United States Department of Agriculture
Forest Service

Francis Marion National Forest

Draft Forest Plan Assessment

Francis Marion National Forest, Berkeley and Charleston Counties, South Carolina

Sections 3.1, 3.2 and 3.3 Additional System Drivers Introduction, Climate Change and Insects & Diseases

December 2013

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Francis Marion National Forest
Draft Forest Plan Assessment
Berkeley and Charleston Counties, South Carolina

Lead Agency:	**USDA Forest Service**
Responsible Official:	**John Richard Lint, Forest Supervisor** **Francis Marion and Sumter National Forests**
For Information Contact:	**Mary Morrison, Forest Planner** **4931 Broad River Road** **Columbia, SC 29212** **803-561-4000**
Email Comments or Questions to:	**fmplanrevision@fs.fed.us**
Documents are Posted at:	**http://www.fs.usda.gov/scnfs**

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3 Additional System Drivers

3.1 Introduction

This section includes information regarding the primary system drivers and stressors on the Francis Marion National Forest. These include climate change, insects and disease, wildland fire/fuels, invasive species, natural vegetation succession, natural disturbance, and human disturbance.

3.2 Climate Change

The best available science information provided in this section is based on models and literature derived through the use of the Template for Assessing Climate Change Impacts and Management Options (TACCIMO) (http://www.taccimo.sgcp.ncsu.edu/).

3.2.1.1 Preliminary Findings

1. There is no direction in the 1996 Forest plan that responds to climate change.

2. Long-term monitoring on the Santee Experimental Forest found a statistically significant increase in air temperatures over the 63-year period from 1946 to 2008, with an average increase of about 0.3 °F per decade (Dai et al. 2011). Mean annual daily minimum temperatures were found to increase at an even greater rate of about 0.5 °F per decade (Dai et al. 2011). Changes in precipitation were small over the 63-year period; however, seasonally there was a slight increase in fall and winter rainfall and a decrease in spring and summer rainfall (Dai et al. 2011).

3. Future projections specific to the Francis Marion National Forest are based on the A2 (high) emissions scenario. All of the projections indicate warming with median (50^{th} percentile) annual average temperatures increasing by 1.2 °F for the time period 2010 to 2039. Even the most conservative ensemble considered (25^{th} percentile) estimates 1.1 °F of warming during the same time period, which is greater than the range of uncertainty considered (25 to 75^{th} percentile) of 0.5 °F (Girvetz et al. 2009; Maurer et al. 2007).

4. Precipitation projections seem to indicate a generally wetter future, with a median increase of 2.8 percent for the 2010 to 2039 time period. However, this change is well within the range of uncertainty considered (25 to 75^{th} percentile) of 4.0 inches for 2010 to 2039 (Girvetz et al. 2009; Maurer et al. 2007). In addition, changing climate variability is expected to continue to lead to more intense rainfall events and longer periods of drought in the future (Breshears et al. 2005).

5. All seasonal averages show warming, with the greatest change occurring in the fall and the least change occurring in the winter (increase of 1.0 °F) for the timer period 2010 to 2039. In all cases the projected changes are greater than the 25 to 75^{th} percentile range, which represent the level of model uncertainty considered. Seasonal precipitation projections seem to indicate a trend toward a wetter fall with less pronounced changes in other seasons. However, this change is well within the range of uncertainty considered (25to 75^{th} percentile) of 2.3 inches for 2010 to 2039 (Girvetz et al. 2009; Maurer et al. 2007).

6. Airborne particulate matter is expected to decrease as precipitation increases; however, a climate-driven increase in wildfires can potentially increase both particulate and ozone concentrations (Jacob and Winner 2009).

7. Due to increased climate variability, destructive insects, such as bark beetles, will be better able to take advantage of forests stressed by more frequent drought (Duehl et al. 2011; Gan 2004).

Certain invasive plant species, including cogongrass (Bradley et al. 2010), are expected to increase dramatically as they are able to tolerate a wide range of harsh conditions, allowing them to rapidly move into new areas (Hellmann et al. 2008).

8. Wildfire frequency is expected to increase across the Southeast region in the future (Heilman et al. 1998). Prescribed burning will remain an important tool to reduce fuels on Forest lands, but the number of days when burning is prohibited may increase, due to dry, windy conditions (Liu et al. 2012).

9. The potential for severe storms is expected to increase in the future, including less frequent but more intense hurricanes making landfall in the southern U.S. (Emanuel 2005), with potential increases in both inland flooding and coastal storm surge events (Seneviratne et al. 2012).

10. Depressional wetlands, such as Carolina bays, will be particularly vulnerable to changing climate because temperature and rainfall changes have the potential to lower groundwater table levels, altering the length of time that wetlands hold standing water (Stroh et al. 2008; Erwin 2009). Any changes in the hydrology of these wetlands may lead to forest vegetation encroachment into historically herbaceous areas (De Steven and Toner 2004).

11. Rising seas, in combination with more intense hurricanes, will alter the composition of coastal marshes (Day et al. 2008; Voss et al. 2012). Tidal forests, including bald cypress swamps, may serve as sentinels for sea-level rise, due to their low tolerance to salinity changes. The loss of tidal forests would have potentially negative consequences for wildlife species such as endangered wood storks that often nest in cypress swamps (Craft 2012).

12. Sea-level rise will increase the potential for saltwater intrusion into coastal freshwater tables. Increasing salinity of coastal aquifers may affect groundwater resources within 3 miles of the coast (Langevin and Zygnerski 2012).

