CHAPTER 17.
Fire

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KEY FINDINGS

- Climate forecasts indicate that the South's spring and fall wildfire seasons will be extended.
- Prescribed fires, currently conducted on roughly a 3 to 5 year rotation across much of the South, would need to become more frequent if conditions become drier.
- Major wildfire events, such as the 2007 Okefenokee wildfires, 2008 Evans Road Fire in eastern North Carolina, and recent west Texas fire seasons, are also likely to occur more often. Such events currently occur once every 50 years; however they could be more frequent in a warmer/drier climate.
- Land use change will have the most immediate effects on fuels and wildland fire management by constraining prescribed burning and increasing suppression complexity and cost.
- Air quality issues will likely increase restrictions on prescribed burning over large areas, not just in the wildland-urban interface.
- Potential health and safety concerns, in addition to air quality restrictions, will add to the regulatory constraints on use of prescribed burning.
- Alternatives to prescribed burning are generally not cost-effective and do not provide the ecological benefits of fire to adapted ecosystems; nor do they provide adequate protection for structures and human communities.
- Restrictions on use of prescribed burning to manage fuels will exacerbate potential climate change effects, particularly in the Coastal Plain and on the western Appalachian Mountains, where models predict an increase in wildfire potential.
- Fuels buildups combined with more intense wildfires under a warmer, drier climate could severely degrade fire-dependent communities that often support one or more threatened, endangered, or sensitive species.
- In addition to increasing the severity of wildfire events, the drier conditions and increased variability in precipitation that are associated with climate change could hamper successful forest regeneration and cause shifts in vegetation types over time.

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INTRODUCTION

Fire is an integral part of the southern landscape. The pervasive role of fire predates human activity in the South (Lafon 2010, Stanturf and others 2002), and human society has magnified that role. The South leads the nation in number of wildfires per year, averaging approximately 45,000 wildfires per year from 1997 through 2003 (Gramley 2005). Continued population growth in this region increases the potential threat that wildfires pose to life and property. In addition, forestry and forestry related industry represent a significant portion of the region's economy, making each wildfire a potential loss to a local economy.

Prescribed fire is an important tool used in the South to manage hazardous fuels and provide other ecological and economic benefits (Wade and Lunsford 1989). Each year approximately 8 million acres (3.2 million ha) of land are treated with prescribed fire in the South — more than in all other regions combined (Wade and others 2000). Most of this acreage is burned for hazardous fuel reduction, wildlife management, and range management; although an increasing number of acres are burned for ecosystem restoration and maintenance. Most prescribed burning is carried out in the Coastal Plain and Piedmont; however, its use is increasing in the Southern Appalachians and Ozark/Ouachita Highlands as historic fire regimes are reintroduced into these physiographic regions. Of increasing importance is the use of prescribed burning in landscape restoration, in particular for longleaf pine (*Pinus palustris*; see Brockway and others 2005). In March 2009, the Regional Working Group for America's Longleaf published a "Range-wide conservation plan for longleaf pine" that calls for increasing the extent of longleaf forests from 3.4 million acres to 8 million acres over 15 years (online report available at http://www.americaslongleaf.net/resources/the-conservationplan/Conservation%20Plan.pdf, last accessed on 9 December 2010). Because periodic burning is essential to maintain the longleaf ecosystem, successful restoration will require a significant increase in the area burned annually in the South (Southern Regional Partnership for Planning and Sustainability 2011).

In the United States, the popular notion of wildfires often focuses on the large conflagrations common in the western States. However, wildfires occur more frequently in the Southeast, where rapid vegetation growth and fuel accumulation combine with frequent ignitions from lightning and humans. Wildfires in the Southeast have the potential to develop into large, dangerous conflagrations, as epitomized by the Volusia Fire (111,130 acres) and the Flagler/St. John Fire (94,656 acres) that occurred in Florida in 1998 and more recently the Bugaboo Fire/Big Turn Around/Sweat Farm Road Fires (Okefenokee) Fires of 2007 (over 600,000 acres), which occurred in Georgia and Florida and the 2008 Evans Road Fire in North Carolina (over 41,000 acres). Despite the annual wildfire acreage typically being relatively small compared to the West, a disproportionate number of the structures destroyed nationally by wildfires are located in the Southeast (Monroe 2002). For example, in 2008 the Highway 31 Fire in South Carolina burned 19,000 acres, destroyed or damaged 176 homes and caused economic losses in excess of $50 million.

Wildland fire is an integral component of southern ecosystems across a range of climatic conditions, including recent warming associated with greenhouse gas emissions. Westerling and Swetnam (2003) have linked annual areas burned in the Southwest to similar large-scale patterns favoring unusually dry conditions. Their reconstructed paleo-fire records reveal that the drought-producing, year-to-year variability in the atmospheric circulation patterns of the past are still a driving force in the variability of wildfire season severity. Wildfires continue to exhibit significant variability from one year to the next. For example, the burned area in the United States increased from 1.3 million acres (0.5 million ha) in 1998 to 5.6 million acres (2.3 million ha) the next year (National Interagency Fire Center 2010). This mainly results from the inter-annual variability of atmospheric condition, which is a determinant for wildfires along with fuel properties and topography (Pyne and others 1996).

The close relationship between droughts and wildfires provides a basis for evaluating and predicting wildfire potential. Several studies have linked long-term atmospheric anomalies and wildfire activities in the South (Brenner 1991, Dixon and others 2008, Goodrick and Hanley 2009), using atmospheric teleconnection patterns to predict wildfire season severity and help establish a strong tie between wildfire activity and the global climate system. Using the Keetch-Byram Drought Index to forecast changes in wildfire potential at a global scale, Liu and others (2009) found that wildfire potential in the United States is likely to increase by the end of this century, although the magnitude of this increase varied widely, depending on the climate model and emissions scenario selected for the projection.

The remainder of this chapter examines how wildland fire conditions could evolve over the next 50 years, and how these changing conditions may impact prescribed fire in the South. Our examination of changing wildland fire conditions builds upon the methodology of Liu and others (2009) by using a simple water balance-based wildfire potential index to relate changes in temperature and precipitation patterns across the South to changes in fire potential. We evaluate four possible futures (chapter 2) each of which represent a different combination of general circulation model and greenhouse gas emission scenario (IPCC 2007). For each of these Cornerstone Futures, we examine potential changes in the duration and severity of future wildfire seasons and how these changes may impact prescribed burning.

The issues affecting continued use under current conditions of prescribed burning will be presented, along with a discussion of alternatives and their efficacy. Prescribed burning is used routinely to reduce fuel loads and decrease the risk of catastrophic wildfires, improve forest health, and manage habitat for threatened and endangered species. Increasingly, one of the most effective tools in the manager's kit, fuel reduction by frequent understory burning, is off-limits because of safety and liability risks (Achtemeier and others 1998, Wade and Brenner 1995) or public dislike for the inconvenience of smoke (Macie and Hermansen 2002). The concluding section will describe the effects of potential climate change on prescribed fire practice.

METHODS

To address questions regarding future wildfire potential, we examine the response of a drought index to a set of simulated future conditions. A description of these methods follows. Questions regarding the future of prescribed burning are addressed using a synthesis of the scientific literature linked to these forecasts.

Climate Scenarios

Four climate scenarios are used in evaluating potential changes in wildfire potential over a 50 year period from 2010 and 2060. These four scenarios represent four of the six Cornerstone Futures presented in chapter 2 and represent different combinations of general circulation model and IPCC greenhouse gas emission scenario. Cornerstone A uses the MIROC model developed by the University of Tokyo's Center for Climate System Research (National Institute for Environmental Studies) and forced by the IPCC's A1B emissions scenario. Also using the A1B emissions scenario, Cornerstone B uses the CSIRO mk3.5 model developed by the Commonwealth Scientific and Industrial Research Organization of Australia. Cornerstone C employs an older version of the CSIRO model (mk2) forced by the IPCC's

B2 emissions scenario. Cornerstone D uses version 3 of the Hadley Centre Coupled Model forced by the IPCC's B2 emissions scenario.

IPCC emissions scenarios combine two sets of divergent tendencies: one set varies between strong economic values and strong environmental values, the other set between increasing globalization and increasing regionalization (Nakicenovic and others 2000). The A1 scenario family describes a future of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Within that family, A1B represents a balance between fossil fuels and alternative energy sources. The B2 scenario describes a world with continuously increasing global population, moderate levels of economic development, and less rapid but more diverse technological change than in the A1B scenario.

The climate and wildfire potential information presented in this chapter is based on decadal averages, rather than on individual years. Therefore, data for 2010 represents the average of all the years from 2001 to 2010. Monthly data is also expressed as a decadal average, for example, April 2060 would represent the average of the 10 Aprils from 2051 to 2060.

Measuring Wildfire Potential

Wildfire potential is a complex function of recent weather conditions, vegetation and topography. Of these three components, weather exhibits the most variability at any given spot. Wildfire potential is often determined using a system such as the National Fire Danger Rating System (Burgan 1988) that utilizes afternoon weather observations of temperature, humidity, wind speed, and precipitation amount/duration. In general, the output from general circulation models does not include all the information that would be required by such a system to project future changes in wildfire potential.

The Keetch-Byram Drought Index (KBDI) is a rather simple drought index designed specifically for assessing wildfire potential in the South (Keetch and Byram 1968). The KBDI is a cumulative measure of the balance between evapotranspiration and rainfall; and only requires three inputs: daily high temperature, daily rainfall and annual average rainfall. The high temperature and annual rainfall are used to estimate daily evapotranspiration (annual rainfall acts as a surrogate for the amount of vegetation as higher annual rainfall supports more vegetation which leads to increased evapotranspiration).

The KBDI has two potential limitations for climate change work. First, because the function defining evapotranspiration was derived for historical rainfall and temperature regimes, the fit may not be as good under climate change conditions. Secondly, the index scale is fixed to be from 0 (very wet) to 800 (extremely dry) with a nonlinear, asymptotic approach to this maximum value. For a changing climate where conditions could potentially get much drier than they are currently, use of the KBDI could underestimate the potential drought conditions by compressing the changes into the asymptotic portion of the curve.

As an alternative index, referred to as simply the potential drought index (PDI), we use the balance between 0.75 times the potential evapotranspiration minus precipitation. The 0.75 scaling is designed to reflect the fact that the potential evapotranspiration is an overestimate of the actual evapotranspiration (Eagleman 1967). The exact value of this scaling coefficient is not critical; the primary requirement is that it provides reasonable estimates of the current water balance conditions to serve as a basis for evaluating future changes. The slight change in how evapotranspiration is calculated compared to the KBDI will cause the PDI to accentuate drought conditions and thus highlight areas of potential increases in wildfire potential. The PDI has an open-ended scale with units of millimeters. Positive values of the PDI indicate drought conditions.

RESULTS

Future Wildfire Potential Changes

Annual fire potential—Wildfire reports compiled as part of the Southern Wildfire Risk Assessment (Buckley and others 2006) reveal three primary areas of wildfire activity from 1997 to 2002: the Coastal Plain, the western Appalachian Mountains (eastern parts of Kentucky and Tennessee) and eastern Oklahoma/Arkansas (fig. 17.1). Other areas may be important locally but are of limited geographic extent, such as the Coastal Plain sandhills, where longleaf pine burns regularly. Care must be taken when examining this figure as not all States provided wildfire records with latitude/longitude for each fire; some States located all wildfires at the geographic center of counties. This is especially noticeable in Texas, where counties are larger.

