[8] Most of the remaining livestock-related GHG emissions are from manure management practices that produce both CH_4 and N_2O.[9] In 2008, manure management in the Southeast resulted in 9.4 Tg CO_2 eq., considering both CH_4 and N_2O, with the majority attributed to CH_4 (U.S. Department of Agriculture, 2011).

Enteric Fermentation

The primary emitters of enteric CH_4 are ruminants (e.g., cattle and sheep). Emissions are produced in smaller quantities by other livestock, such as swine, horses, and goats.

The per-head emissions of enteric CH_4 for dairy cattle are 40 to 50 percent greater than for beef cattle (e.g., 2.2 metric tons CO_2 eq./head/year for dairy vs. 1.6 metric tons for beef in 2008 due primarily to their greater body weight and increased energy requirements for extended periods of lactation (U.S. Environmental Protection Agency, 2014). However, in the Southeast, because 95 percent of all cattle are beef, their overall contribution to enteric CH_4 emissions is much higher than it is for dairy

Table 9: Emissions from enteric fermentation in the Southeast

Animal	$Tg\ CO_2$ eq.	% of Region's CH_4 Enteric Emissions
Beef cattle[a]	17.87	86.9%
Dairy cattle[a]	2.20	10.7%
Goats[b]	0.02	0.1%
Horses[b]	0.07	0.4%
Sheep[b]	0.01	0.0%
Swine[b]	0.39	1.9%
Total	20.55	100.0%

[a] Source: USDA (2011).
[b] Source: based on animal population from USDA (2011) and emission factors as provided in IPCC (2006).

[8] The enteric CH_4 emissions total for the region includes cattle and non-cattle.
[9] Livestock respiration also produces carbon dioxide (CO_2), but the effects of ingesting carbon-based plants and expelling CO_2 result in zero-net emissions.

cattle (U.S. Department of Agriculture, 2011). Table 9 presents CH_4 emissions by animal type for 2008. As indicated, the majority of emissions are from beef and dairy cattle.

Emissions from Manure Management Systems

Manure management in the Southeast resulted in 7.9 Tg CO_2 eq. of CH_4 and 1.5 Tg CO_2 eq. of N_2O in 2008. Table 10 presents a summary of CH_4 and N_2O emissions by animal category. Swine and poultry waste account for the majority of manure-related emissions, with swine waste accounting for 62 percent of CH_4 and 20 percent of N_2O, and poultry waste accounting for 22 percent and 67 percent, respectively.

Table 10: Emissions from manure management in the Southeast, in Tg of CO_2 eq. and as a percent of regional emissions

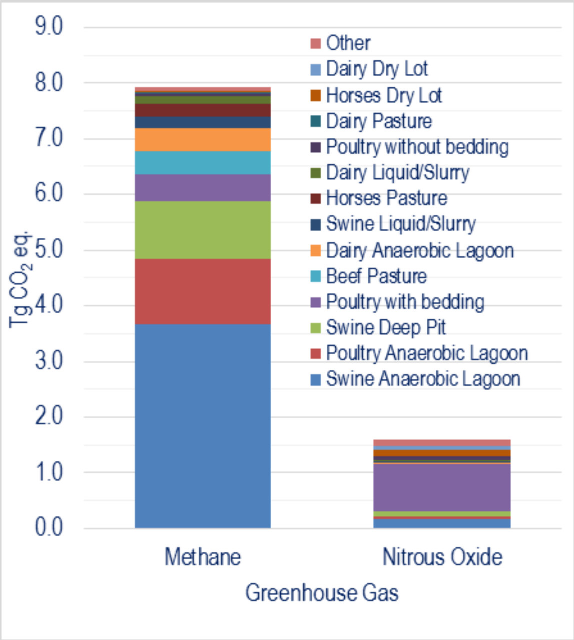
		Methane		Nitrous Oxide	
Animal	Population	Tg CO_2 eq.	Percent[a]	Tg CO_2 eq.	Percent[a]
Swine	12,282,250	4.94	62%	0.30	20%
Dairy cattle	839,213	0.62	8%	0.14	10%
Beef cattle	14,768,434	0.42	5%	0.04	3%
Poultry	1,329,999,532	1.71	22%	0.98	67%
Horses[b]	2,373,948	0.23	3%		
Sheep[b]	252,637	0.00	0%		
Goats[b]	566,806	0.00	0%		
Total	**1,361,082,820**	**7.92**	**100%**	**1.46**	**100%**

Source: USDA (2011)
[a] N_2O emissions are minimal and not included in this total.
[b] Percent of regional total.

The distribution of animal populations among different farm sizes varies across animal categories. The majority of swine and poultry are raised on large farms in the Southeast; 71 percent of swine are raised on farms with more than 5,000 head, and 67 percent of broilers are raised on farms with 100,000 head of poultry or more. Conversely, the majority of dairy cattle are managed on smaller farms, with only 9 percent of animals raised on farms with more than 2,500 head. Mitigation technologies such as anaerobic digesters[10] are more economically feasible on large-farm than small-farm operations due to economies of scale. Figure 12 provides a summary of CH_4 and N_2O emissions by animal category and baseline manure management practices.[11] The largest sources of CH_4 are anaerobic lagoons and deep pits with poultry and swine waste. The largest source of N_2O emissions is poultry with bedding. Figure 13 describes the proportion of beef cattle, dairy cattle, and swine that are managed using various manure management systems. The majority of beef waste is deposited on pasture, whereas dairy waste is mostly either deposited on pasture or managed in a dry lot system. Swine waste is managed using mostly anaerobic lagoons and deep pit systems.

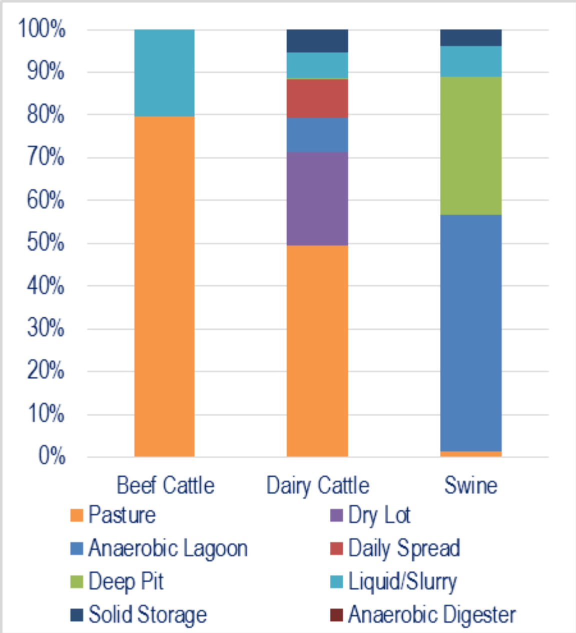
[10] Anaerobic digesters are lagoons and tanks that maintain anaerobic conditions and can produce and capture methane-containing biogas. This biogas can be used for electricity or heat, or it can be flared. In general, anaerobic digesters are categorized into three types: covered lagoon, complete mix, and plug flow digesters.
[11] Definitions for manure management practices can be found in Appendix 3-B of (ICF International, 2013).