13. An increase in disturbance may promote longleaf pines at the expense of loblolly pine, as longleaf pines are more resilient to wind damage (Bragg et al. 2003; Johnsen et al. 2009). Populations of bald cypress may be particularly vulnerable to future changes, including higher air and water temperatures (Middleton 2009; Middleton and McKee 2004) as well as increased salinity with sea-level rise (Krauss et al. 2009).

14. Higher temperatures will cause many species to shift ranges, generally moving to track their suitable habit (e.g., northward or up in elevation) (McKenney et al. 2007; Heller and Zavaleta 2009). However, in some cases, the rate of warming combined with land use changes will restrict the ability of plants and animals to move into suitable habitat (Hitch and Leberg 2007; Pickles et al. 2012).

15. Freshwater mussel species already declining in the region may see increased risk with future changes, as impacts from land use changes in combination with drought-induced low water levels and high summer temperatures may potentially extirpate thermally sensitive mussel populations (Galbraith et al. 2010; Golladay et al. 2004).

16. Amphibians may be most at risk among terrestrial wildlife species, due to dependencies on moisture and cool temperatures that could be altered in a future climate (Corn 2005; Blaustien et al. 2010).

17. With more days with extreme heat, recreation areas could see decreased use in the summer if temperatures impact visitor comfort (Richardson and Loomis 2004; Scott et al. 2004).

3.2.1.2 Background

The background information disclosed in this section on climate change will be used to help in the following ways:

- Determine the effects of climate change on air quality (i.e., ozone and smoke).
- Determine the effects of climate change on precipitation, evapotranspiration patterns, temperature and drought.
- Determine the effects of land use, projects, and activities, and other stressors on hydrologic and geomorphic processes and water resources. Determine the effects of climate change on sources of drinking water. Determine if rising sea level may impact ground water.
- Evaluate changes in predominant climatic regimes, evaluating climate characteristics such as precipitation, temperature, growing season, or drought.
- Evaluate broad-scale natural disturbance regimes, including wildfire, wind, hurricanes, sea-level rise, flooding, and insects and disease where applicable.
- Evaluate invasive plant species, and how this may change based on a changing climate.
- Evaluate natural vegetation succession, and how this may change based on a changing climate.
- Evaluate plant species composition and how this may change based on a changing climate.
- Evaluate the ability of ecosystems within the plan area to adapt to changes. Adaptation of ecosystems may occur through functional redundancies and/or evolutionary or behavioral adaptations of species.
- Consider the influence of changing climate on key ecosystem characteristics to evaluate their vulnerability to potential future conditions and ability to provide ecosystem services and other benefits to society.

3.2.1.3 Current Condition and Trends

The Francis Marion National Forest is experiencing increased threats from fire, insect and plant invasions, disease, extreme weather, and drought. Scientists project increases in temperature and changes in rainfall patterns that can make these threats occur more often, with more intensity, and/or for longer durations.

Current Climate

In evaluating historic climate two estimates are made for temperature and precipitation. One is based on observed (Gibson et al. 2002; PRISM) historic data, the other is based on predictive models (global climate models; GCMs). The intent of providing multiple representations of current climate is to establish a chain of logic enabling analysis of future projections at coarser scales (about 12 kilometers) with respect to historic reference conditions that are observationally based and available at finer scales (about 4 kilometers). Having both representations of current climate available supports an understanding of the strengths and weaknesses of current and future projections and limitations related to scale. The Girvetz et al. (2009) representation of current climate will serve as the baseline for comparison with future climate projections in subsequent sections of this report.

Recent Climate Change. Long-term monitoring on the Santee Experimental Forest found a statistically significant increase in air temperatures over the 63-year period from 1946 to 2008, with an average increase of about 0.3 °F per decade (Dai et al. 2011). Mean annual daily minimum temperatures were found to increase at an even greater rate of about 0.5 °F per decade (Dai et al. 2011). Changes in precipitation were small over the 63-year period; however, seasonally there was a slight increase in fall and winter rainfall and a decrease in spring and summer rainfall (Dai et al. 2011).

Current Annual and Seasonal Temperature. GCM and PRISM annual average temperature estimates for the time period 1980 to 2009 differ by 0.8 °F, with PRISM estimating 64.7 °F and the median GCM estimating 65.0 °F (Table 3-1). GCM and PRISM seasonal average estimates temperature over the same time period are quite similar in the summer, winter, and fall (less than 0.2 °F difference) and most different in the spring (differ by 0.8 °F).

Table 3-1. Summary of annual and seasonal historic temperature (°F) from 1980–2009

	Annual	Dec–Feb	Mar–May	Jun–Aug	Sep–Nov
Observed Historic (PRISM; Gibson et al. 2002)	64.7	49.0	63.7	79.9	66.1
Predicted Historic (GCM[1]; Maurer et al. 2007)	65.0	49.1	64.5	80.1	66.1

[1] Average of the median A2 ensemble value (Girvetz et al. 2009).

Current Annual and Seasonal Precipitation. GCM and PRISM annual average precipitation estimate for the time period 1980 to 2009 differ by 0.5 inches, with PRISM estimating 50.6 inches and the median GCM estimating 51.1 inches (Table 3-2). GCM and PRISM historic estimate of seasonal average estimates precipitation over the same time period are most similar in the winter and spring (differ by less than 0.3 inches) and most different in the summer and fall (0.6 inches and 1.1 inches, respectively).

Table 3-2. Summary of annual and seasonal historic precipitation (inches) from 1980–2009

	Annual	Dec–Feb	Mar–May	Jun–Aug	Sep–Nov
Observed Historic (PRISM; Gibson et al. 2002)	50.6	10.5	10.4	17.5	12.3
Predicted Historic (GCM[1]; Maurer et al. 2007)	51.1	10.6	10.7	18.1	11.2

[1] Average of the median A2 ensemble value (Girvetz et al. 2009).