All four Cornerstone Futures provide a consistent view of the current annual fire potential as expressed by the PDI (fig. 17.2). On these maps brown areas define regions where evapotranspiration exceeds precipitation (positive PDI) while in blue regions precipitation dominates (negative PDI). White areas show a balanced moisture budget (PDI near zero). Areas farthest west are dominated by the highest PDI values because of lower precipitation and higher summer temperatures; areas farther east are dominated by higher precipitation, leading to negative PDI values. The primary differences among the Cornerstone Futures are primarily

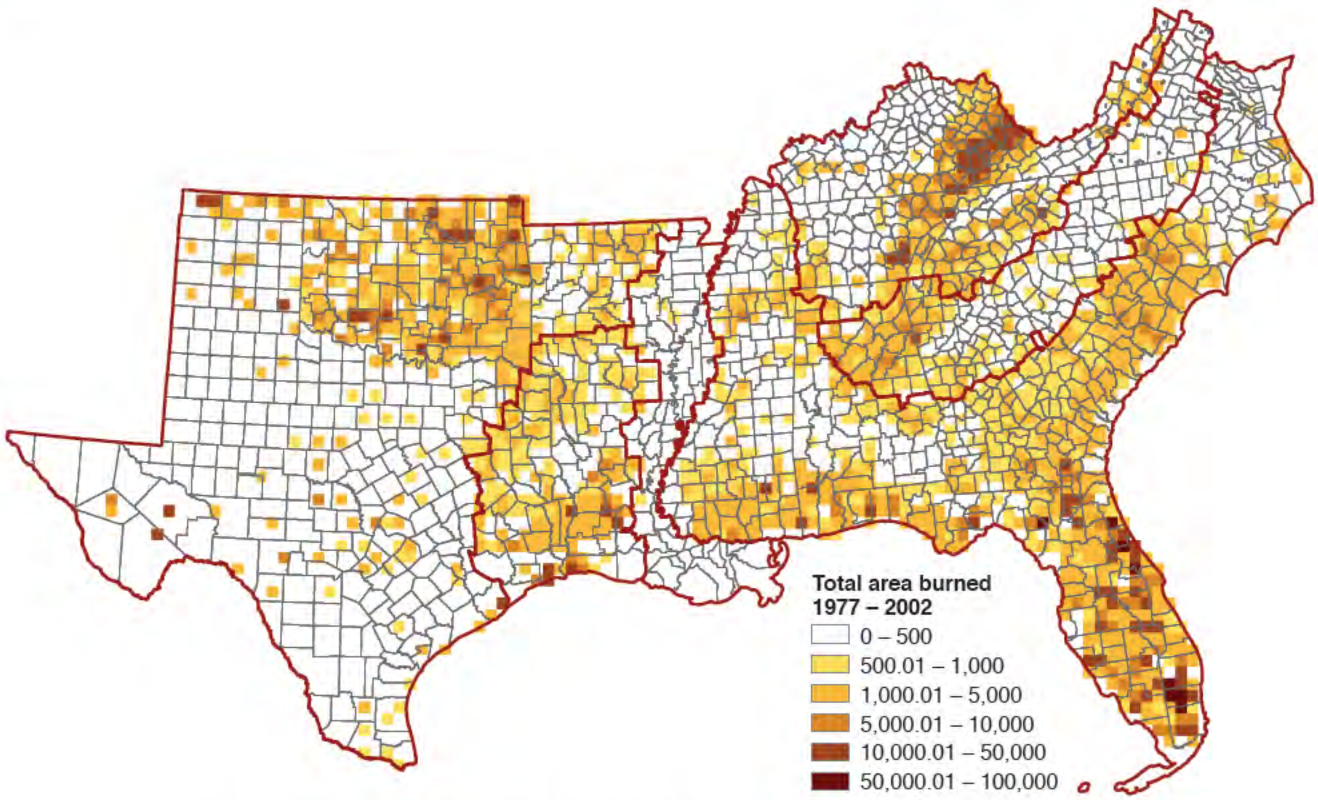

Figure 17.1—Total area burned by wildfires, 1997 to 2002, displayed as a raster image with 25-km cell size. (Data source: Sanborn Map Company (2008) Southern Fire Risk Assessment (version 9.3) [computer software]. http://www.southernwildfirerisk.com/sfras/aboutsfras.html. Retrieved (9 February 2012).)

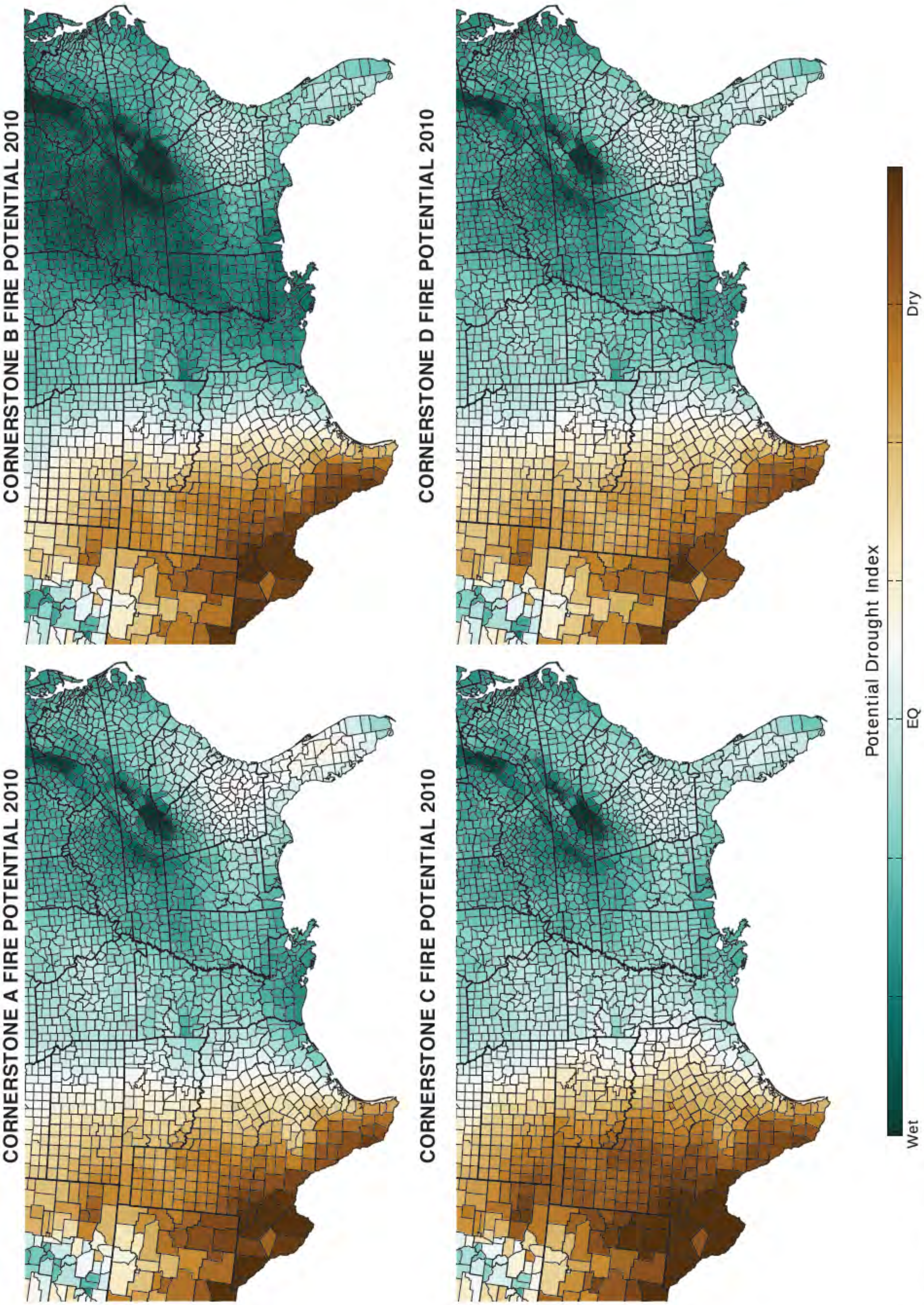

Figure 17.2—Comparison of annual fire potential for current conditions (2010) by Cornerstone Future.

focused in the Ohio River Valley where Cornerstone B is the wettest, and along a band just inland of the coast where the PDI is near zero. This band is most evident for Cornerstones C and D.

Comparing these PDI maps to the map of acres burned in figure 17.1 shows that areas with the driest conditions (highest PDI) do not necessarily have the highest acres burned. The Coastal Plain, whose annual PDI in Cornerstones B, C and D is near zero has some of the highest amounts of burned area. The areas with highest positive PDI values are not productive enough to support sufficient build up of fuels to support frequent wildfires. The eastern Oklahoma/Arkansas region is another area of transition in the PDI reflecting near balance between rainfall and precipitation. The western Appalachians shows significant areas burned despite having the lowest PDI values.

In 50 years, all Cornerstone Futures depict drier conditions (fig. 17.3). Cornerstone A depicts the most severe conditions with an eastward expansion of the western dry area and the development of a similar area in southern Georgia and Florida; only the Appalachians maintain a negative PDI. The other Cornerstone Futures are very consistent in their depiction of drier conditions, though the magnitude of the drying is far less than in Cornerstone A. The central part of the region shifts from negative PDI values to a more balanced condition and the band of near zero PDI in the Coastal Plain becomes better defined. All three of the primary fire areas depicted in figure 17.1 experience an increase in wildfire potential, with Cornerstone A showing the most dramatic increase and B, C and D showing more modest increases.

Seasonal variation of wildfire potential—These annual numbers provide a glimpse of future wildland fire conditions, but examination of PDI changes at the seasonal scale provides more information. Splitting the area burned information presented in figure 17.1 by season provides insight into the current wildfire season. Figure 17.4 shows the number of acres burned during the winter months (December, January and February). South Florida and the western Appalachians are the areas showing highest wildfire activity; although wildfire activity is present at a low level across much of the South. For southern Florida, the heart of the dry season is the winter months, when natural ignitions are uncommon, but human ignitions are sufficient to support significant winter wildfire activity. In the Appalachians, much of the winter wildfire season is tied to either the start or end of the season reflecting either a prolonged fall wildfire season or an early start to a spring wildfire season.

Spring (March, April, May) brings more wildfire activity, particularly to the Coastal Plain and Piedmont (fig. 17.5). Along the Coastal Plain, sea-breeze induced thunderstorms provide a natural ignition source along with the ever present human ignition component. By summer (June, July, August), wildfire activity decreases throughout the Appalachians while a low level of wildfire activity persists in the Coastal Plain, where continuing thunderstorms produce sufficient rainfall to reduce the probability ignition by late June or early July (fig. 17.6). Fall brings a return of wildfire activity to the Appalachians and a great reduction in the Coastal Plain, particularly Florida (fig. 17.7). For much of the Appalachians the input of litter to the forest floor provides the fuel to support the spread of wildfires when coupled with dry conditions.

Although wildfires are possible in any season, the two areas discussed above have distinct wildfire seasons. For the Coastal Plain, wildfire activity is lowest in the fall and highest in the spring, with some activity spilling over into summer and winter. For the Appalachians, activity is lowest in the summer and highest in the fall, with spring providing a secondary peak in wildfire activity. Winter wildfire activity in the Appalachians is considerably more than during summer, but is largely tied to either an extended fall wildfire season or an early spring season. Although no other area shows a seasonal peak in wildfire activity as pronounced as the Coastal Plain or Appalachians, the eastern Oklahoma/Arkansas region experiences wildfire activity in all seasons.