Figure 12: CH_4 and N_2O emissions in the Southeast by animal type and management system (Tg of CO_2 eq.)



Note: Figures are from 2008. Source: EPA (2010).

Figure 13: Proportion of cattle and swine by manure management system in the Southeast



Source: EPA (2010).

4.4 Forest Carbon Stocks and Stock Changes

In the annual GHG inventory reported by the USDA, forests and harvested wood products from forests sequester 208 Tg CO_2 eq. per year in the Southeast; in addition, the 190 million acres of forest land in the Southeast maintain 40.6 Pg (i.e., 10^{15} g) CO_2 equivalent in forest carbon stocks.[12]

Managed forest systems in the Southeast focus primarily on the production of both hardwood and softwood timber, in addition to serving as riparian buffers, wind breaks, and reserved forest. Forestry activities represent significant opportunities to manage GHGs. Forest managers in the Southeast use a wide variety of silvicultural techniques to achieve management objectives, most of which will have effects on the carbon dynamics. The primary effects of silvicultural practices on forest carbon include enhancement of forest growth (which increases the rate of carbon sequestration) and forest harvesting practices (via which carbon from standing trees is transferred into harvested wood products and residues that eventually decay or are burned as firewood or pellets). Other forest management activities will result in accelerated loss of forest carbon, such as when soil disturbance increases the oxidation of soil organic matter, or when prescribed burning releases CO_2 (N_2O and CH_4). However, although prescribed burns may temporarily contribute to GHG emissions, in the longer-term (years and decades), prescribed burns reduce GHG emissions by increasing carbon sequestration through more robust forest growth. Therefore, prescribed burning is considered to have a positive effect in combating climate change and global warming.

[12] Other GHGs such as N_2O and CH_4 are also exchanged by forest ecosystems. N_2O may be emitted from soils under wet conditions or after nitrogen fertilization; it is also released when forest biomass is burned. CH_4 is often absorbed by the microbial community in forest soils but may also be emitted by wetland forest soils. When biomass is burned in either a prescribed fire/control burn or in a wildfire, precursor pollutants that can contribute to ozone and other short-lived climate forcers as well as CH_4 are emitted (U.S. Department of Agriculture, 2014).

Forest management activities and their effects on carbon storage vary widely across the Southeast depending on forest type, ownership objectives, and forest stand conditions. However, there are some common silvicultural options that are considered generalized practice in the Southeast. Several of these are presented in USDA Technical Bulletin 1939 (*Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory*) (2014); see Table 6-6 on page 6-59).

Table 11: Southeast Forest Carbon Stock and Stock Changes

Source	Units	Southeast
Net Area Change	1000 ha yr^{-1}	90
Non-Soil Stocks	Tg CO_2 eq.	23,875
SOC	Tg CO_2 eq.	16,703
Non-Soil Change	Tg CO_2 eq. yr^{-1}	-163[a]
Harvested Wood Products Change	Tg CO_2 eq. yr^{-1}	-46[a]
Forest Carbon Stock Summary (Tg CO_2 eq.)		
Non-Soil Stocks + SOC		40,578
Forest Carbon Stock Change Summary (Tg CO_2 eq. yr^{-1})		
Forest Carbon Stock Change		-208

Source: USDA (2011)
Negative values indicate a net removal of carbon from the atmosphere.

The *Forest Service 2010 Resources Planning Act Assessment* General Technical Report (2012) describes future projections of forest carbon stocks in the United States resulting from various vulnerabilities (e.g., less-than-normal precipitation, above-normal temperature) and other stressors (e.g., urbanization, other land development, demand for forest fuel and fiber). The assessment projects that "declining forest area, coupled with climate change and harvesting, will alter forest-type composition in all regions." For example, the report notes that for the Southeast, upland hardwoods are projected to decline in total area, whereas planted pine forest area is projected to increase.

Overall, the loss of forest land to other uses represents a significant threat to the ability of southeastern forests to sequester carbon and reduced the rate of GHG buildup in the atmosphere. Additionally, as forests mature, the rate of carbon sequestration slows so to maximize carbon sequestration potential, southeastern forests should be regularly harvested and replanted, with the harvested material incorporated into long-term, stable products such as lumber and furniture.

4.5 Mitigation Opportunities

Figure 14 presents the mitigation potential by sector for the Southeast. Each bar represents the GHG potential below a break-even price of $100/metric ton CO_2 eq.[13] A break-even price is the payment level (or carbon price) at which a farm will view the economic benefits and the economic costs associated with adoption as exactly equal. Conceptually, a positive break-even price represents the minimum incentive level needed to make adoption economically rational. A negative break-even price suggests that no additional incentive should be required to make adoption cost-effective; or that there are nonpecuniary factors (such as risk or required learning curve) that discourage adoption. The break-even price is determined through a discounted cash-flow analysis such that the revenues or cost savings are equal to the costs.[14] The left two bars represent reductions from changes in management practices that mitigate GHGs. The right three bars represent increased carbon storage from changes in management practices. A total of 4.1 Tg CO_2 eq. can be mitigated at a break-even price below $100/metric ton CO_2 eq. Changes in land management practices can increase carbon storage by 17.5 Tg CO_2 eq. at a break-even price below $100/metric ton CO_2 eq. The color shading within a bar represents the mitigation potential or the potential increased carbon storage below different break-even prices indicated in the legend. For example, changes in land retirement practices have the potential to contribute to 11.1 Tg CO_2 eq. of increased carbon storage for less than $20/metric ton CO_2 eq. (i.e., light blue and light green bar).

[13] Break-even prices are typically expressed in dollars per metric ton of CO_2 eq. This value is equivalent to $100,000,000 per Tg of CO_2 eq., or $100,000,000 per million metric tons of CO_2 eq.
[14] See ICF International (2013) for additional details.