Future Climate

Accounting for uncertainty is an essential step when considering projections of future climate. Uncertainty in climate projections comes from model uncertainty, uncertainty about future rates of greenhouse gas emissions, and uncertainty related to the spatial and temporal scales of analysis. Considering multiple climate models and evaluating model agreement is one approach for addressing model uncertainty. Uncertainty about future greenhouse gas emission rates is addressed by considering high (SRES A2) and low (SRES B1) emissions scenarios. However, emissions scenarios only begin to differ significantly in the second half of the 21st century and therefore model uncertainty captures the majority of uncertainty in the first half of the century. In addition, considering the high emissions scenario reduces simplifies the analysis while highlighting key trends. Finally, spatial and temporal uncertainty is addressed by comparing results for a given location and time period with results produced for broader geographic areas and longer time periods. This information is available at broader scales from previous published analyses (e.g., national and regional assessments).

The climate projections summarized within this report are drawn from a comprehensive and accessible inventory of downscaled climate data available for the conterminous U.S. The ensembles derived by Girvetz et al. (2009) provide efficient insight into the broad range of model variability from 16 nationally downscaled climate models, which is particularly valuable in the context of gauging uncertainty, especially in the near term. The 25to 75th percentile (interquartile range) of models was selected to define the range of uncertainty considered in this analysis because it captures the range that the majority of models agree on without emphasizing extremes. The analysis focused on the SRES A2 (high) emissions scenario because our planning horizon is focused on the first half of the 21st century, where emissions scenarios only differ slightly and model uncertainty is the largest contributor to overall uncertainty. In addition, considering the highest emissions (worst case) is the most useful scenario for the purposes of identifying potential issues of concern.

Future projections considered here are consistent with expectations found in the literature for the southern U.S. for both annual and seasonal projections. Karl et al. (2009) discussed annual changes ranging from 4.5 °F to 9 °F by the 2080s for the B1 and A2 scenarios, respectively. Sobolowski and Pavelsky (2012) found that seasonal temperatures would increase by 4.5 °F in the summer and 3.2 °F in the winter and spring by the time period 2040 to 2070.

Future projections specific to the Francis Marion National Forest are based on the A2 (high) emissions scenario (Girvetz et al. 2009; Maurer et al. 2007). All of the projections indicate warming with median (50th percentile) annual average temperatures increasing by 1.2 °F for the time period 2010 to 2039. Even the most conservative ensemble considered (25th percentile) estimates 1.1 °F of warming during the same time period, which is greater than the range of uncertainty considered (25 to 75th percentile) of 0.5 °F. Precipitation projections seem to indicate a generally wetter future, with a median increase of 2.8 percent for the 2010 to 2039 time period. However, this change is well within the range of uncertainty considered (25 to 75th percentile) of 4.0 inches for 2010 to 2039.

Trends in Annual Temperature and Precipitation. See Table 3-3 and Figure 3-1 and Figure 3-2.

Table 3-3. Summary of mean annual historic and future climate under the A2 scenario

Temperature (° F)						Precipitation (Inches)								
Absolute			Change			Absolute			Absolute Change			% Change		
25th	50th	75th	25th	50th	75th	25th	50th	75th	25th	50th	75th	25th	50th	75th
64.9	65.0	65.3	-	-	-	49.3	51.1	52.1	-	-	-	-	-	-
66.0	66.3	66.5	1.1	1.2	1.1	50.5	52.6	54.5	1.2	1.4	2.3	2.5	2.8	4.5
67.9	68.1	68.3	3.0	3.1	3.0	51.3	53.0	54.8	2.0	1.8	2.7	4.2	3.6	5.1
69.9	70.5	71.1	5.0	5.5	5.8	48.8	55.3	56.4	-0.5	4.2	4.3	-1.0	8.1	8.2

Source: Girvetz et al. (2009) and Maurer et al. (2007).

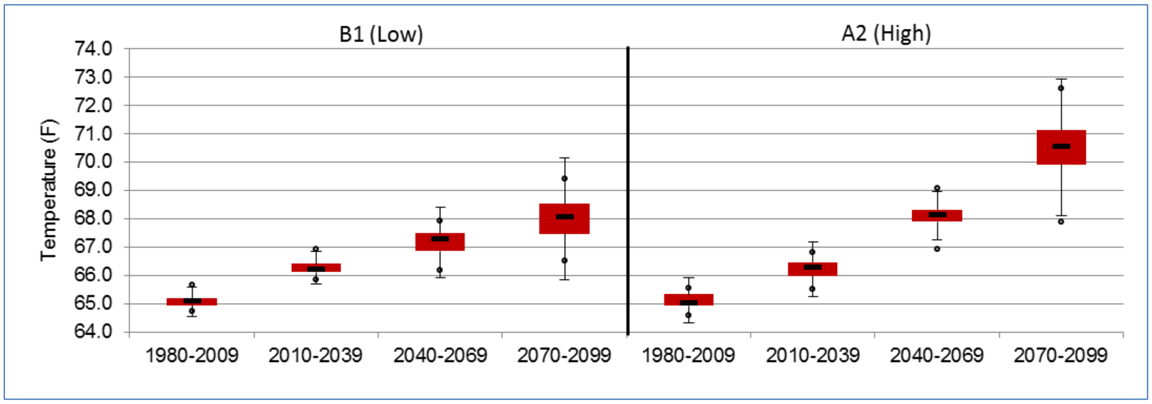

Figure 3-1. Box and whisker plots of projected mean annual temperature

Note: Box and whisker plots of projected mean annual temperature depicting the 25–75th percentile (interquartile range; IQR, or 75th percentile minus the 25th percentile) as the red box with the median value marked with a dash. The error bars represent uncertainty as calculated from 1.5*IQR, with potential outliers (maximum and minimum ensembles) represented by small circles (Girvetz et al. 2009; Maurer et al. 2007).