For current conditions under Cornerstone A, winter is the primary rainy season, although the areal extent of this wet area is restricted to the Appalachians as reflected by the PDI (fig. 17.8). During the summer, Cornerstone A is dominated by pronounced drying and fails to capture the summer rains in Florida and along the Coastal Plain. Over the course of 50 years, this drying is further reinforced and virtually eliminates all areas of negative PDI values (fig. 17.9).

Cornerstone B offers a better representation of current conditions compared to Cornerstone A (fig. 17.10); especially in capturing the evolution of the spring/fall wildfire season of the Coastal Plain. Key features of note are the improved flow of moisture from the Gulf of Mexico northward across the Appalachians and dry conditions across Florida during winter. The area of moist conditions shifts northward during spring as dry conditions expand across the Coastal Plain. Summer brings dry conditions to much of the South, with the exception of the Coastal Plain where precipitation from afternoon thunderstorms balances the dry conditions. During fall, dry conditions return to the Coastal Plain.

Compared to Cornerstone A, the changes in wildfire potential in 50 years are much more subtle under Cornerstone B (fig. 17.11), which shows substantial drying along the Gulf of Mexico during winter and areas of dryness in spring and summer that are similar but smaller than in Cornerstone A. Unlike the domination by strong, widespread drying under

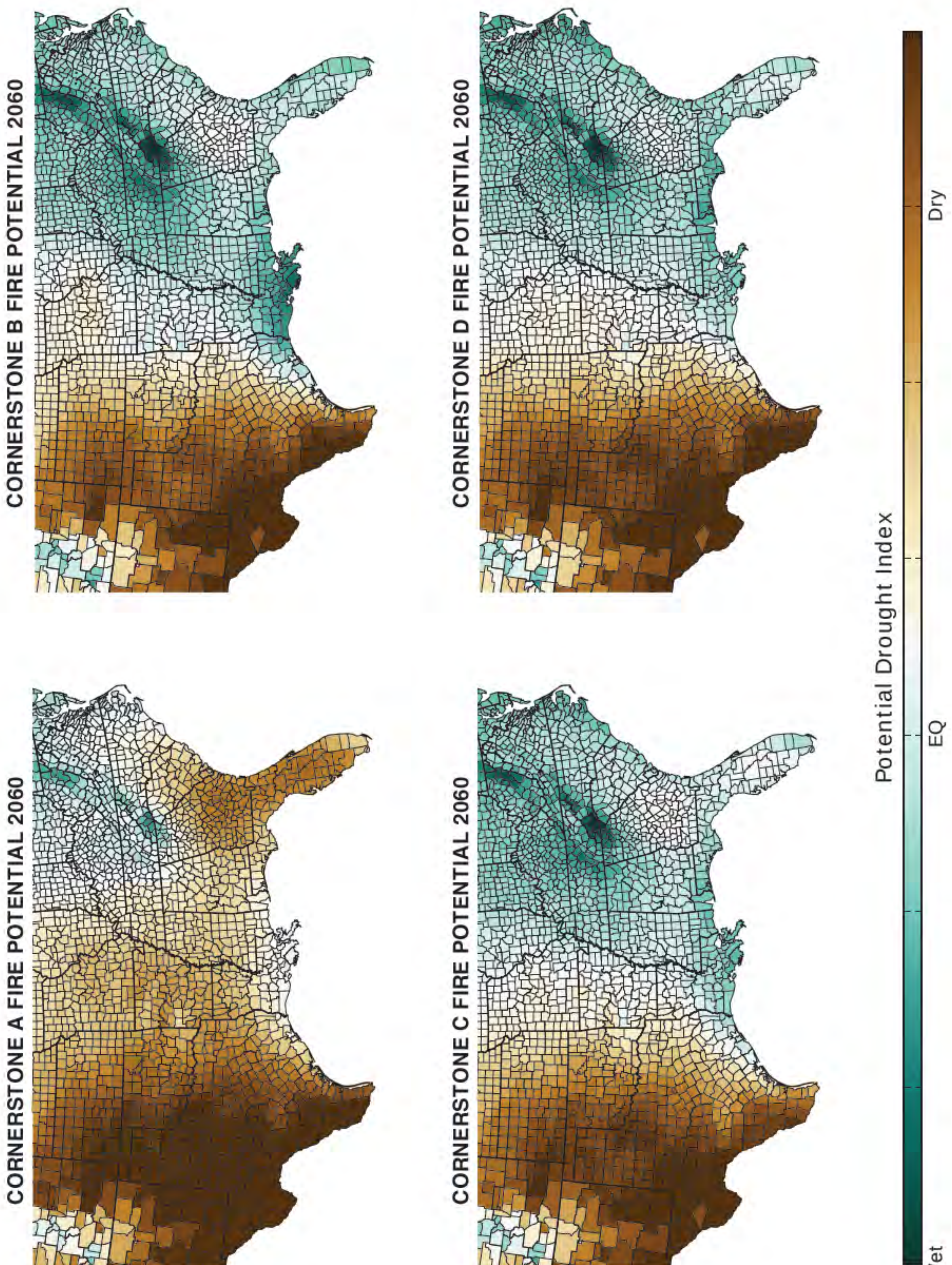

Figure 17.3—Comparison of annual fire potential for future conditions (2060) by Cornerstone Future.

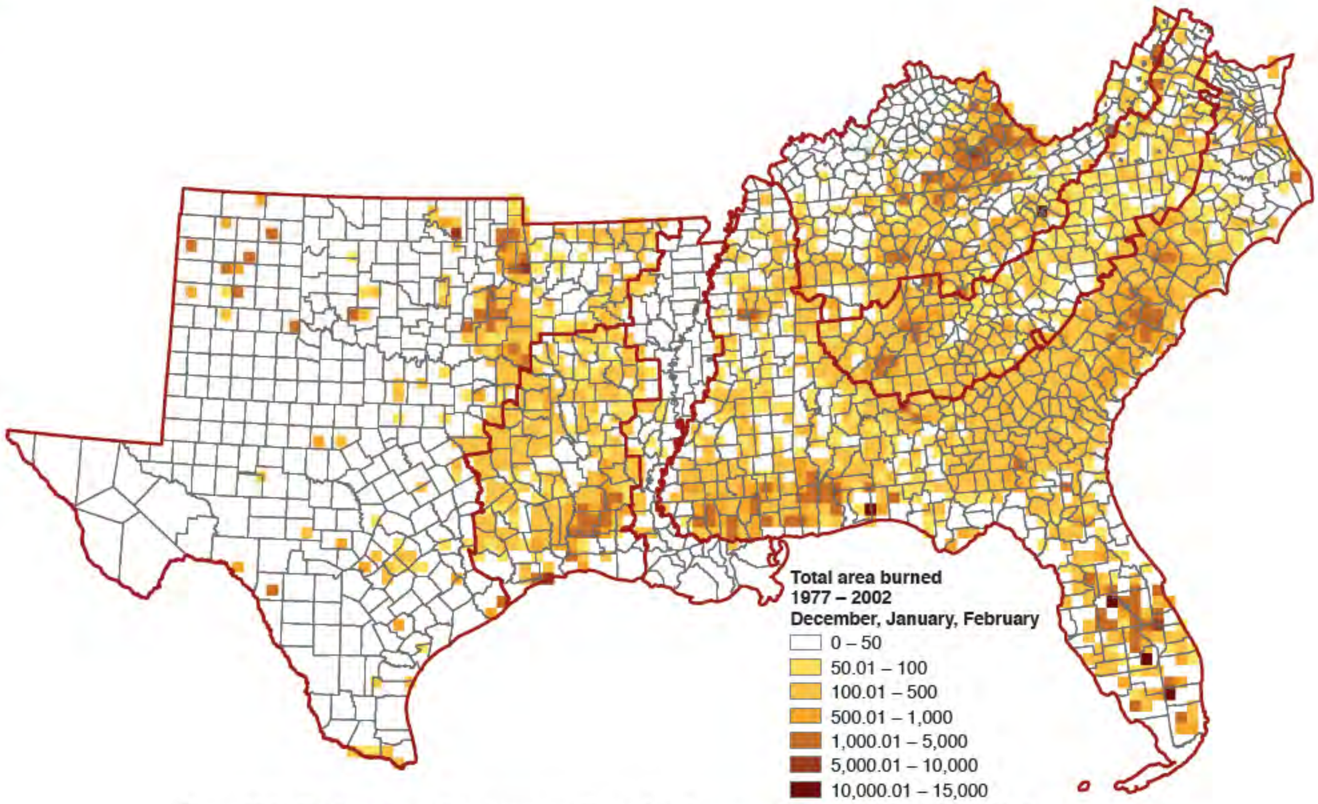

Figure 17.4—Total area burned during winter (December, January, and February) for 1997–2002, displayed as a raster image with 25-km cell size. (Data source: Sanborn Map Company (2008) Southern Fire Risk Assessment (version 9.3) [computer software]. http://www.southernwildfirerisk.com/sfras/aboutsfras.html. Retrieved (9 February 2012).)