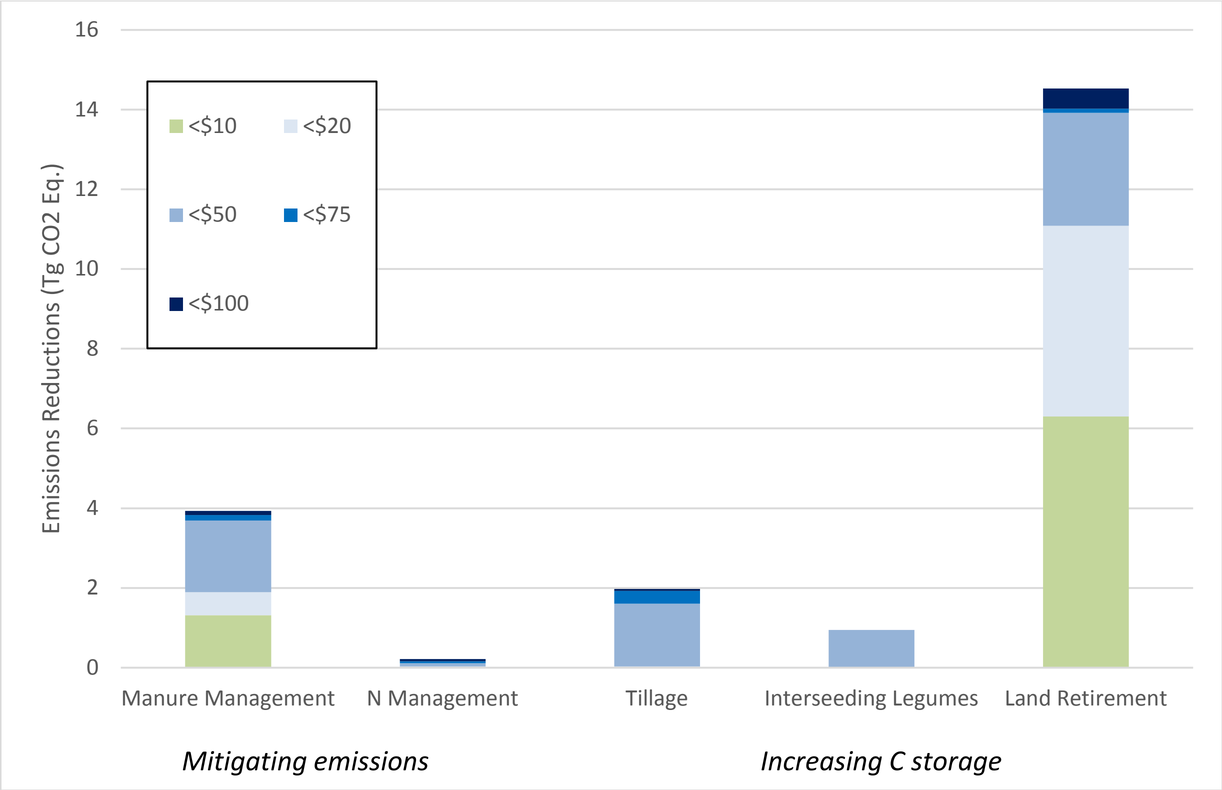


Figure 14: Mitigation potential by sector in the Southeast

- Most of the opportunity for reducing net GHG emissions is from changes in land retirement practices (i.e., retire organic and marginal soils).
- The second largest opportunity is by decreasing emissions from manure management.
- The highest reductions in emissions from manure management would be achieved by installing complete mix digesters with electricity generation, covered lagoon digesters with electricity generation or flaring, and covering existing lagoons at large swine and dairy farms, improved separators at dairy farms, and nitrification-denitrification system at large swine farms.[15]

Agricultural Soils

For farms larger than 250 acres, variable rate technology is a relatively low-cost option for reducing N_2O emissions from fertilizer application.[16] Reducing nitrogen application can be a relatively low cost option for all farm sizes. Transitioning from conventional tillage to continuous no-tillage or reduced tillage to continuous no-tillage field management practices results in relatively large potential for carbon storage at low cost (i.e., the magnitude of the carbon storage potential is orders of magnitude higher than the potential to reduce N_2O emissions). Carbon gains can be realized only if no-till is adopted permanently, otherwise gains will be reversed.

[15] The emission reduction excludes indirect emission reductions from the reduced use of fossil fuels to supply the electricity for on farm use (i.e., the emission reductions only account for emissions within the farm boundaries).
[16] Variable rate technology (VRT), a subset of precision agriculture, allows farmers to more precisely control the rate of crop inputs to account for differing conditions within a given field. VRT uses adjustable rate controls on application equipment to apply different amounts of inputs on specific sites at specific times (Alabama Precision Ag Extension, 2011).

Land Retirement

This category includes retiring marginal and organic soils from cultivation and establishing conservation cover, restoring wetlands, establishing windbreaks, and restoring riparian forest buffers. Retiring organic soil and restoring forested wetlands provide the most opportunities for increasing carbon storage.

Manure Management

The total CH_4 mitigation potential for livestock waste in the Southeast is 3.9 Tg CO_2 eq. Lower-cost GHG mitigation opportunities for manure management are used primarily by large swine and dairy farms. The greatest CH_4 reductions can be achieved on large swine and dairy farms by transitioning from anaerobic lagoons and deep pit management systems to complete mix digesters. The CH_4 can then either be used for electricity generation or converted into water vapor and CO_2 through flaring. Although CO_2 is also a greenhouse gas, the heat trapping potential for CO_2 is much less than CH_4.

Enteric Fermentation

Emissions from enteric fermentation are highly variable and are dependent on livestock type, life stage, activity, and feeding situation (e.g., grazing, feedlot). Several practices have demonstrated the potential for efficacy in reducing emissions from enteric fermentation. Although diet modification (e.g., increasing fat content, providing higher-quality forage, increasing protein content) and providing supplements (e.g., monensin, bovine somatotropin) have been evaluated for mitigation potential, the effectiveness of each option is not conclusive.

5. USDA Programs

The recently published USDA Climate Change Adaptation Plan[17] presents strategies and actions to address the effects of climate change on key mission areas including agricultural production, food security, rural development, forestry, and natural resources conservation. USDA programs administered through the Agriculture Research Service (ARS), Natural Resources Conservation Service (NRCS), U.S. Forest Service, Farm Service Agency (FSA), Rural Development (RD), Risk Management Agency (RMA), and Animal and Plant Health Inspection Service (APHIS) have been and will continue to play a vital role in sustaining working lands in a variable climate and are key partner agencies with the USDA Climate Hubs. In the Southeast, Hub partner agencies are also vulnerable to climate variability and have programs and activities in place to help stakeholders respond to climate-induced stresses.

5.1 Natural Resources Conservation Service

Natural Resources Conservation Service (NRCS) has many conservation practices and programs that can provide technical and financial assistance to help producers mitigate GHG emissions and adapt to climate change effects. A few key programs in the Southeast include soil health initiatives; Mississippi River Basin and Mississippi Delta Water Sustainability initiatives; grassed waterways; wetland restoration; windbreak implementation; and the practices of nutrient, water, and manure management. Also in the Southeast, NRCS (through its East National Technology Center, ENTSC, in Greensboro, NC) is the co-lead in the USDA Southeast Regional Climate Hub (SERCH), contributing to development and delivery of technical and educational programs, tools, and assessments for use by landowners to help with climate variability adaptation efforts at the farm, basin, and regional levels. ENTSC also leads the efforts in design, delivery, and hosting of a rich webinar series to address internal and external client needs on most aspects of conservation and climate change science and practice.