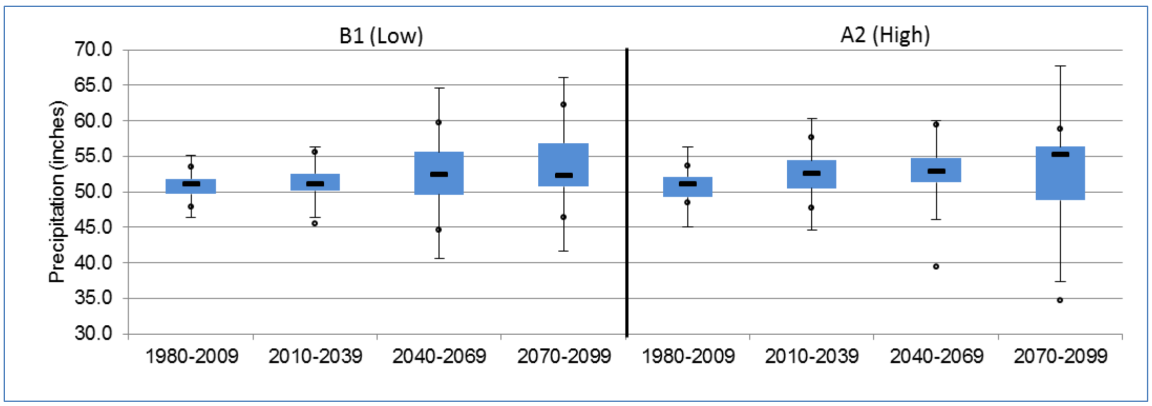

Figure 3-2. Box and whisker plots of projected mean annual precipitation

Note: Box and whisker plots of projected mean annual precipitation depicting the 25–75th percentile (interquartile range; IQR, or 75th percentile minus the 25th percentile) as the blue box with the median value marked with a dash. The error bars represent uncertainty as calculated from 1.5*IQR, with potential outliers (maximum and minimum ensembles) represented by small circles (Girvetz et al. 2009; Maurer et al. 2007).

Trends in Seasonal Temperature and Precipitation (Table 3-4; Figure 3-3 and Figure 3-4). All seasonal averages show warming, with the greatest change occurring in the fall and the least change occurring in the winter (increase of 1.0 °F) for the timer period 2010 to 2039. In all cases the projected changes are greater than the 25 to 75th percentile range, which represent the level of model uncertainty. Seasonal precipitation projections seem to indicate a trend toward a wetter fall with less pronounced changes in other seasons. However, this change is well within the range of uncertainty considered (25 to 75th percentile) of 2.3 inches for 2010 to 2039.

Table 3-4. Summary of mean seasonal historic and future climate under the A2 scenario

		Temperature (° F)						Precipitation (Inches)								
		Absolute			Change			Absolute			Absolute Change			% Change		
		25th	50th	75th	25th	50th	75th	25th	50th	75th	25th	50th	75th	25th	50th	75th
Winter	**1980-2009**	48.8	**49.1**	49.8	-	**-**	-	10.1	**10.6**	11.1	-	**-**	-	-	**-**	-
	2010-2039	49.8	**50.1**	50.7	1.0	**1.0**	0.9	10.1	**10.8**	11.6	0.0	**0.1**	0.5	0.5	**1.1**	4.1
	2040-2069	51.1	**51.6**	52.5	2.4	**2.5**	2.7	9.5	**10.7**	12.1	-0.6	**0.1**	1.0	-6.1	**0.5**	8.7
	2070-2099	52.9	**53.5**	54.3	4.2	**4.4**	4.5	9.9	**11.2**	12.3	-0.2	**0.5**	1.2	-2.3	**4.8**	10.4
Spring	**1980-2009**	64.2	**64.5**	64.9	-	**-**	-	10.2	**10.7**	11.2	-	**-**	-	-	**-**	-
	2010-2039	65.2	**65.6**	65.9	1.0	**1.1**	1.0	10.4	**11.1**	11.8	-0.8	**0.3**	0.4	2.6	**3.5**	4.7
	2040-2069	66.8	**67.4**	68.0	2.6	**2.9**	3.1	9.7	**10.5**	11.1	-1.8	**-0.5**	-0.2	-4.6	**-2.0**	-0.8
	2070-2099	69.1	**69.8**	70.5	4.9	**5.3**	5.6	9.1	**10.1**	11.1	-3.1	**-1.1**	-0.6	-10.4	**-5.7**	-1.0
Summer	**1980-2009**	79.9	**80.1**	80.4	-	**-**	-	17.3	**18.1**	18.8	-	**-**	-	-	**-**	-
	2010-2039	81.0	**81.3**	81.7	1.1	**1.2**	1.3	16.5	**18.1**	20.3	-0.8	**0.0**	1.5	-4.5	**0.1**	8.2
	2040-2069	83.0	**83.3**	83.8	3.1	**3.2**	3.4	16.1	**18.3**	20.6	-1.2	**0.3**	1.8	-7.2	**1.4**	9.8
	2070-2099	85.4	**85.9**	86.9	5.5	**5.8**	6.5	16.6	**18.8**	21.2	-0.7	**0.8**	2.4	-3.9	**4.2**	12.9
Fall	**1980-2009**	65.8	**66.1**	66.6	-	**-**	-	10.5	**11.2**	12.2	-	**-**	-	-	**-**	-
	2010-2039	67.1	**67.7**	67.9	1.3	**1.6**	1.3	11.0	**11.8**	13.3	0.5	**0.7**	1.0	4.4	**6.0**	8.6
	2040-2069	68.7	**69.5**	70.0	2.9	**3.3**	3.4	11.6	**12.5**	13.6	1.1	**1.3**	1.3	10.2	**11.4**	11.0
	2070-2099	71.1	**71.9**	73.0	5.3	**5.7**	6.4	11.8	**13.1**	14.3	1.3	**1.9**	2.0	12.2	**16.8**	16.6