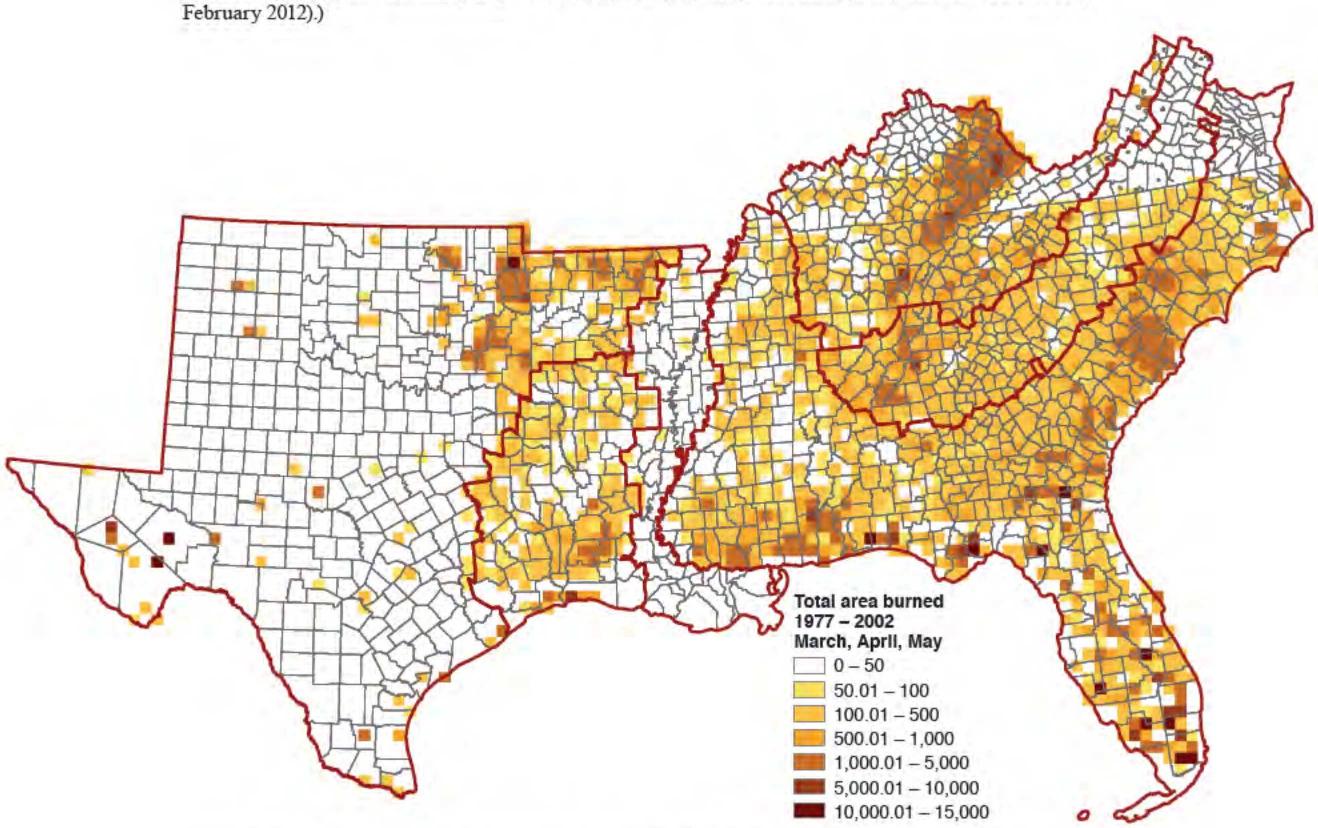

Figure 17.5—Total area burned during spring (March, April, and May) for 1997–2002, displayed as a raster image with 25-km cell size (Data source: Sanborn Map Company (2008) Southern Fire Risk Assessment (version 9.3) [computer software]. http://www.southernwildfirerisk.com/sfras/aboutsfras.html. Retrieved (9 February 2012).)

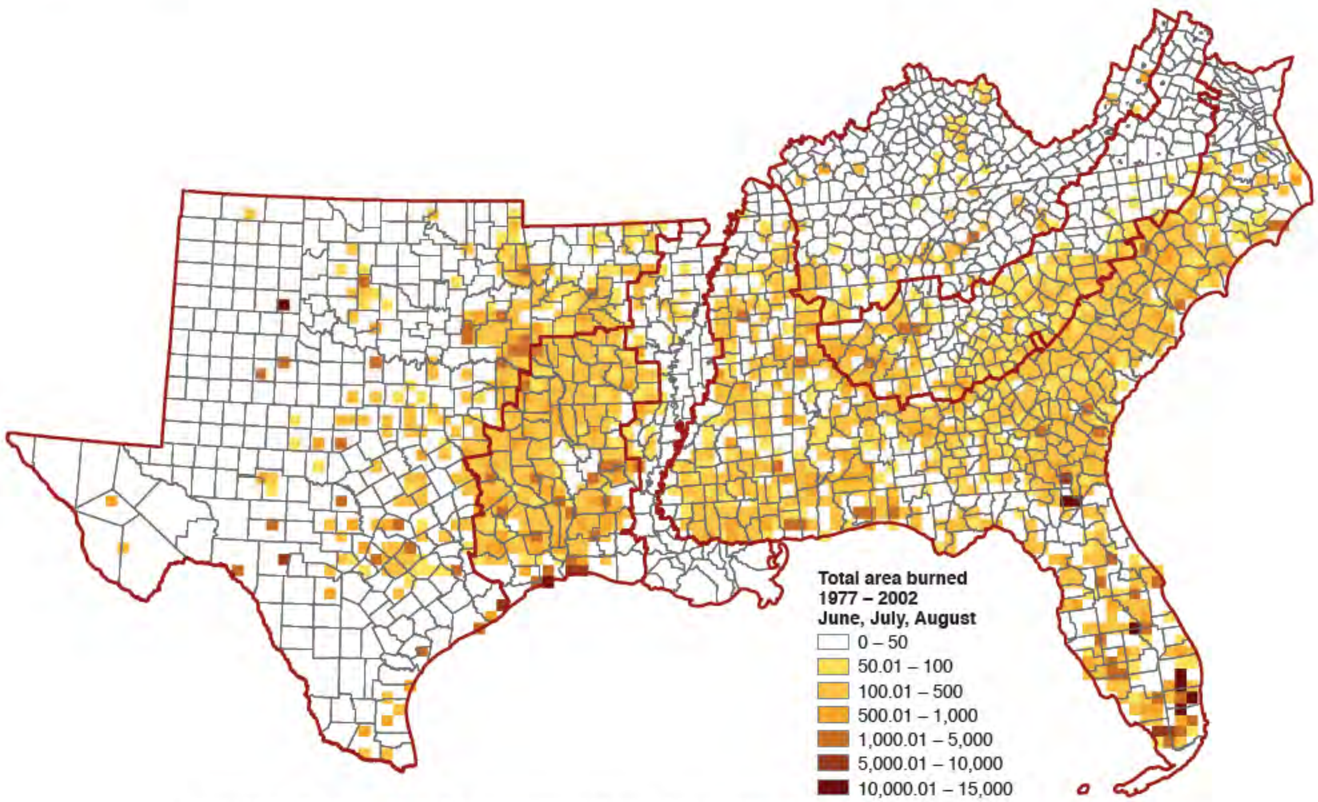

Figure 17.6—Total area burned during summer (June, July, and August) for 1997–2002, displayed as a raster image with 25-km cell size. (Data source: Sanborn Map Company (2008) Southern Fire Risk Assessment (version 9.3) [computer software]. http://www.southernwildfirerisk.com/sfras/aboutsfras.html. Retrieved (9 February 2012).)

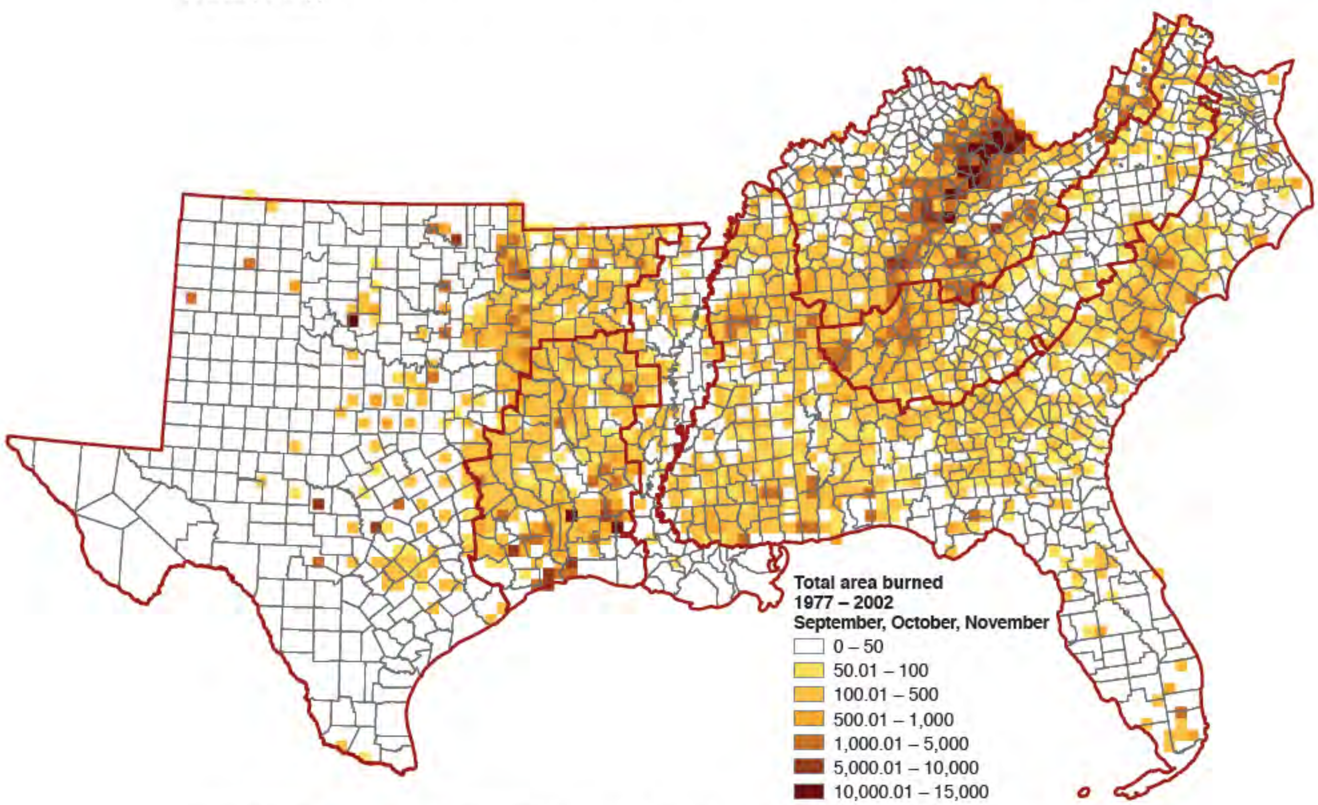

Figure 17.7—Total area burned during fall (September, October, and November) for 1997-2002, displayed as a raster image with 25-km cell size.(Data source: Sanborn Map Company (2008) Southern Fire Risk Assessment (version 9.3) [computer software]. http://www.southernwildfirerisk.com/sfras/aboutsfras.html. Retrieved (9 February 2012).)