[17] The 2014 USDA Climate Change Adaptation Plan includes input from eleven USDA agencies and offices. It provides a detailed vulnerability assessment, reviews the elements of USDA's mission that are at risk from climate change, and provides specific actions and steps being taken to build resilience to climate change. Find more here: http://www.usda.gov/oce/climate_change/adaptation/adaptation_plan.htm

Other important NRCS conservation practices for cropland in the Southeast include cover crops, conservation tillage, and conservation crop rotation to increase soil resilience. Additional practices include prescribed grazing to improve pastures, manure management to reduce greenhouse gases from confined livestock operations, tree planting to sequester carbon (especially with agroforestry practices such as riparian forest buffers and silvopasture), habitat development that supports wildlife, and water management and supplemental irrigation to control both excessive runoff and drought.

The NRCS silvopasture and agroforestry practices further help mitigate climate change effects in the Southeast by providing shade for plants and animals in the hot and humid southeastern climate, which enhances productivity by reducing tree and animal heat stress. Another important element of NRCS support in the Southeast includes promoting soil resilience on cropland, as well as the overall enhancement of soil health that help mitigate the increasingly occurring drought conditions. The Southeast region is particularly vulnerable to extreme tropical storms and hurricanes that can cause beach erosion and reduction in wetland habitats, so the currently used NRCS Critical Area Planting practice and the WRP (Wetland Reserve Program) can be of significant benefit in those areas.

The Southeast has many communities with producers that historically have been underserved and resource-limited. The USDA StrikeForce Initiative, a cross-agency effort to accelerate assistance to these groups, in partnership with local community-based organizations, is working to improve USDA's outreach to these communities to increase their access to and participation in USDA conservation programs. These communities are most vulnerable to climate disturbances, and enhanced conservation on these lands is expected to equally lead to enhanced resiliency to adverse climate change effects. In the Southeast, StrikeForce is currently active in 137 counties in Arkansas, Georgia, and Mississippi where NRCS is working in three key areas to promote the initiative: 1) expediting services and the enrollment of producers in StrikeForce counties with a premium placed on providing fast service to communities in the wake of recent natural disasters; 2) devoting greater staff resources to outreach and local education seminars in the pilot states; and 3) removing barriers and identifying regulatory roadblocks to getting service to the StrikeForce counties. In fulfilling its commitment to the StrikeForce Initiative, NRCS augmented its allocations to resource limited producers in these three States by providing $6 million in additional financial and technical assistance.

NRCS also offers benefits through Conservation Innovation Grants (CIG) and interim conservation practices to further field-test and integrate promising climate-related tools and technologies. NRCS has provided grants for activities in soil health and cover crops, precision agriculture, and manure-to-energy and GHG mitigation-specific grants. Other important CIG grants include projects at major southeastern universities (i.e., University of Florida, University of Georgia, and Clemson University) and 1890 universities (i.e., Tuskegee University) to develop tools, applications, and methodologies to address agricultural drought and water management under changing climate.

All NRCS conservation practices are updated on a regular cycle to stay current with changing climate. Programs that support and promote the adoption of these practices through financial assistance, including the Environmental Quality Incentives Program (EQIP), Conservation Stewardship Program (CSP), Agricultural Conservation Easement Program (ACEP), and the Regional Conservation Partnership Program (RCPP) in addition to funding support through NRCS CIGs.

NRCS has the field service centers and thus boots on the ground in every southeastern county to help convey the needs at the field level back the Hubs while promoting conservation practices that help mitigate climate change effects and enhance adaptation and resilience. NRCS can further assist in helping farmers and other technical service providers with products that help assess and measure effects associated with climate change and the ability to adapt to these changes. NRCS maintains many databases, tools, and assessments that could be utilized directly or in conjunction with other climate-related tools.

5.2 U.S. Forest Service

The USDA Forest Service is divided into three components: State & Private Forestry, National Forest System, and Research & Development. Each section of the Forest Service has a separate focus, but each component is devoted to the sustainability of forest lands for multiple use benefits.

State and Private Forestry

The State and Private Forestry (S&PF) branch is the Federal leader in providing technical and financial assistance to landowners and resource managers to help sustain the Nation's forests and protect communities and the environment from wildland fires. S&PF works closely with State and private consultants across the Southeast to provide the tools and information to land managers. Changing climate and increasing climate variability are affecting traditional forest management practices. Conveying the need for these changes is an important component of S&PF.

National Forest System

The Southern Region of the Forest Service consists of 13 States (all 11 SERCH States plus Texas and Oklahoma) and Puerto Rico. Also known as Region 8, the Southern Region manages 13.3 million acres of National Forest System land, including 14 National Forests and two special units. The Atlanta headquarters houses 250 employees and another 3,000 are spread throughout the region.

The Forest Service works in partnership with public agencies, private organizations, tribes, watershed groups, volunteer organizations, nonprofit organizations, schools, and individuals to manage national forest resources. These include water, fish, trees, soil, recreation facilities, trails, roads, terrestrial habitats, invasive weeds, and many more. These National Forests and Grasslands are often the front line interacting with the public on natural resource management. A combination of climate change and public land pressure are complicating the ability of Forest Service managers to maintain the sustainability of these forests.

Research and Development

Forest Service research involves the translation and delivery of information and technical tools for the public and private forestry sectors. Forest and rangelands are key sinks of carbon, and carbon sequestration is increasingly an important management objective. Research in this area provides baseline tools and information to managers and provides methods to assess and manage carbon in the forests and forest products and provides management strategies to consider carbon in management strategies. The Research and Development (R&D) branch is the principal in-house forestry and natural resource research arm of USDA. The Southern Research Station employs 130 scientists in Research Work Units across the country who examine the direct and indirect effects of climate change on the nation's forests, rangelands, and urban ecosystems.

A section of R&D focuses on climate variability and translating these projections into potential effects on forest, rangeland, and urban ecosystems. These effects include changes in species composition, appearance, and function due to invasive plants, insect outbreaks, pathogens, fire, drought, and forest fragmentation (among others). The resulting information is used to assess vulnerability and devise management strategies to keep these ecosystems healthy, resilient, and productive. Forest Service Research Stations assist land managers in assessing vulnerabilities, at times with direct publication of assessments or synthesis reports, but also indirectly by providing models and tools for land managers to use. Such efforts are underway throughout the country. Forest Service R&D also provides the information needed to develop appropriate adaptation actions to provide maintain or increase ecosystem resilience, diversity, and productivity.

Forest Service Cooperative Forestry Program

The Forest Service Cooperative Forestry program works with States, private landowners, and other partners to promote healthy forests and livable communities throughout the United States. In partnership with State forestry agencies, Cooperative Forestry currently manages a number of programs, including the Forest Stewardship Program (FSP). This program helps private forest landowners develop plans for the sustainable management of their forests. S&PF's Forest Health Protection's mission is to protect and improve the health of America's rural, wildland, and urban forests. Forest Health Protection provides technical assistance on forest health-related matters, particularly those related to disturbance agents such as native and nonnative insects, pathogens, and invasive plants. In addition, Forest Health Protection provides forest insect, disease, and invasive plant survey and monitoring information, and technical and financial assistance to prevent, suppress, and control outbreaks threatening forest resources. More than 250 specialists in the areas of forest entomology, forest pathology, invasive plants, pesticide use, survey and monitoring, suppression and control, technology development, and other forest health-related services provide expertise to forest land managers throughout the nation. The Urban and Community Forestry Program encourages States, Federally recognized tribes, and other partners to focus financial, educational, and technical assistance on helping localities improve the resilience of their urban and community forests in response to climate-related stressors.