Source: Girvetz et al. (2009) and Maurer et al. (2007).

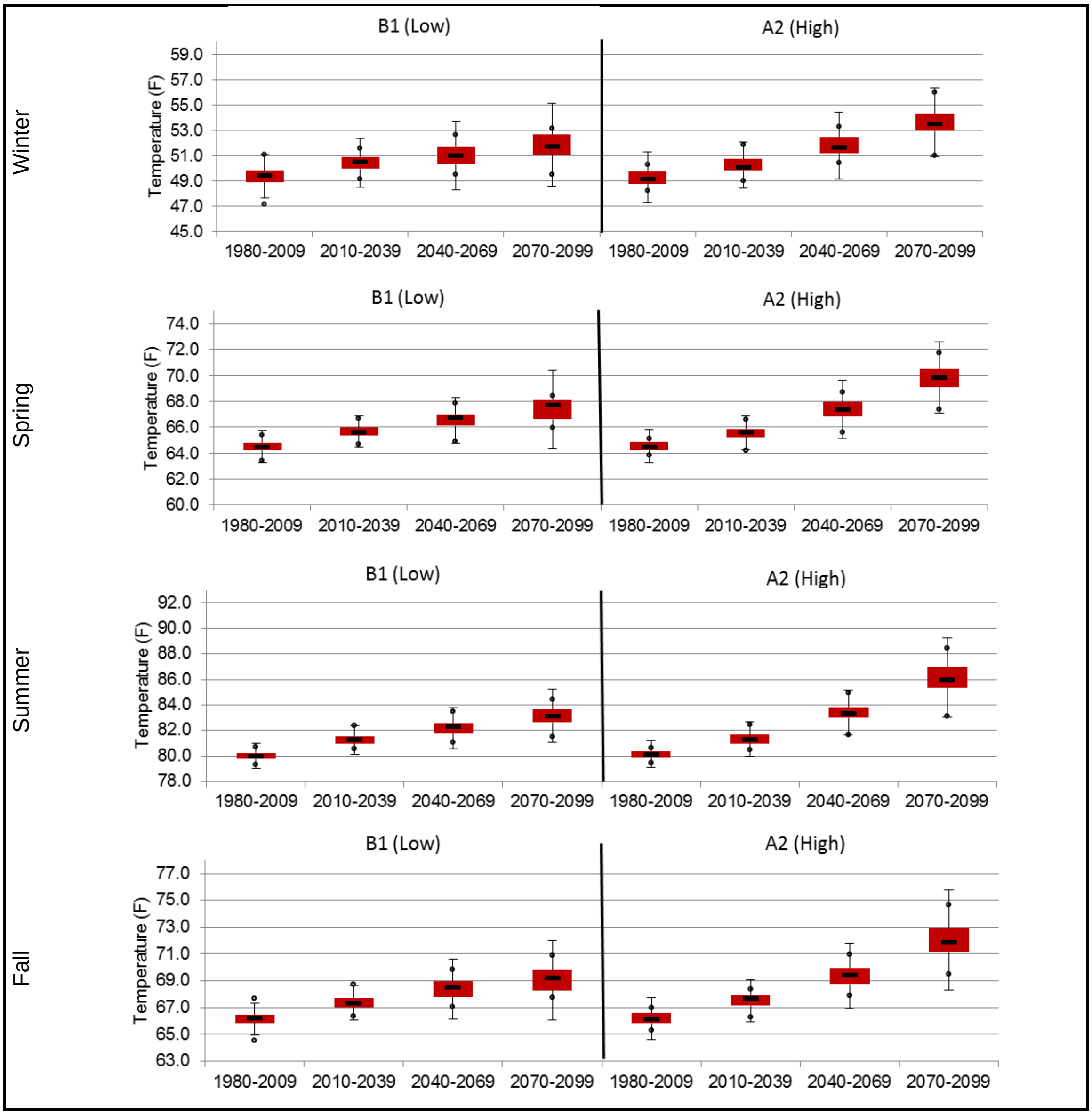

Figure 3-3. Box and whisker plots of projected mean seasonal temperature

Note: Box and whisker plots of projected mean seasonal temperature depicting the 25th–75th percentile (interquartile range; IQR, or 75th percentile minus the 25th percentile) as the red box with the median value marked with a dash. The error bars represent uncertainty as calculated from 1.5*IQR, with potential outliers (maximum and minimum ensembles) represented by small circles (Girvetz et al. 2009; Maurer et al. 2007).