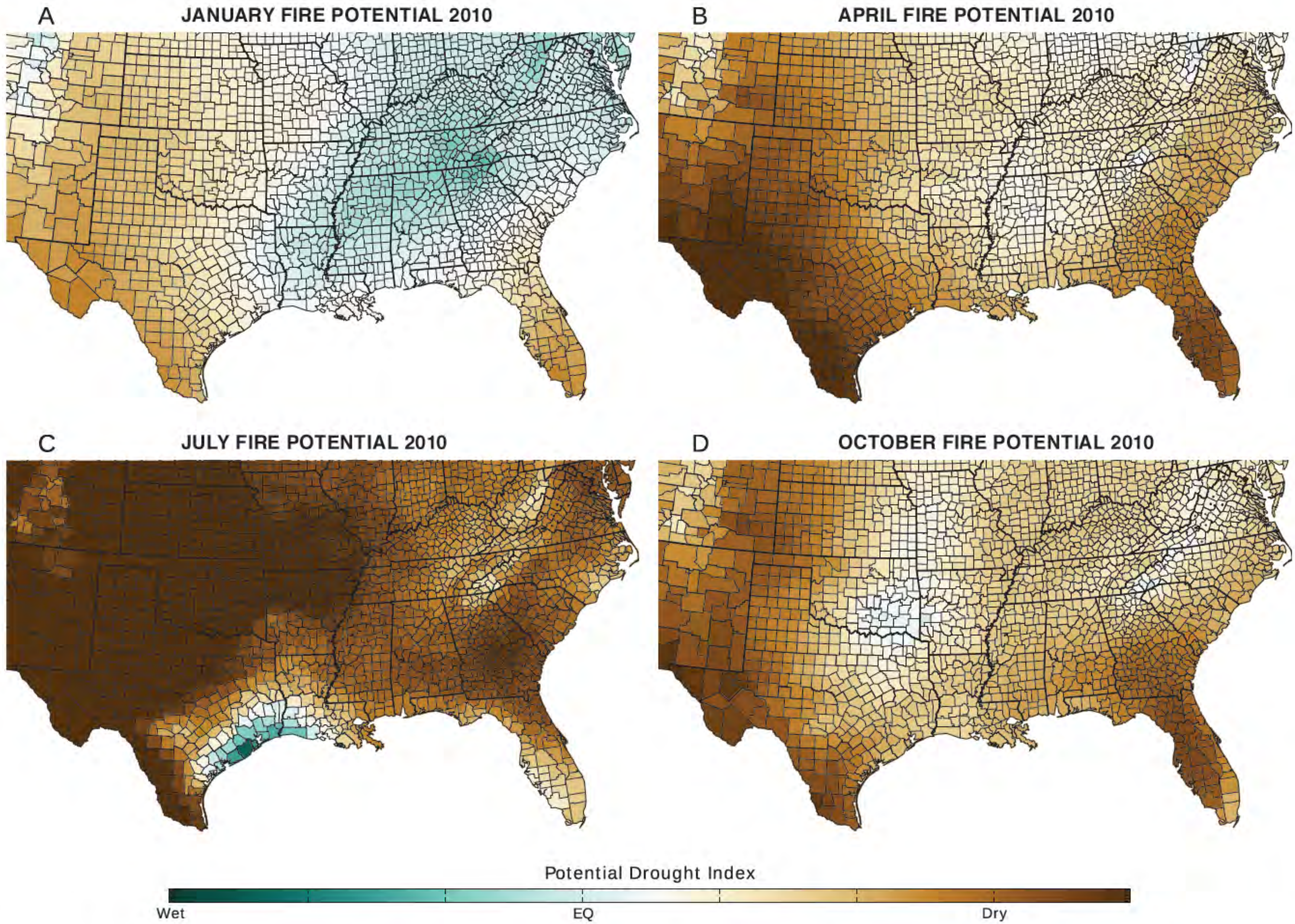

Figure 17.8—Seasonal view of fire potential under current conditions for (A) January, (B) April, (C) July, and (D) October (Cornerstone A).

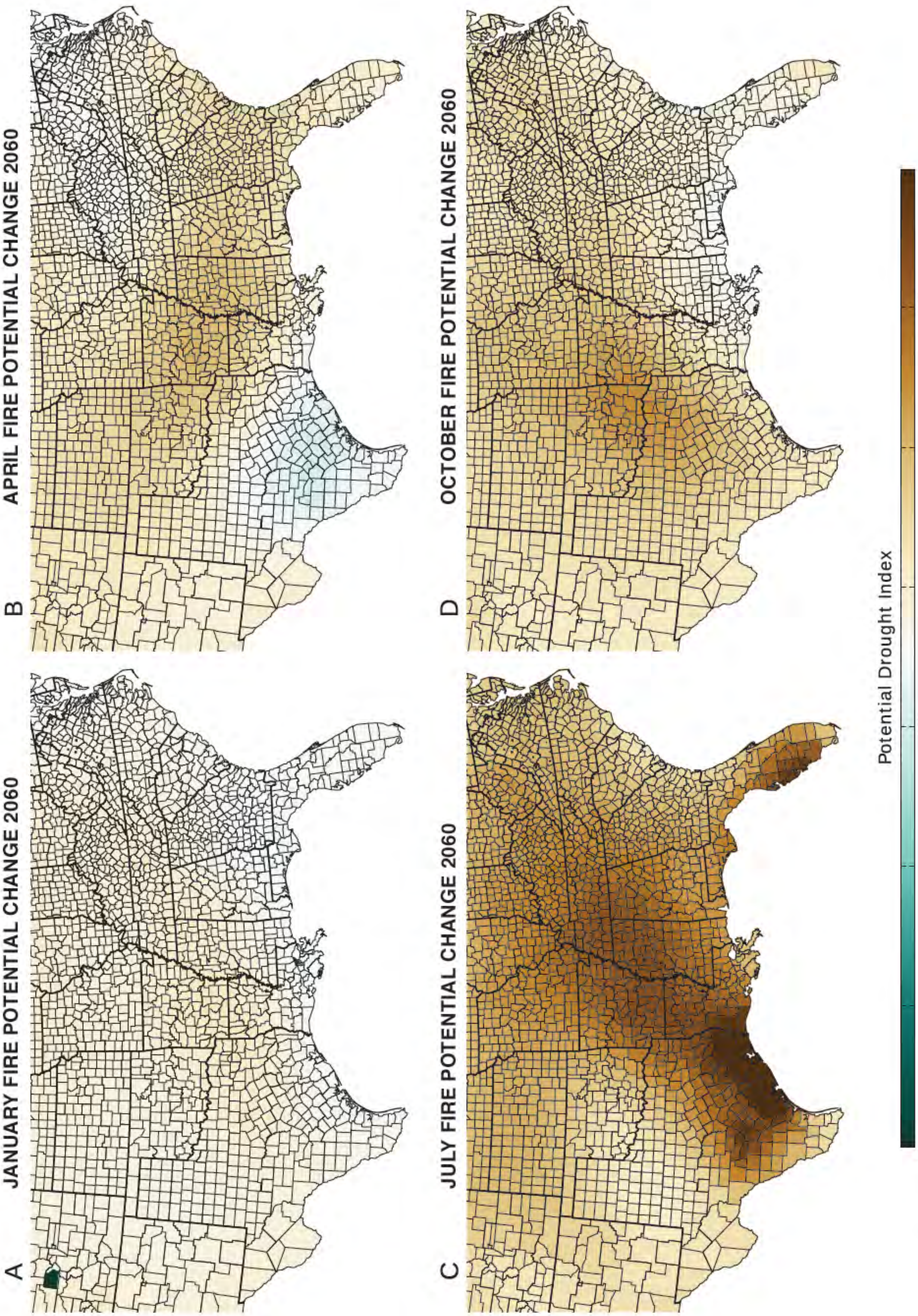

Figure 17.9—Change in seasonal fire potential in 2060 for (A) January, (B) April, (C) July, and (D) October (Cornerstone A).

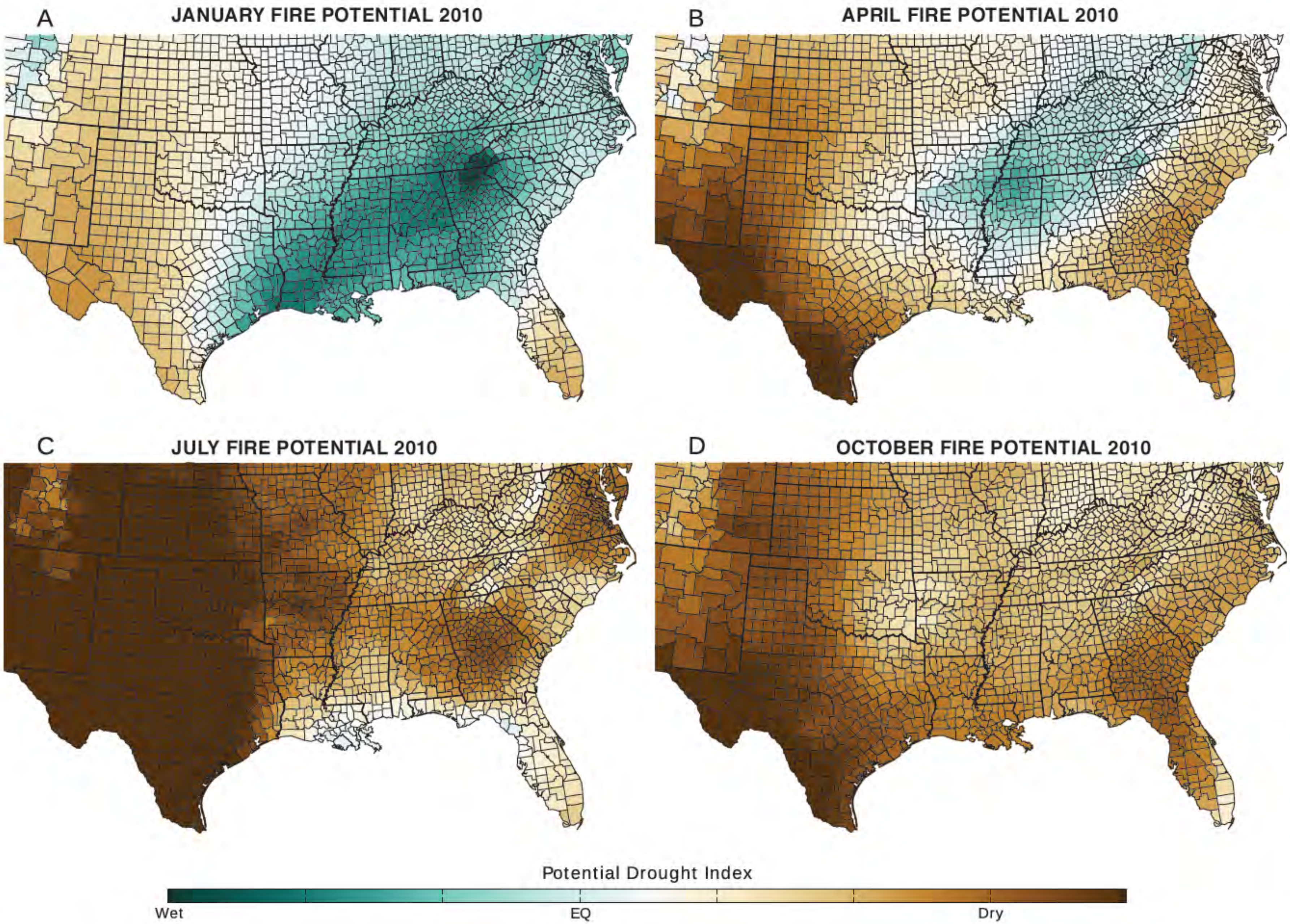

Figure 17.10—Seasonal view of fire potential for current conditions for (A) January, (B) April, (C) July, and (D) October (Cornerstone B).