National Agroforestry Center

The USDA National Agroforestry Center (NAC) is a partnership between the Forest Service and NRCS to accelerate the application of agroforestry through a national network of partners. NAC conducts research, develops technologies and tools, coordinates demonstrations and training, and provides useful information to natural resource professionals (http://nac.unl.edu/). Agroforestry will likely become an increasingly important tool under a changing climate. Very high air temperatures can have negative effects dairy production, beef cattle weight gain, animal mortality, and forage quality and quantity. Properly used, agroforestry also has benefits for the establishment of forest species that could be susceptible to mortality from the increased climate variability and change.

Programs and Measures Addressing Climate Change

Much of the efforts toward addressing the risks and vulnerabilities within the Southeast have been focused on building organizational capacities and creating region-wide relevance. Numerous partnerships with mutual interests in ecosystem restoration and climate change have been developed. Local ecosystem restoration partnerships have been formed to develop resilience in restored systems at the landscape scale. Restoration initiatives for bottomland hardwoods, longleaf pine, and shortleaf pine ecosystems have been put in place region-wide with partnerships that include numerous public and private partners.

Science development and transfer has focused on regionalizing and localizing climate projections, interpreting effects and interactions with other stressors, and synthesizing and delivering results for the public and land managers. The Southern Research Station has committed significant resources to address science development and transfer. The Eastern Forest Environmental Threat Assessment Center (EFETAC) was established under the Healthy Forests Restoration Act as part of a network of early warning activities established by the Forest Service nationwide to generate, integrate, and apply knowledge to predict, detect, and assess environmental threats to eastern U.S. public and private forests and to deliver this knowledge to managers in ways that are timely, useful, and user friendly. A partnership between EFETAC and National Forest System has generated a risk assessment document for the Southern Appalachians titled *Forest Tree Genetic Risk Assessment System* (Potter & Crane, 2010). The USDA Southeastern Regional Climate Hub has been established with partners to deliver science-based knowledge and practical information to farmers, ranchers, and forest landowners that will help them to adapt to climate change and weather variability by coordinating with local and regional partners in Federal and state agencies, universities, nongovernmental organizations, private companies, and tribes.

The Forest Service Southern Research Station and Southern Region a set of synthesis products that project scenarios and interactions of threats to southern forests, including climate change (Wear & Greis, 2013). The Template for Assessing Climate Change Effects and Management Options (TACCIMO) was established in partnership with the National Forest System in the Southern Region to deliver available science, scaled and localized to their information needs and questions. Climate Change *Adaptation, Mitigation, and Management Options: A Guide for Natural Resource Managers in Southern Forest Ecosystem*s provides a synthesis of the best available science for guiding climate change response for forest managers in the southern United States (Vose & Klepzig, 2013).

Partnerships are vital for effectively addressing and managing the risks and vulnerabilities from climate change. The Southern region has worked cooperatively to establish strong partnerships for managing national forests and State and private lands through shared strategies with other forest and land management partners. National forests interact with these partners and the public to address climate change through national Forest Management Act forest planning, initially under the 1982 Planning Rule, and currently under the 2012 Planning Rule. Forest plan monitoring and broader-scale monitoring is being established for all national forests under the requirements of the 2012 Planning Rule. Southern Region national forests are following and implementing the Forest Service Climate Change Roadmap and Climate Change Scorecard to build forest-level climate change capacity, relationships, adaptation, and mitigation.

5.3 Farm Service Agency

The mission of the Farm Service Agency (FSA) is to deliver timely, effective programs and services to America's farmers and ranchers to support them in sustaining our Nation's agricultural economy, as well as to provide important support for domestic and international food aid efforts. The southeastern offices of FSA work with producers as they address the challenges of growing crops in an environment of climate variability through four central goals that include a financial safety net against climate variability effects on harvest; increased natural resource stewardship leading to increased resiliency; commodities procurement and distribution efficiency and equity; modernizing and transforming the FSA to meet growing needs.

The Conservation Reserve Program (CRP) is the largest conservation program administered by FSA. This important program has been removing marginally productive lands for at least 10 years. This action allows the land to become more climate resilient through the accumulation of soil organic matter and the creation of a repository for carbon sequestration.

Producers are required to have a conservation plan for their farms as a condition of participation in FSA loan, price support, disaster relief, and conservation programs. This is one mechanism that addresses a few of the manifestations of climate variability. These conservation plans are created in concert with NRCS, and they address such issues as soil erosion and water conservation. Additionally, these plans could be modified as strategies emerge to address the emerging effects of climate variability.

Producers are expected to use BMPs to receive loans and program benefits from FSA. Although loan officers do not require BMPs, their adoption and use may influence loan decisions because of their effect on yield and the farm's potential profitability. Additionally, members of FSA county committees are responsible for assessing a farmer's practices when evaluating the extent of benefits they might extend. Strategies that help the at-large agricultural community could easily be incorporated into a BMP protocol. As such, FSA would be a good conduit for helping educate producers. FSA has hundreds of offices throughout the southern United States and these are frequently integrated with extension services in promoting educational efforts.

5.4 Rural Development

Rural development represents the infrastructure around which goods from working lands are produced. Any stress or disruption of the rural networks will have an immediate and significant effect on southeastern forest, agriculture, and rangeland productivity. The loss of electrical power due to greater storm frequency or intensity could lead to high rates of mortality for hog, poultry, and dairy cattle. Direct damage to structures could be equally problematic. Flooding and wildfires can destroy or block access and transport of livestock and produce, thereby causing spoilage and loss of commodity value. The infrastructure of rural areas may need to be reinforced or reengineered to account for these increasing stresses.

Warmer air temperatures and changes in the precipitation pattern could increase the need for irrigation across the Southeast. Conversely, overuse of water supplies (particularly groundwater) could lead to conflicts between agricultural and metropolitan was use. These types of conflicts have already occurred in southern Georgia and northern Florida. New infrastructure (e.g., interbasin water transfers, (Caldwell et al., 2015)) or management practices (e.g., switch from center pivot to drip irrigation) may be needed to meet future water demand needs.

In addition to these programs and grants, RD is modifying how it conducts business in the face of a changing climate. For example, the (2014) Rural Development Climate Change Adaptation Plan applies to all three RD agencies. The plan was prepared to in support of Departmental efforts to respond to EO 13514 (Federal Leadership in Environmental, Energy, and Economic Performance) as well as DR 1070-001. The Planning Document discusses increased efforts at risk assessment and identifies five specific actions related to climate change planning and adaptation.