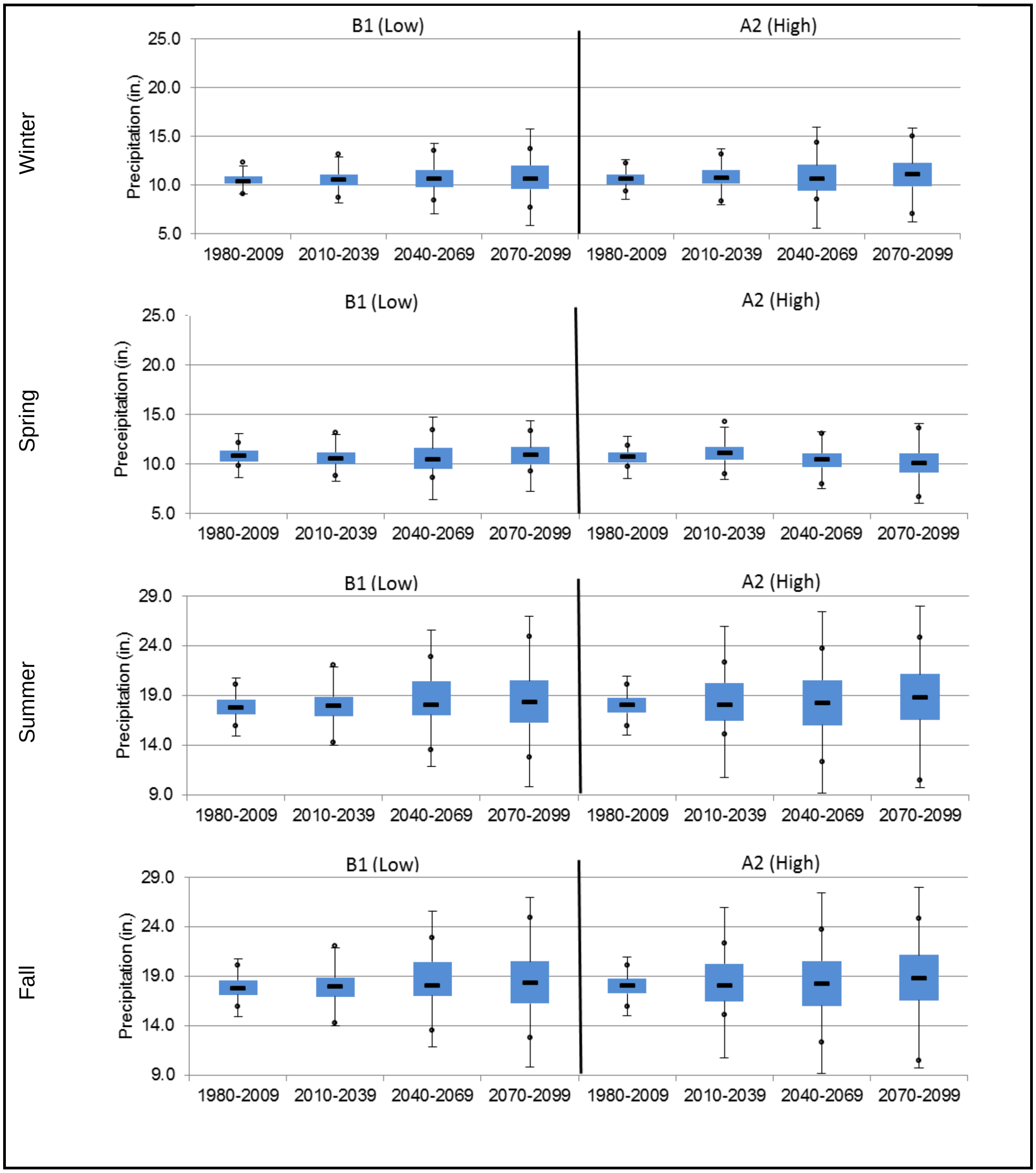

Figure 3-4. Box and whisker plots of projected mean seasonal precipitation

Note: Box and whisker plots of projected mean seasonal precipitation depicting the 25–75th percentile (interquartile range; IQR, or 75th percentile minus the 25th percentile) as the blue box with the median value marked with a dash. The error bars represent uncertainty as calculated from 1.5*IQR, with potential outliers (maximum and minimum ensembles) represented by small circles (Girvetz et al. 2009; Maurer et al. 2007).

Potential Effects of Climate Change

Air Quality. Climate change may affect the distribution patterns and concentrations of air pollutants through changing wind and precipitation patterns (Bytnerowicz et al. 2007) as well as increased temperatures (Bedsworth 2011). Increases in summer temperatures can increase the severity and duration of air pollution episodes potentially offsetting any future reductions in emissions (Wu et al. 2008). Airborne particulate matter is expected to decrease as precipitation increases; however, a climate-driven increase in wildfires can potentially increase both particulate and ozone concentrations (Jacob and Winner 2009). An increase in nitrogen deposition is also predicted (Civerolo et al. 2008), which could lead to acid loading in forest streams (McNuly and Boggs 2010).

Biological Diversity. Plants and animals at-risk will respond to environmental changes by adapting, moving, or declining (Aitken et al. 2008). Species with high genetic variation will be better able to survive in new conditions. Higher temperatures will cause many species to shift ranges, generally moving to track their suitable habit (e.g., northward or up in elevation) (McKenney et al. 2007; Heller and Zavaleta 2009). However, in some cases, the rate of warming combined with land use changes will restrict the ability of plants and animals to move into suitable habitat (Hitch and Leberg 2007; Pickles et al. 2012). The species most likely to be negatively impacted by climate change will be highly specialized and habitat restricted (Rodenhouse et al. 2009).