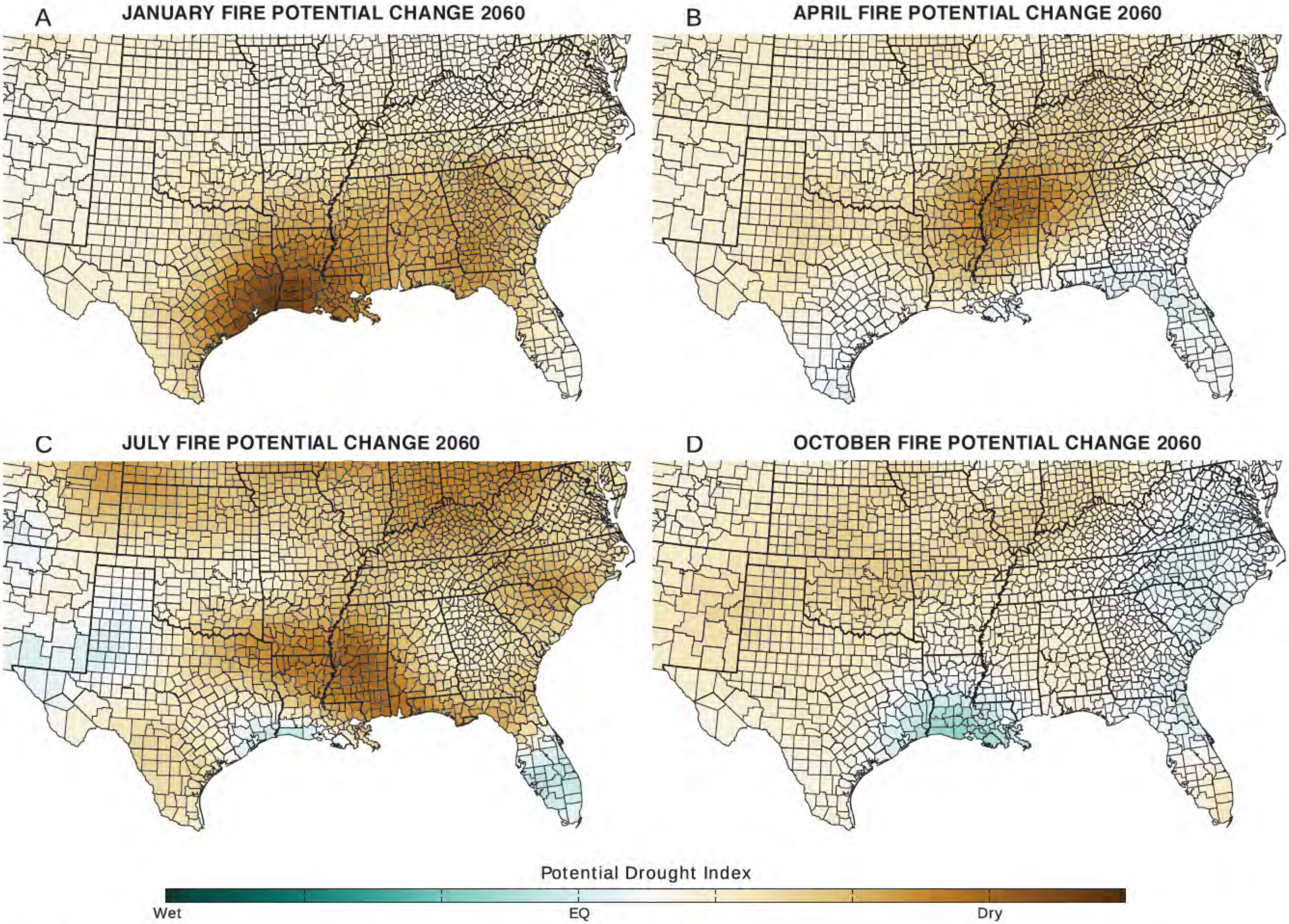

Figure 17.11—Change in seasonal fire potential in 2060 for (A) January, (B) April, (C) July, and (D) October (Cornerstone B).

Cornerstone A; Cornerstone B shows a much smaller area of change that is strongest during winter rather than summer. Wintertime drying could adversely affect prescribed burning by favoring conditions that promote escaped prescribed fires. Drier conditions would also promote increased fuel consumption on prescribed burns, increasing the likelihood of air quality problems. Cornerstones C and D resemble Cornerstone B in spatial patterns but their magnitudes of changes after 50 years are smaller.

Monthly variation in wildfire potential—To get a better feel for the spatial extent of these changes in wildfire potential as described by the PDI, we examine the changes in areal extent of wet and dry conditions within each State by month. What constitutes wet versus dry conditions for each Cornerstone is determined by taking all PDI estimates for 2010 and splitting this collection of values into thirds. The third with the highest PDI values represents dry conditions and the lowest third wet conditions. The breakpoints defining dry versus wet conditions are shown in table 17.1 along with maximum/minimum values for each Cornerstone.

For current conditions, Cornerstones A, C and D have many of the States predominantly in the wettest category for November through March, then transitioning to the driest category for June through August (tables 17.2 to 17.5). Cornerstone B has a much more prolonged and gradual transition in the spring for many of the States. These transition periods in spring and fall are typical of the southern wildfire season, and they largely depend on the annual evolution of live fuel moisture conditions. In spring, live fuel moisture values are low until the start of green up. Periods of drought during this time create periods of high fire danger. When live fuel moisture peaks, the moisture content acts as a heat sink, reducing the fire danger. In the fall, live fuel moistures begin to decline in many species, which along with drying from high summer temperatures brings about the fall wildfire season. The onset of winter rains typically signals the end of the fall wildfire season.

Notable Exceptions to this Pattern are Florida, Texas, and Oklahoma

Florida has a complex climate as the northern part of the State has both a summer and winter rainy season, while the southern part exhibits only a single summer rainy season. In Florida the primary wildfire season is in the spring as this is the time of year when most of the acres burn. For the southern part of Florida, spring marks the peak of dry conditions prior to the start of the summer rainy season. During May and June, the summer rainy season begins with isolated thunderstorms. Lightning from these storms provides a major ignition source until the rainy season progresses to a point where most areas are receiving rain on a regular basis.

Texas and Oklahoma represent the dry western portion of the region. During winter, the storms that move eastward out of the Rocky Mountains are dry and must begin rebuilding their moisture levels from southerly winds coming from the Gulf of Mexico. This process is just getting started as the storms move across Texas and Oklahoma, only reaching significant moisture levels in those States' eastern parts (hence the very low acreage in the wet category).

In 50 years, Cornerstone A has almost every acre of the South in the driest category during the summer (table 17.6). This scenario completely erases Florida's summer rainy season. This reveals a possible flaw in the downscaling used to generate the Cornerstone Futures. Florida's summer rains are small-scale local events, far below the resolution of the underlying general circulation models. These storms are forced by the difference in temperature between the land and ocean, which is not going to disappear due to climate change. Cornerstones B, C and D show only subtle differences (tables 17.7 to 17.9). The gradual transition from winter rainy season to summer dry season in Cornerstone B is largely erased which brings the 2060 conditions into much closer alignment with Cornerstones C and D.

Impacts of climate change—Results from the four Cornerstone Futures indicate that wildfire potential is likely to increase over the next 50 years. The magnitude of that increase is likely to be fairly slight, although one scenario (Cornerstone A) predicts a significant increase. Predicted results for Cornerstone B are much more aligned with Cornerstones C and D despite being forced with the same emissions scenario as Cornerstone A (A1B). This suggests that the simulated severe drying of Cornerstone A may be more closely tied to the general circulation model used for the simulation than any forcing from the emissions scenario.

From Cornerstone B we can expect both the spring and fall wildfire seasons to increase in duration across the Coastal Plain. Drier conditions in winter, spring, and summer will likely both extend and worsen the spring wildfire season. Although the results presented above reflect average conditions, it is likely that we will see shifts in variability that will result in the bad wildfire seasons being worse than they currently are. Winter and summer drying will likely extend the fall wildfire season, but the overall fall magnitude is little changed from current conditions. Outside of the Coastal Plain, the western Appalachians would see drier summers, resulting in a prolonged spring and earlier fall wildfire season.

These changes in wildfire potential in the South would lead to longer fire seasons, but for the elevated fire potential to translate to increased acres burned requires ignitions. Because the vast majority of southern wildfires are human caused, not natural; changes in ignitions will be more

Table 17.1—Breakpoints defining the wettest and driest thirds of potential drought index (PDI) values for current conditions in the South for each Cornerstone Future

Scenario	Wet breakpoint	Dry breakpoint	Wettest value	Driest value
Cornerstone A	95	562	-585	1162
Cornerstone B	-3	530	-708	1169
Cornerstone C	133	634	-510	1222
Cornerstone D	19	500	-582	1083
Average	61	556	—[a]	—

[a]Averages are not provided for extreme values.

Table 17.2—Percent of area in dry and wet classes for current conditions (2010) by State and month for Cornerstone A

Percent area in driest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	0	0	0	0	0	100	32	85	0	0	0	0
Arkansas	0	0	0	0	0	100	75	100	36	0	0	0
Florida	0	0	0	32	48	33	6	0	0	37	0	0
Georgia	0	0	0	0	0	97	73	56	1	1	0	0
Kentucky	0	0	0	0	0	91	16	30	0	0	0	0
Louisiana	0	0	0	0	0	100	0	20	51	0	0	0
Mississippi	0	0	0	0	0	100	19	61	30	0	0	0
North Carolina	0	0	0	0	0	63	0	2	0	0	0	0
Oklahoma	0	0	0	0	0	100	100	100	54	0	0	0
South Carolina	0	0	0	0	0	100	28	12	0	0	0	0
Tennessee	0	0	0	0	0	88	20	49	0	0	0	0
Texas	0	0	19	55	45	100	73	93	96	18	0	0
Virginia	0	0	0	0	0	63	6	10	0	0	0	0
Percent area in wettest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	100	100	100	9	0	0	0	0	0	0	99	100
Arkansas	96	100	97	0	0	0	0	0	0	14	100	100
Florida	21	41	22	0	0	5	0	18	18	0	8	22
Georgia	84	100	82	4	1	0	0	0	0	1	31	84
Kentucky	100	100	100	0	0	0	0	0	0	0	100	100
Louisiana	100	100	82	0	0	0	18	34	0	0	100	100
Mississippi	100	100	100	27	0	0	0	0	0	0	100	100
North Carolina	100	100	100	4	3	0	0	0	2	11	45	100
Oklahoma	3	12	4	0	0	0	0	0	0	36	5	16
South Carolina	98	100	100	0	0	0	0	0	0	0	19	96
Tennessee	100	100	100	5	0	0	0	0	0	0	100	100
Texas	12	8	0	0	0	0	8	1	0	3	7	15
Virginia	100	100	100	0	0	0	0	0	0	12	97	100

Table 17.3—Percent of area in dry and wet classes for current conditions (2010) by State and month for Cornerstone B

Percent area in driest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	0	0	0	0	0	0	0	94	17	0	0	0
Arkansas	0	0	0	0	0	17	61	100	73	0	0	0
Florida	0	0	0	0	0	0	0	1	0	0	0	0
Georgia	0	0	0	0	0	0	7	71	20	0	0	0
Kentucky	0	0	0	0	0	0	0	26	3	0	0	0
Louisiana	0	0	0	0	0	85	0	58	34	0	0	0
Mississippi	0	0	0	0	0	11	0	93	73	0	0	0
North Carolina	0	0	0	0	0	0	0	19	0	0	0	0
Oklahoma	0	0	0	0	0	26	100	100	52	8	0	0
South Carolina	0	0	0	0	0	0	0	47	0	0	0	0
Tennessee	0	0	0	0	0	0	0	92	30	0	0	0
Texas	0	0	25	32	65	80	97	99	75	64	0	0
Virginia	0	0	0	0	0	0	0	4	0	0	0	0
Percent area in wettest class												
State	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Alabama	100	100	66	61	39	0	0	0	0	0	26	100
Arkansas	100	89	100	97	9	0	0	0	0	0	100	100
Florida	49	39	0	0	3	45	17	57	7	0	0	11
Georgia	100	100	32	21	16	0	0	0	1	0	11	55
Kentucky	100	100	100	100	100	0	0	0	0	0	96	100
Louisiana	100	100	48	38	88	0	26	0	0	0	32	100
Mississippi	100	100	83	89	91	0	5	0	0	0	43	100
North Carolina	100	100	87	22	86	2	1	0	15	0	16	96
Oklahoma	39	13	32	10	0	0	0	0	0	0	20	62
South Carolina	100	100	26	6	17	0	0	0	0	0	6	53
Tennessee	100	100	100	100	93	0	0	0	1	0	92	100
Texas	30	32	3	4	0	0	0	0	0	0	93	33
Virginia	100	100	100	45	51	0	0	0	0	0	35	100

Table 17.4—Percent of area in dry and wet classes for current conditions (2010) by State and month for Cornerstone C