Programs and Measures Addressing Climate Change

Rural Housing Service

The Rural Housing Service (RHS) administers programs that provide financial assistance (i.e., loans and grants) for quality housing and community facilities for rural residents within the Southeast.

RHS will implement several measures in an effort to reduce the effects of climate change and become more resilient to adverse effects predicted to be incurred by flooding, storm surges, hurricanes, tropical storms, and other severe weather that could adversely affect structures funded through RHS programs. For example, RHS provides training on the proper siting of facilities/infrastructure for the life of a structure in locations where the effects from climate change (e.g., sea level rise, other potential flooding) will not adversely affect the facility or the surrounding environment.

Additionally, in an effort to reduce the effects of climate change, RHS provides funding for programs that have been designed to lessen the need for fossil fuels, promote renewable energy, and increase energy efficiency. The overall goal is to make rural areas more climate resilient.

Rural Business-Cooperative Service

The Rural Business-Cooperative Service (RBS) administers programs that lessen the need for fossil fuels, promote biomass utilization and renewable energy, and increase energy efficiency within all of the Climate Hub regions. The Rural Energy for America Program lowers the demand on base plants by investing in energy efficiency and renewable energy. Lower base load demand conserves water and helps to reduce greenhouse gases that contribute to climate change. Renewable energy investments can provide extra resiliency by distributing energy resources. RBS is investing in alternative fuels, renewable chemicals, biogas, wastewater conservation, and harvesting combustible material that results from thinning forests for use in advanced biofuels.

Rural Utilities Service

The Rural Utilities Service (RUS) administers programs that provide clean and safe drinking water and sanitary water facilities, broadband, telecommunications, and electric power generation and transmission/distribution within all of the Climate Hub regions. RUS administers several programs to help improve resiliency and lessen the effects of droughts, floods, and other natural disasters and to increase energy efficiency. For example, grants through the National Rural Water Association (NRWA) are designed to promote energy-efficient practices in small-water and wastewater systems. Additionally, NRWA conducts energy assessments, recommends energy-efficient practices and technologies, and provides support to land owners in achieving recommendations.

Climate change effects often extend beyond individual agency missions. Therefore, a Memorandum of Agreement signed between the U.S. Environmental Protection Agency (EPA) and RUS is meant to promote sustainable rural water and wastewater systems. The goals are to increase the sustainability of drinking water and wastewater systems nationwide to ensure the protection of public health, water quality, and sustainable communities, to ensure that rural systems have a strong foundation to address 21st century challenges, and to assist rural systems to implement innovative strategies and tools to allow them to achieve short- and long-term sustainability in management and operations.

Grants and programs have been developed to achieve the joint EPA/RUS goals. For example, EPA Emergency Community Water Assistance Grants (ECWAG) are designed to assist rural communities that have experienced a significant decline in quantity or quality of drinking water due to an emergency, or if such decline is considered imminent. Grants are to be used to obtain or maintain adequate quantities of water that meet the standards set by the Safe Drinking Water Act. Emergencies are considered to include incidents such as drought, earthquake, flood, tornado, hurricane, disease outbreak, or chemical spill, leakage, or seepage. The Electric Program–Energy Efficiency and Conservation Loan Program (EECLP) is designed to assist electricity borrowers to implement demand-side management, energy efficiency, and conservation programs, and on-grid and off-grid renewable energy systems. Goals of the program include increasing energy efficiency at the end-user level; modifying electric load such that there is a reduction in overall system demand; affecting a more efficient use of existing electric distribution, transmission, and generation facilities; attracting new businesses and creating jobs in rural communities by investing in energy efficiency; and encouraging the use of renewable energy fuels for either demand-side management or the reduction of conventional fossil fuel use within the service territory.

In addition to grants and programs, RUS is modifying engineering design standards and approved materials requirements as the RUS electric program envisions greater incorporation of climate change-related effects as it revised its standards and materials for RUS-financed infrastructure. Already, some borrowers in coastal areas have received agency approval for ‘hardened’ electric poles and lines.

5.5 Risk Management Agency

The Risk Management Agency (RMA) provides a variety of a crop- and livestock-related insurance products to help farmers and ranchers manage the risks associated with agricultural production. Coverage is provided against agricultural production losses due to unavoidable natural perils such as drought, excessive moisture, hail, wind, hurricane, tornado, lightning, and insects. In 2014, RMA’s National liability was $109.8 billion. The 11 states located in the Southeast Climate Hub region accounted for $14.4 billion in liability in 2014. The region’s primary insured crops include citrus, flue-cured tobacco, fresh market tomatoes, corn, soybeans, sugarcane, pecans, onions, avocadoes, peanuts, and peaches. These policies provide financial stability for agricultural producers and rural communities and are frequently required by lenders.

RMA strives to improve the effectiveness of programs by refining insurance offers to recognize changes in production practices, and where appropriate, adjusting program parameters (e.g., premium rates, planting dates) within each county to recognize structural changes to the risks of growing the crop in those areas. In that regard, RMA monitors climate change research and, to the extent that climate changes emerge over time, updates these program parameters to reflect such adaptation or other changes. RMA also updates loss adjustment standards, underwriting standards, and other insurance program materials to ensure that they are appropriate for prevailing production technologies.

In the Southeast Climate Hub region, RMA's regional office in Jackson, Mississippi manages crop insurance programs in Arkansas, Kentucky, Louisiana, Mississippi, and Tennessee. The regional office in Valdosta, Georgia manages crop insurance programs in Alabama, Florida, Georgia, and South Carolina. The regional office in Raleigh, North Carolina manages crop insurance programs in North Carolina and Virginia.

In 2010, RMA's crop insurance national liability (book of business) was $78 billion. In 2014, RMA's national liability was $109.8 billion. The 11 states in the Southeast Climate Hub region accounted for more than $11 billion in liability in 2010, and the liability increased to more than $14.4 billion in 2014. The region's book of business is citrus, flue-cured tobacco, fresh market tomatoes, corn, soybeans, sugarcane, pecans, onions, avocadoes, peanuts, peaches and numerous other crops.

5.6 Animal and Plant Health Inspection Service

APHIS is responsible for protecting and promoting U.S. agricultural and forest health, regulating certain genetically engineered organisms, enforcing the Animal Welfare Act, and carrying out wildlife damage management activities. APHIS works to defend U.S. plant and animal resources from agricultural and forest pests and diseases. Once a pest or disease is detected, APHIS works in partnership with affected regions to manage and eradicate the outbreak. In its Strategic Plan[18] for 2015, APHIS lists seven goals:

1. Prevent the entry and spread of agricultural pests and diseases.
2. Ensure the humane treatment and care of covered vulnerable animals.
3. Protect forests, urban landscapes, rangelands and other natural resources, as well as private working lands from harmful pests and diseases.
4. Ensure the safety, purity, and effectiveness of veterinary biologics and protect plant health by optimizing our oversight of genetically engineered organisms.
5. Ensure the safe trade of agricultural products, creating export opportunities for U.S. producers.
6. Protect the health of U.S. agricultural resources, including addressing zoonotic disease issues and incidences, by implementing surveillance, preparedness and response, and control programs.
7. Create an APHIS for the 21st century that is high-performing, efficient, adaptable, and embraces civil rights.