Forest Health. With changing climatic variability, invasive and aggressive plant and insect species may increasingly outcompete or negatively affect native species in the future (Dukes et al. 2008; Hansen et al. 2001). Winter freezes currently limit many forest pests, and higher temperatures will likely allow these species to increase in number (Morrison et al. 2005). Destructive insects, such as bark beetles, will be better able to take advantage of forests stressed by more frequent drought (Duehl et al. 2011; Gan 2004). Certain invasive plant species, including cogongrass (Bradley et al. 2010), are expected to increase dramatically as they are able to tolerate a wide range of harsh conditions, allowing them to rapidly move into new areas (Hellmann et al. 2008).

Wildland Fire and Fuels. Wildfire frequency is expected to increase across the Southeast region in the future (Heilman et al. 1998). More cloud-to-ground lightning due to warming may increase wildfire ignitions (Podur and Wotton 2010), while more frequent droughts and forest stress will lead to drier fuels which will burn more easily and at hotter temperatures, contributing to more and bigger wildfires (Flannigan et al. 2000). Prescribed burning will remain an important tool to reduce fuels on Forest lands, but the number of days when burning is prohibited may increase, due to dry, windy conditions (Liu et al. 2012).

Extreme Weather. The potential for severe storms is expected to increase in the future, including less frequent but more intense hurricanes making landfall in the southern U.S. (Emanuel 2005), with potential increases in both inland flooding and coastal storm surge events (Seneviratne et al. 2012). Hurricane events are likely to become more severe, with increased wind speeds, rainfall intensity, and storm surge height (Knutson et al. 2010; Karl et al. 2009). On the other hand, droughts have become more common in the Southeast since the 1970s, and changing climate variability is expected to continue to lead to longer periods of drought in the future (Breshears et al. 2005). As annual temperatures increase, extreme heat events will occur with increasing regularity, while the amount of freezing days will decline (Nicholls and Alexander 2007).

Water Resources. Shifts in rainfall patterns will lead to periods of flooding and drought that can significantly impact water resources (Seager et al. 2009). Increases in heavy downpours and more intense hurricanes can lead to greater erosion and more sedimentation in waterways (Karl et al. 2009; Carpenter et al. 1992). Increased periods of drought may lead to decreasing dissolved oxygen content and poor water quality in some areas (Mulholland et al. 1997). Depressional wetlands, such as Carolina bays, will be particularly vulnerable to changing climate as temperature and rainfall changes have the potential to lower groundwater table levels, altering the length of time that wetlands hold standing water (Stroh et al. 2008; Erwin 2009). Any changes in the hydrology of these wetlands may lead to forest vegetation encroachment into historically herbaceous areas (De Steven and Toner 2004). Higher temperatures will cause increased evapotranspiration that is predicted to further water stress, decreasing the water available to both forests (Lu et al. 2009) and wetlands (Pitchford 2011).

Coastal Ecosystems. Coastal areas in the Southeast have already experienced an average of 1 inch of sea-level rise per decade over the 20th century (Kemp et al. 2009), a rate that will continue to increase in the future (Pfeffer et al. 2008). Rising seas, in combination with more intense hurricanes, will alter the composition of coastal marshes (Day et al. 2008; Voss et al. 2012). As saltwater flooding expands, low-lying coastal wet forests could become marshland where land use barriers do not exist (Erwin et al. 2006). Tidal forests, including bald cypress swamps, may serve as sentinels for sea-level rise, due to their low tolerance to salinity changes. The loss of tidal forests would have potentially negative consequences for wildlife species such as endangered wood storks that often nest in cypress swamps (Craft 2012). Sea-level rise can also increase the potential for saltwater intrusion into coastal freshwater tables. Increasing salinity of coastal aquifers may affect groundwater resources within 3 miles of the coast (Langevin and Zygnerski 2012).

Terrestrial Ecosystems. Heat stress may limit the growth of some southern pines and hardwood species (Iverson et al. 2008). Additional stresses from drought, in combination with wide-scale pest outbreaks, have the potential to cause broad-scale forest dieback (Allen et al. 2010). Intensified extreme weather events, such as hurricanes, ice storms, and fire, are also expected to lead to changes in natural vegetation succession and plant community composition (Walther 2003). An increase in disturbance may promote the establishment of longleaf at the expense of loblolly pine, as longleaf pine is more resilient to wind damage (Bragg et al. 2003; Johnsen et al. 2009). Populations of bald cypress may be particularly vulnerable to future changes, including higher air and water temperatures (Middleton 2009; Middleton and McKee 2004) as well as increased salinity with sea-level rise (Krauss et al. 2009).

Aquatic Ecosystems. Increases in temperature and changes in precipitation patterns leading to lower baseflows and altered hydrology in streams and lakes will affect both plant and animal species in aquatic environments (Mulholland et al. 1997). Increased frequency of droughts can lead to poor water quality and habitat squeezes (Ficke et al. 2007), reducing diversity and increasing the incidence of waterborne diseases (Rahel and Oden 2008). Higher temperatures will negatively affect coolwater adapted fishes, including striped bass (Coutant 1990) and Atlantic and shortnose sturgeons (Waldman 2011), while warmwater adapted species may expand in range (Meyer et al. 1999). Fish kills due to high summertime temperatures are likely to become more common in shallow waters of the Southeast (Stefan et al. 2001; Fang et al. 2004). Freshwater mussel species already declining in the region may be most at-risk with future changes, as impacts from landuse changes in combination with drought-induced low water levels and high summer temperatures may potentially extirpate thermally sensitive mussel populations (Galbraith et al. 2010; Golladay et al. 2004).