Percent area in driest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	0	0	0	0	0	64	0	92	0	0	0	0
Arkansas	0	0	0	0	0	93	98	100	1	0	0	0
Florida	0	0	0	9	0	0	0	0	0	2	0	0
Georgia	0	0	0	0	0	23	0	64	25	0	0	0
Kentucky	0	0	0	0	0	14	17	63	0	0	0	0
Louisiana	0	0	0	0	0	84	48	67	11	0	0	0
Mississippi	0	0	0	0	0	97	39	93	10	0	0	0
North Carolina	0	0	0	0	0	0	0	8	0	0	0	0
Oklahoma	0	0	0	15	10	96	100	100	49	24	0	0
South Carolina	0	0	0	0	0	0	0	21	0	0	0	0
Tennessee	0	0	0	0	0	35	17	83	0	0	0	0
Texas	0	0	28	60	63	99	99	100	73	50	0	0
Virginia	0	0	0	0	0	0	10	0	0	0	0	0

Percent area in wettest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	100	100	100	1	0	0	0	0	0	0	26	100
Arkansas	99	96	100	0	0	0	0	0	0	0	99	100
Florida	32	32	20	0	7	17	25	16	17	0	0	16
Georgia	99	99	62	5	0	0	0	0	0	0	15	67
Kentucky	100	100	100	0	0	0	0	0	0	0	100	100
Louisiana	100	100	88	0	0	0	0	0	0	0	58	100
Mississippi	100	100	100	0	0	0	0	0	0	0	64	100
North Carolina	100	100	100	9	3	0	0	0	1	4	28	76
Oklahoma	12	5	25	0	0	0	0	0	0	0	6	6
South Carolina	100	100	81	0	0	0	0	0	0	0	6	43
Tennessee	100	100	100	4	0	0	0	0	0	0	99	100
Texas	13	7	3	0	0	0	0	0	0	0	4	13
Virginia	100	100	100	0	0	0	0	0	0	2	92	99

Table 17.5—Percent of area in dry and wet classes for current conditions (2010) by State and month for Cornerstone D

Percent area in driest class												
State	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Alabama	0	0	0	0	0	96	0	79	7	0	0	0
Arkansas	0	0	0	0	0	71	70	70	87	0	0	0
Florida	0	0	0	0	1	8	0	0	0	24	0	0
Georgia	0	0	0	0	5	72	0	47	19	0	0	0
Kentucky	0	0	0	0	0	7	7	45	17	0	0	0
Louisiana	0	0	0	0	0	83	7	36	44	0	0	0
Mississippi	0	0	0	0	0	100	2	68	53	0	0	0
North Carolina	0	0	0	0	0	0	0	2	0	0	0	0
Oklahoma	0	0	0	0	0	76	100	94	71	26	0	0
South Carolina	0	0	0	0	0	6	0	15	0	0	0	0
Tennessee	0	0	0	0	0	39	8	72	16	0	0	0
Texas	0	0	7	40	35	96	97	99	77	64	1	0
Virginia	0	0	0	0	0	0	0	7	0	0	0	0
Percent area in wettest class												
State	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Alabama	100	100	95	0	0	0	0	0	0	0	56	100
Arkansas	99	97	100	2	0	0	0	0	0	0	100	100
Florida	32	35	5	0	4	22	15	15	35	0	0	22
Georgia	100	100	36	1	0	0	0	0	0	0	21	74
Kentucky	100	100	100	0	0	0	0	0	0	0	100	100
Louisiana	100	100	100	0	0	0	0	0	0	0	82	100
Mississippi	100	100	100	0	0	0	0	0	0	0	93	100
North Carolina	100	100	97	5	3	0	11	0	0	0	21	100
Oklahoma	6	5	16	0	0	0	0	0	0	0	29	32
South Carolina	100	100	32	0	0	0	0	0	0	0	6	82
Tennessee	100	100	100	2	0	0	0	0	0	0	100	100
Texas	16	9	12	0	0	0	0	0	0	0	18	20
Virginia	100	100	98	0	0	0	0	0	0	2	42	100

Table 17.6—Percent of area in dry and wet classes for future conditions (2060) by State and month for Cornerstone A

Percent area in driest class												
State	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Alabama	0	0	0	0	46	100	100	100	100	0	0	0
Arkansas	0	0	0	0	0	100	100	100	100	0	0	0
Florida	0	0	0	81	60	93	96	95	93	59	4	0
Georgia	0	0	0	44	80	100	100	100	98	52	0	0
Kentucky	0	0	0	0	0	100	100	100	100	0	0	0
Louisiana	0	0	0	0	0	100	83	100	88	0	0	0
Mississippi	0	0	0	0	1	100	100	100	100	0	0	0
North Carolina	0	0	0	0	8	98	93	95	88	0	0	0
Oklahoma	0	0	1	60	26	100	100	100	100	23	0	0
South Carolina	0	0	0	10	83	100	100	100	100	0	0	0
Tennessee	0	0	0	0	0	100	100	100	99	0	0	0
Texas	0	0	68	59	89	100	96	100	100	66	21	0
Virginia	0	0	0	0	0	100	100	97	98	0	0	0
Percent area in wettest class												
State	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Alabama	100	100	8	0	0	0	0	0	0	0	0	98
Arkansas	38	93	0	0	0	0	0	0	0	0	65	100
Florida	20	8	0	0	0	0	0	0	0	0	0	5
Georgia	74	58	15	0	0	0	0	0	0	0	2	32
Kentucky	100	100	12	0	0	0	0	0	0	0	0	100
Louisiana	98	52	0	0	0	0	0	0	0	0	0	93
Mississippi	100	100	0	0	0	0	0	0	0	0	16	100
North Carolina	100	100	16	0	0	0	0	0	0	1	7	86
Oklahoma	0	3	0	0	0	0	0	0	0	0	8	0
South Carolina	89	84	6	0	0	0	0	0	0	0	0	26
Tennessee	100	100	35	0	0	0	0	0	0	0	14	100
Texas	3	0	0	0	0	0	0	0	0	0	1	1
Virginia	100	100	8	0	0	0	0	0	0	0	0	100

Table 17.7—Percent of area in dry and wet classes for future conditions (2060) by State and month for Cornerstone B

Percent area in driest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	0	0	0	0	0	0	93	100	21	0	0	0
Arkansas	0	0	0	0	0	10	100	100	50	0	0	0
Florida	0	0	0	0	0	0	3	11	12	0	0	0
Georgia	0	0	0	0	0	30	83	65	77	1	0	0
Kentucky	0	0	0	0	0	30	66	0	30	0	0	0
Louisiana	0	0	0	0	0	0	45	55	0	0	0	0
Mississippi	0	0	0	0	0	2	91	90	0	0	0	0
North Carolina	0	0	0	0	0	0	64	41	8	0	0	0
Oklahoma	0	0	0	8	14	36	100	100	87	55	0	0
South Carolina	0	0	0	0	0	18	68	45	58	0	0	0
Tennessee	0	0	0	0	0	0	59	34	3	0	0	0
Texas	0	0	40	59	85	50	97	100	63	78	11	0
Virginia	0	0	0	0	0	3	76	32	0	0	0	0
Percent area in wettest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	100	94	45	0	6	0	0	0	0	0	0	100
Arkansas	76	46	0	8	0	0	0	0	0	0	25	61
Florida	16	1	0	0	14	57	33	42	4	0	0	32
Georgia	71	42	19	4	4	0	0	0	0	0	2	100
Kentucky	100	100	16	43	0	0	0	0	0	0	0	100
Louisiana	43	89	0	0	21	17	12	0	22	0	11	93
Mississippi	100	100	24	4	15	0	0	0	0	0	0	100
North Carolina	100	71	59	10	7	0	0	0	0	3	6	100
Oklahoma	0	0	0	0	0	0	0	0	0	0	0	0
South Carolina	76	32	13	0	0	0	0	0	0	0	0	100
Tennessee	100	100	74	43	0	0	0	0	0	0	0	100
Texas	0	5	0	0	0	7	0	0	3	0	12	2
Virginia	100	100	66	6	0	0	0	0	0	0	2	100

Table 17.8—Percent of area in dry and wet classes for future conditions (2060) by State and month for Cornerstone C

Percent area in driest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	0	0	0	0	65	75	17	89	9	0	0	0
Arkansas	0	0	0	0	12	100	100	100	12	0	0	0
Florida	0	0	0	23	67	0	0	0	0	0	0	0
Georgia	0	0	0	0	73	52	28	60	41	0	0	0
Kentucky	0	0	0	0	0	38	38	100	0	0	0	0
Louisiana	0	0	0	0	0	48	54	61	17	0	0	0
Mississippi	0	0	0	0	36	87	73	92	28	0	0	0
North Carolina	0	0	0	0	0	1	31	30	0	0	0	0
Oklahoma	0	0	0	27	78	100	100	100	78	23	0	0
South Carolina	0	0	0	0	19	13	27	32	0	0	0	0
Tennessee	0	0	0	0	0	61	42	98	0	0	0	0
Texas	0	0	37	71	64	94	99	100	75	37	12	0
Virginia	0	0	0	0	0	9	64	76	0	0	0	0
Percent area in wettest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	100	100	100	15	0	0	0	0	0	0	15	100
Arkansas	21	82	27	0	0	0	0	0	0	0	65	99
Florida	27	8	21	0	0	12	0	25	4	0	0	25
Georgia	97	46	60	6	0	0	0	0	0	0	8	88
Kentucky	100	100	96	5	0	0	0	0	0	0	72	100
Louisiana	96	75	40	0	0	0	0	0	0	0	0	100
Mississippi	100	100	100	18	0	0	0	0	0	0	32	100
North Carolina	100	79	99	9	0	0	0	0	3	4	13	100
Oklahoma	0	0	0	0	0	0	0	0	0	0	0	3
South Carolina	100	29	68	0	0	0	0	0	0	0	4	96
Tennessee	100	100	100	35	0	0	0	0	0	0	91	100
Texas	4	0	0	0	0	0	0	0	1	0	0	11
Virginia	100	100	60	0	0	0	0	0	0	0	3	100

Table 17.9—Percent of area in dry and wet classes for future conditions (2060) by State and month for Cornerstone D

Percent area in driest class												
State	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Alabama	0	0	0	0	0	91	83	94	3	0	0	0
Arkansas	0	0	0	0	0	100	100	100	100	0	0	0
Florida	0	0	0	0	0	0	0	0	0	0	0	0
Georgia	0	0	0	0	6	63	56	61	2	0	0	0
Kentucky	0	0	0	0	0	85	82	100	34	0	0	0
Louisiana	0	0	0	0	0	91	78	88	54	0	0	0
Mississippi	0	0	0	0	0	99	94	96	73	0	0	0
North Carolina	0	0	0	0	0	53	15	14	0	0	0	0
Oklahoma	0	0	0	36	11	100	100	100	100	44	0	0
South Carolina	0	0	0	0	0	37	33	29	0	0	0	0
Tennessee	0	0	0	0	0	83	81	98	42	0	0	0
Texas	0	0	25	75	55	97	100	100	98	76	17	0
Virginia	0	0	0	0	0	77	44	47	0	0	0	0
Percent area in wettest class												
State	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Alabama	100	100	100	0	0	0	0	0	0	0	22	100
Arkansas	51	74	99	0	0	0	0	0	0	0	82	100
Florida	23	39	25	0	4	20	1	39	6	0	0	22
Georgia	91	100	89	1	1	0	0	0	0	0	11	74
Kentucky	100	100	100	38	0	0	0	0	0	0	50	100
Louisiana	100	100	85	0	0	0	0	0	0	0	49	100
Mississippi	100	100	100	0	0	0	0	0	0	0	58	100
North Carolina	100	100	100	8	3	0	0	0	0	1	13	100
Oklahoma	0	3	8	0	0	0	0	0	0	0	8	6
South Carolina	100	100	100	0	0	0	0	0	0	0	6	57
Tennessee	100	100	100	2	0	0	0	0	0	0	91	100
Texas	3	8	3	0	0	0	0	0	0	0	3	9
Virginia	100	100	100	2	0	0	0	0	0	0	2	100

closely tied to social issues than to climate. As the population in the South continues to increase and the wildland-urban interface continues to expand, ignitions caused by human carelessness are likely to increase, creating wildfire conditions that quickly exceed local suppression capabilities.