APHIS works to achieve these goals through the actions of several mission area programs and support units. The text below describes the APHIS programs and their respective responsibilities, as well as their expected vulnerabilities related to a changing climate, and the measures in place to minimize risks from these vulnerabilities. As an agency with nationwide regulatory concerns, APHIS programs are typically national in scope and application.

Animal Care (AC)

The mission of the AC program is to protect animal welfare by administering the Animal Welfare Act and the Horse Protection Act. AC also protects the safety and well-being of pet owners and their pets during disasters by supporting the Federal Emergency Management Agency (FEMA).

AC's supporting role in these efforts may be vulnerable to climate change. An increase in the frequency and severity of storms as the climate warms may increase the need for evacuations and other response

[18] http://www.aphis.usda.gov/about_aphis/downloads/APHIS_Strategic_Plan_2015.pdf

activities. In anticipation of the increase in emergency response activities, AC proactively organizes and participates in emergency planning together with FEMA, Emergency Support Function (ESF) #11,[19] and other response partners to strengthen the nation's capacity to respond to natural disasters.

Biotechnology Regulatory Services (BRS)

BRS implements the APHIS regulations for genetically engineered (GE) organisms that may pose a risk to plant health. APHIS coordinates these responsibilities along with EPA and the Food and Drug Administration as part of the Federal Coordinated Framework for the Regulation of Biotechnology.

Although no BRS actions are directly "vulnerable" to climate change, they may shift geographically if climate change affects the distribution of agricultural crops and other plants that BRS regulates. For example, if growing areas for regulated GE plants shift, BRS would need to conduct field inspections in those new locations.

BRS has in place a flexible staffing plan and practice—not all of its staff members are centrally located; they are set up to provide mobile inspection service to wherever GE crops are growing in field trials. Additionally, BRS receives reports each year from those holding permits for conducting field trials. BRS uses this information to plan inspections throughout the life cycle of the field trials. The flexibility and regular use of new information inherent in BRS planning and practice will help minimize risks from climate change.

Plant Protection and Quarantine (PPQ)

PPQ is responsible for safeguarding and promoting U.S. agricultural health. PPQ is constantly working to defend U.S. plant and forest resources from agricultural pests and diseases. Once a quarantine plant pest or disease (one not previously found in the U.S. or if found, is under official control) is detected, PPQ works in partnership with affected regions to manage and eradicate the outbreak. PPQ has three strategic goals:

1. Strengthen PPQ's pest exclusion system.
2. Optimize PPQ's domestic pest management and eradication programs.
3. Increase the safety of agricultural trade to expand economic opportunities in the global marketplace.

In the face of an increasingly variable climate and more erratic weather conditions, PPQ will continue to play a central role in responding to risk and managing vulnerabilities. In this capacity, PPQ operates on the international and national levels, with regional emphasis as needed, to address and divert pest incursions.

PPQ is tasked with assessing risk and predicting where an invasive plant pest may be introduced, establish, and spread; these assessments are often based on climatic conditions and host availability. As climate changes, host distribution and landscape conditions deviate from what is considered "normal." PPQ assessments are based on available data that often reflect past conditions. As climate changes, the actual relevance of these data may lessen our ability to accurately predict and understand risk.

Some of the challenges in predicting future risk under climate change require a shift from analyzing mean responses (e.g., an increase of 2 to 3 degrees temperature on average) and instead to focus on trying to understand how pest invasiveness and the potential for establishment change with greater weather variability and more extreme events. For example, several years of warmer than normal weather can allow the establishment of invading pest populations and result in their spread to new areas. Once arriving in new areas, if such pest populations can secure warmer microclimates to survive the winter, they can become more prevalent earlier the following season. Anticipating global trade shifts in response to

[19] http://www.fema.gov/pdf/emergency/nrf/nrf-esf-11.pdf

climate change is another challenge, as is the subsequent risk of new crop pests and diseases associated with them.

PPQ partners with other agencies, universities, and the Climate Hubs to increase our capacity to obtain and analyze data and implement models that inform climate change-specific policies and pest programs. PPQ is increasing its capacity to perform pest risk modeling at regional, national, and global levels with new platforms. These platforms are designed to project climate change scenarios onto the landscape to model geographic shifts in climatic suitability and host availability. PPQ is also developing phenological models that can be used to analyze how climate change and greater weather variability might affect temporal sequencing of pest development and subsequent population response. Being able to produce robust projections of such shifts will improve the efficacy of PPQ's early detection surveillance programs conducted in cooperation with States and Territories.

Veterinary Services (VS)

VS is responsible for regulating the importation and inter-State movement of animals and their products to prevent the introduction and spread of foreign animal diseases of livestock. If a foreign animal disease is detected in the United States, VS is responsible for responding to the outbreak in coordination with States, Territories, tribes, and producers. VS also regulates the licensing of veterinary biologics such as vaccines.

Changing Vector Distribution

Vulnerabilities

Climate change is expected to enhance the dispersal and redistribution of arthropod vectors along with their ability to transmit economically important pathogens, potentially allowing their spread from areas where they are already established to new locations. This change in distribution could result in significant increases in morbidity and mortality to livestock, wildlife, and people, along with a reduction in market value of animals from affected areas.

Current measures to address vulnerabilities

VS conducts passive—as well as some active—surveillance for arthropod-borne diseases such as equine piroplasmosis, bovine babesiosis (Texas cattle fever), vesicular stomatitis virus (VSV), equine encephalitis viruses (EEE, WEE, and VEE),[20] and hemorrhagic disease viruses (EHDV and BTV).[21] This surveillance activity may help identify any changes in vector populations and pathogens and inform recommended changes to disease surveillance and production practices. VS could identify other mitigations through further research. Such projects may include using climate models and scenario analyses to identify geographic areas likely to undergo environmental changes that would lead to an increased risk of infection with selected pathogens, and simulating economic effects of potential vector and pathogen range expansion to livestock and wildlife industries.

Increased Wildlife-Livestock Interaction

Vulnerabilities

Increased pest infestation, fires, and expansion of the wilderness-urban interface could alter wild animal distribution, movements, and feeding patterns, thereby increasing contact and the potential for disease exchange with agricultural animal populations. For example, sudden oak death pathogen (*Phytophthora ramorum*) may lead to widespread tree death and fires followed by variable regrowth in forested and transient grassy areas as trees regrow. Habitat suitability may improve for species such as white-tailed

[20] Eastern, western, and Venezuelan equine encephalitis viruses, respectively.
[21] Epizootic hemorrhagic disease virus and blue tongue virus, respectively.

deer and feral swine, which could increase contact and subsequent disease transmission between these wild species and livestock.