Wildlife. Wildlife species will be affected in different ways, depending on their needs (Currie 2001). Amphibians may be most at-risk, due to dependencies on moisture and cool temperatures that could be altered in a future climate (Corn 2005; Blaustien et al. 2010). Birds may see a decrease in population size as vegetation types change, and heat stress makes migration more difficult (Matthews et al. 2004). In order to adapt, arrival date and nesting times of some common birds may start earlier in the year (Torti and Dunn 2005). Species with small population sizes and low genetic diversity, such as red-cockaded woodpecker, may not be able to adapt, making them susceptible to further population declines (Schiegg et al. 2002). On the other hand, populations of large mammals such as deer and bear may increase with warmer winter temperatures due to a higher winter survival rate (Ayres and Lombardero 2000).

Recreation. Environmental changes may negatively impact recreational experiences due to changes in the plant and animal communities that make those recreational experiences unique (Joyce et al. 2009; Irland et al. 2001). Fishing in coastal marshes could be affected, as intense storm events and rising sea levels may lead to degraded habitat conditions for game fish (Najjar et al. 2000). More days above freezing could increase tick and mosquito populations throughout the year (Erickson et al. 2012; Runyon et al. 2012). With more days with extreme heat, recreation areas could see decreased use in the summer if temperatures impact visitor comfort (Richardson and Loomis 2004; Scott et al. 2004).

These effects are discussed in more detail under the "Trends" sections of this report.

3.3 Insects and Disease

3.3.1.1 Preliminary Findings

1. As discussed in annual monitoring and evaluation reports, native insects and diseases have generally remained at endemic levels and not caused significant problems during the life of the current plan. Outbreaks could always occur, however, and they always seem to eventually happen with southern pine beetle where host species are present.

2. The Forest has aged 17 years since the current plan was signed. The older age classes of trees on the Forest have reduced vigor and increased susceptibility to pests. As of April 2013, 10 percent of the Forest is over 100 years of age, 29 percent is over 803. A higher expected level of tree mortality due to increased age and increased susceptibility to pests is consistent with the desired condition on page 1-4 of the 1996 plan.

3. Since this Forest plan has been in place, a new nonnative disease has come into the Forest. Laurel wilt is a disease of redbay (*Persea borbonia*) and other plant species in the family Lauraceae. It is causing widespread mortality in the coastal regions of South Carolina, Georgia, Florida, and North Carolina.

3.3.1.2 Existing Information

Several species of potentially damaging native insects and diseases remain endemic in the ecosystems of the Francis Marion National Forest. As noted in recent annual monitoring reports, two of the most common diseases, fusiform rust and annosum root rot, have remained present, but have not caused any significant problems during the life of the current plan. Southern pine beetle populations have generally been low through most of the plan period, with the exception of a small outbreak during 2002. Integrated pest management has been evident with the Forest emphasis on thinning small-diameter stands to maintain moderate stand densities, making young pine stands less susceptible to southern pine beetle attack.

Each year most Southern Region National Forests, including the Francis Marion, set out and collect traps to monitor southern pine beetle populations. From the numbers of southern pine beetles and their insect predators (clerid beetles) collected in these traps, Southern Region Forest Health personnel publish southern pine beetle trend predictions each year. Detailed trend predictions for all monitored locations in the Southern Region are posted on the Texas A&M Forest Service website. As of May 20, 2013, status and trends are not yet available. For 2012 the population status was low, with a trend of static. The South Carolina Forestry Commission (SCFC) also monitors southern pine beetle populations across the State. They do this both through trapping as described above, and with monitoring flights during the year. The

SCFC typically notifies the Forest Service if they discover southern pine beetle spots on national forest land during aerial monitoring.

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Since this Forest plan has been in place, a new disease has come into the Forest, laurel wilt, which is a disease of redbay (*Persea borbonia*) and other plant species in the family Lauraceae. It is causing widespread mortality in the coastal regions of South Carolina, Georgia, Florida and North Carolina. The disease is caused by a fungus (*Raffaelea* species) that is introduced into trees by a nonnative insect, the redbay ambrosia beetle (*Xyleborus glabratus*), which is native to Asia and is the 12th new species of ambrosia beetle introduced into the U.S. since 1990. The disease has also been discovered in sassafras (*Sassafras albidum*) and avocado (*Persea americana*). In a few locations, the disease has also been found in individual plants of the federally endangered pondberry (*Lindera melissifolia*) and the threatened pondspice (*Litsea aestivalis*). However, it generally does not affect pondberry or pondspice due to their small size, and has not seemed to affect these species on the Francis Marion National Forest. This disease appears destined to eliminate redbay from the Francis Marion National Forest as well as throughout the rest of its range.

Integrated pest management as discussed in the desired condition in the 1996 Forest plan has been seen especially with the emphasis on commercial thinning. This has made large acreages much less susceptible to southern pine beetle attack and has maintained the health and vigor of trees in these same stands.

The Forest is likely to be affected by influences beyond its border in the future as it has been in the past, as with imported fire ants and laurel wilt for example. The risk of nonnative insect and disease introductions is increased both by travelers and by the ever increasing global economy. The proximity of the Forest to the port of Charleston further increases this risk. Predicted warmer winters, as discussed in section 3.2 “Climate Change”, increases the potential for higher populations of insects and diseases.

3.3.1.3 Current Condition and Trends

- Native insects and diseases have generally remained at endemic levels and not caused significant problems during the life of the current plan. Outbreaks could always occur.
- Increasing acreages of older forest are reducing tree vigor and increasing susceptibility to pests.

Laurel wilt is a new disease that is now established across the Francis Marion National Forest. It is not native. It is expected to eliminate redbay from the Forest.