Current measures to address vulnerabilities

VS is a collaborator in a new APHIS Wildlife Services–led program to investigate and mitigate agricultural and natural resource damage and disease risks from feral swine, including several studies in the southeastern United States. VS is also involved in studying and responding to wildlife-livestock interactions with regard to disease transmission, such as tuberculosis and brucellosis, which can be spread through contact with free-ranging cervids, including white-tailed deer, as well as other wildlife.

Emerging Infectious Diseases

Vulnerabilities

In the Southeast, the potential for more extreme hurricane seasons and precipitation events could have direct effects on vegetation and could create favorable ecological niches for emerging infectious diseases of animals (e.g. (de la Rocque et al., 2008)).

Potential measures to address vulnerabilities

Advocating for heightened awareness of potentially emerging diseases can result in the identification of newly emerging diseases in a timely manner.

Current measures to address vulnerabilities

Studies planned or underway in the Southeast on vectors and vector-borne diseases may help address early identification of emerging diseases and inform decisions on the control of the vectors of diseases such as cattle fever ticks (*Rhipicephalus annulatus* and *R. microplus*), which have been predicted to spread north from Mexico and Texas, possibly to Virginia.

Heat Stress on Livestock

Vulnerabilities

In highly optimized, intensive livestock production systems, small changes in maximum temperatures can reduce productivity through decreases in weight gain or milk production or through losses of livestock.

Potential measures to address vulnerabilities

Measures to mitigate heat stress on livestock may include increasing shade for pastured herds (Nash & Galford, 2014) and increasing air circulation (e.g., ventilating fans) and cooling capacity (e.g., sprinkler or mist systems) for housed cattle and other livestock (Adaptation Subcommittee to the Governor's Steering Committee on climate change, 2010; Griffin, 2009; Wolfe et al., 2011). When constructing new facilities, dairy farmers are advised to base their plans on climate expectations for the 21st century as opposed to what they have already experienced during their lives (Wolfe et al., 2011). An important consideration is the significant expense of installing ventilation and cooling systems. Wolfe et al. (2011) notes that farmers with larger herds may find their investments more cost-effective than average due to their economies of scale. In addition to enhancing cooling capacity, feeding adjustments provide another adaptation strategy. Such adjustments include the use of more digestible forages, supplements to enhance digestion and replace mineral losses, feeding during cooler periods of the day, and ensuring that cows have access to sufficient water (Wolfe et al., 2011). Research can also help dairy farmers by breeding animals genetically more tolerant to various climate-related pressures, including heat stress and pathogen and parasite outbreaks (Division of Energy and Climate, 2014).

Aquaculture

Vulnerabilities

Marine and freshwater food fish populations have already declined significantly due to warming waters and the attendant effects that include acidification, oxygen depletion, algal blooms, and increased pathogen loads. These effects exacerbate effects of overharvesting, which has depleted many wild fish populations. Decreases in the wild fish catch place more pressure on the aquaculture industry for higher production and mitigation of health effects.

Potential measures to address vulnerabilities

As demands on the aquaculture industry for fish protein increases, we will rely more heavily on coordinated efforts targeting disease control and improved health of aquaculture species. VS partners with the commercial aquaculture industry and Federal and State agencies to work collectively to protect and certify the health of farm-raised aquatic animals and facilitate their trade and to safeguard the nation's wild aquatic animal populations and resources.

Policy and Program Development (PPD)

PPD performs economic, environmental, and other analyses to support the actions of APHIS programs. PPD analyses would be more robust over time if they were better able to incorporate economic and environmental effects of climate change to relevant agricultural systems and ecosystems. Robust projections of climate change and its effect on the distribution of production areas for various commodities, as well as anticipated needs for commodity movements at an international and domestic scale, can inform our economic analyses. These projections, along with information on pollinators, water, and other resources, as well as effects on low-income, minority, and tribal communities, will better inform our environmental analyses.

PPD is incorporating climate change into many of its environmental compliance (e.g., National Environmental Policy Act; NEPA) documents and is leading an agency-wide effort to develop guidance for addressing climate change in our NEPA documents.

Wildlife Services (WS)

The mission of WS is to provide Federal leadership and expertise to resolve wildlife conflicts to allow people and wildlife to coexist. WS conducts program delivery, research, and other activities through its regional and State offices, the National Wildlife Research Center (NWRC), and its Field Stations, as well as through its national programs. Because the work of WS is greatly influenced by distributions of wildlife, which are expected to shift as the climate changes, much of this work will be changing, as well. The following examples reflect some of those changes that are likely to effect the Southeast.

Managing diseases spread by wildlife

Climate change will likely have dramatic effects on the distribution of both agricultural diseases of concern as well as on zoonotic diseases, both of which can be spread by wildlife. It is expected that endemic disease risks will decrease in some areas, whereas new diseases may emerge in other areas where they were not previously documented. Given the sensitivity of insect vectors to changes in weather-related variables, it is likely that initial changes in disease distribution resulting from climate change will take place for those diseases that are vector-borne. WS NWRC is conducting surveillance and research on diseases and vectors to gather baseline data on their distribution for use in climate change models and future studies. WS NWRC also maintains tissue archives of wildlife samples that are made available for retrospective research on diseases to identify changes in pathogen distribution and prevalence.

Wildlife management to protect agriculture

WS conducts research and management on wildlife and invasive species, such as feral swine, that can have a significant effect on agricultural commodities. As climate changes, the distribution of these species and the agricultural crops they affect will also change. Information on population densities and distribution of target species is important for understanding how climate change will affect production of these agricultural commodities.

Predator management

As climate changes, landscapes and habitats may also shift along with changes in prey distribution and abundance. Changes in native vegetation, and therefore forage, will alter feeding patterns of native wildlife, which will alter the distribution of predators, such as mountain lions, black bears, and coyotes. These shifts will influence the distribution and abundance of such predators and will alter the predictive ability of models related to spatial patterns, behavior, abundance, and habitat use by predators. Results of climate-informed models may be needed to inform predator management strategies to adapt to climate change. WS NWRC researchers are gathering data on changes in species distribution and abundance, behavior, and habitat use for predators from around the country that are already affected by climate change (e.g., polar bears) and will use these studies as a foundation for incorporating climate change into studies of species found locally. WS NWRC is also incorporating climate change models into projections about future habitat availability for predators.

5.7 Additional Needs

The process of change to create effective performance to address climate change risks and vulnerabilities has evolved toward agreement and consensus about the science and appropriate responses. Continued leadership at Federal, State, and private levels is needed to demonstrate, facilitate, and enable effective responses to climate change risks and vulnerabilities.

The processes for climate change science development, transfer, and application have matured to the point that climate change risks and vulnerabilities are largely understood. Continued technology transfer of this understanding to resource management is needed. Science development is needed to address specific forest and resource conditions, such as species response and assisted migration, fuels and fire regime changes, and infrastructure standards for locations within the southeastern region.

Partnerships address restoration that should support resistance and resilience to climate change. Opportunities to address shared concerns specific to climate change adaptation and mitigation need to be identified and developed in these partnerships.

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