Future of Prescribed Fire

Prescribed fire is an important tool used in the South to manage hazardous fuels. The potential for an extended wildfire season will magnify the importance of effective fuels management. However, the same drying that is extending the wildfire season could also limit the ability to use prescribed fire as the dry conditions will likely increase the potential for escaped fires and also increase the potential for the fires to harm resources. Dry conditions will promote increased fuel consumption and consequently increased emissions. With air quality standards continually being tightened, these added emissions could result in further constraints on prescribed fire usage to help protect the health of the growing population. Air quality issues could have the largest impact on prescribed fire, as air quality restrictions would restrict burning over large areas, not just within the wildland-urban interface.

The rapid expansion of the U.S. population since World War II into formerly rural areas has caused significant shifts in land use and land cover. Natural resource managers must cope with constraints on traditional tools as well as a new class of resource and societal problems in the interface zone where urban and wildland uses must coexist. A history of extensive clearing, farming, or grazing has left many legacies, including an extensive road system (fig. 17.12). Population growth since the middle of the last century has caused increasing urbanization and fragmentation of the forested landscape (Stanturf and Wimberly, in press; Wear 2002), increasing the size and importance of the wildland-urban interface. More people now live at the interface and the transportation system is expanding, becoming denser and more pervasive (Riitters and Wickham 2003).

Aside from the physical aspects of urbanization, changing demographic profiles and cultural values (Cordell and others 2004) have altered attitudes towards natural resource management in general (Bliss and others 1997, Hull and Stewart 2002, Jacobson and others 2001) and prescribed burning in particular (Duryea and Hermansen 2002, Loomis and others 2001). More than 50,000 U.S. communities on the wildland-urban interface have been designated as "at risk" for fire, and most of them (70 percent) are in the Southern States (Blue Ribbon Panel 2008). The values at risk are substantial: recent wildfire seasons have been expensive with suppression costs in 2002 at $1.5 billion nationwide (National Interagency Fire Center 2001) and damage estimates from the 1998 wildfires in Florida alone costing close to $800 million (Butry and others 2001).

The growing wildland-urban interface increases both the risk of wildfire occurring and the cost of wildfire by placing higher values at risk than in wildland areas. Use of prescribed burning in the wildland-urban interface is still practical but requires more planning and preparedness, safe conduct, and communication with landowners and local officials (Miller and Wade 2003, Wade and Mobley 2007). In addition to the increased complexity of fire management, State agencies are faced with a dwindling workforce as the number of firefighters dropped by 24 percent between 2004 and 2010.[2] Declining budgets impact more than just staffing as agencies incur increased costs for training their staff and cooperators to work in the interface (State of Georgia 2010). High rates of arson in some states add to the fire risk (USDA Forest Service 2011).

[2]Personal communication with David Frederick, Fire Director, Southern Group of State Foresters, P.O. Box 680235, Prattville, AL 36068-0235. Feb. 2011.

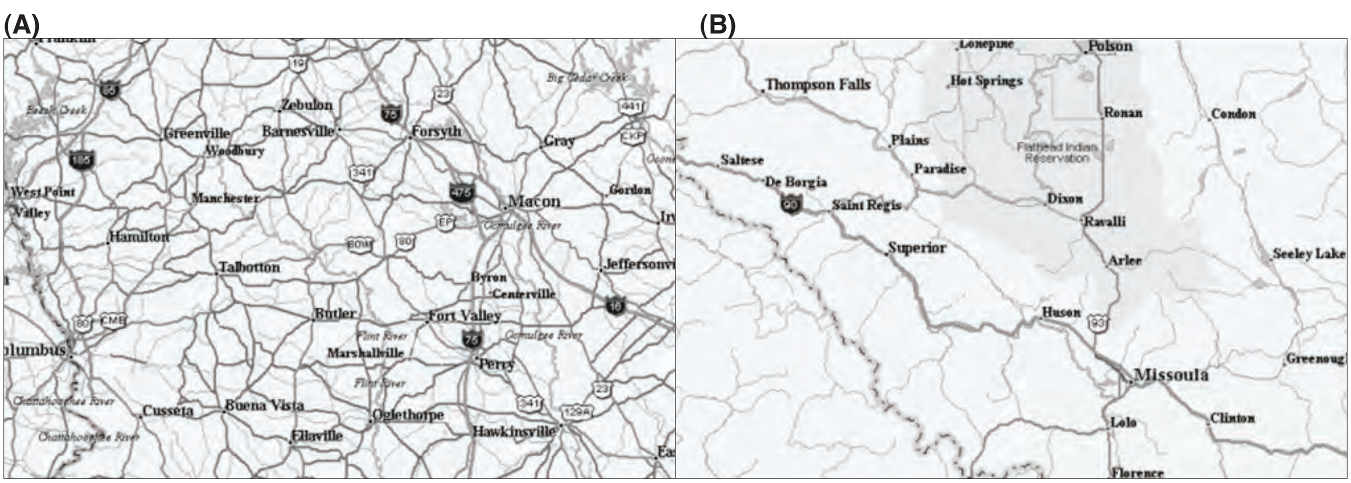

Figure 17.12—Legacy of roads in the South as compared to the West: (A) roads in an approximately 26,000 km^2 area of southwestern Georgia, the Flint River Valley, compared to (B) a similar area of the Bitterroot Valley in Montana. (Source: Stanturf and Wimberly, in press)

The South exemplifies the problems of mixing urbanized land uses with fire-adapted natural vegetation. Urbanization constrains traditional forest management and use of prescribed burning even at the wildland end of the urban-wildland gradient because of concerns for liability from escaped prescribed fire, transportation safety, and regional air quality. Moving toward the urban end of the gradient, these concerns greatly increase often resulting in abandonment of fuel management and increased risk of occurrence and severity of inevitable wildfire. Because of an extensive road system, the entire South may be regarded as a wildland-urban interface, at least in terms of managing smoke from prescribed burning.

Even when continued forest management is feasible, there will likely be further constraints on use of prescribed burning in the wildland-urban interface due to smoke. Smoke from prescribed burning is a critical issue in the South due to a combination of physical (meteorology, climate, topography), biological (fire-affected vegetation and hazardous fuels), and social (population density, road network) factors. In fact, smoke is probably the key issue in suitability of prescribed burning as a way to manage fuel loads in the interface. Concerns with smoke are several: local and regional air quality (Achtemeier 2003, Achtemeier and others 2001, Monroe 2002), visibility on roads (Mobley 1989), and health impacts especially on sensitive segments of the population with respiratory problems (Sorenson and others 1999).

Threat of escapes—Potential liability from escaped prescribed fire is often cited as a constraint on the use of prescribed burning (Brenner and Wade 2003, Haines and Busby 2001, Haines and Cleaves 1999). Even when the best available practices are applied, the possibility of an escape exists. Potential damage to neighboring properties, endangerment of human lives, and smoke-caused transportation accidents pose liability risk, along with litigation costs (Sun 2006).

Following the lead of Florida, all Southern States except Tennessee have revised their liability laws to limit liability unless negligence is involved (Brenner and Wade 2003, Sun 2006); some differentiate between simple and gross negligence. In the 10 States with simple negligence rules (Alabama, Arkansas, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Texas, and Virginia), a landowner who does not exercise the care that would be exercised by a “reasonable prudent person” could be held liable for damage from an escaped prescribed fire. In Florida and Georgia, where the gross negligence rule holds, the burden on the landowner or agent is even lower (Sun 2006). Thus State legislatures in the South offer legal protection for managers who use prescribed burning, provided they follow relevant laws and regulations, and exercise care in planning and execution.

Smoke—Smoke is produced when wood and other organic material combusts (Urbanski and others 2009) and produces a mixture of gases, solid particles, and droplets. Because wood fires are generally inefficient, they produce a large number of chemicals. Emissions from wildland fire are usually expressed as emission factors, defined as the mass of compound released per mass of dry fuel consumed (Urbanski and others 2009). Emission factors are influenced by fuel moisture and whether combustion is smoldering or flaming (Naeher and others 2007). In the South, the preferred time for prescribed burning is when fuel moisture is high and meteorological conditions favor low-intensity fires with lower fuel consumption as compared to wildfires that typically occur under drier conditions that favor high-intensity fires with more complete fuel consumption. Prescribed burning generally results in lower emissions than wildfire (Urbanski and others 2009). Typical emission factors from prescribed burns in a variety of southern forest ecosystems are given in table 17.10; the dominant compounds emitted are carbon dioxide, carbon monoxide, and particulates (Urbanski and others 2009).

Smoke is a problem when it in some way negatively impacts human habitation or activity (Achtemeier and others 2001). Smoke is a health problem when it invades the habitation of those with respiratory problems and other smoke-sensitive illnesses (Naeher and others 2007). Smoke is a nuisance when it irritates the eyes and mucus membranes of the nose and throat. Smoke is a nuisance when it deposits soot on clothes hung out to dry. Smoke is a safety problem when it impedes local visibility to create hazards to drivers of motor vehicles. The enormous wildland—urban interface and dense road network located in a region where up to six million acres of forest land per year are subject to prescribed fire combine to make problem smoke the foremost forestry-related air quality problem in the South. During the daytime, smoke becomes a problem when it drifts into areas of human habitation. At night, smoke can become entrapped near the ground and, in combination with fog, create visibility reductions that cause roadway accidents. Public complaints about smoke-related problems usually begin at levels well below national ambient air quality standards.

Air quality—One of the key indicators of air quality is whether monitoring shows that an area complies with the national air quality standards established by the Environmental Protection Agency (EPA). Although EPA does not directly regulate the use of wildland fire, it is responsible for enforcing the sections of the Clean Air Act that requires States and Tribes to attain and maintain the national ambient air quality standards (NAAQS). The EPA also must develop “primary” and “secondary” standards

Table 17.10—Modeled ranges of emission factors (g kg-[1]) for prescribed burning in several southern forest ecosystems (developed for illustrative purposes and not intended to be definitive because numbers of fires in each ecosystem varied and were conducted under varying conditions); these are fire-weighted average factors comparing compound emitted to dry fuel consumed

Vegetation type	MCE[a]	CO_2	CO	CH_4	C_2H_6	C_2H_4	C_2H_2	C_3H_8	C_3H_6	C_3H_4	$PM_{2.5}$
Longleaf pine, palmetto	0.934-0.952	1681-1712	55.3-75.2	1.26-1.45	0.13-0.18	0.94-1.34	0.40-0.74	.01	0.35-0.37	0.00-0.09	10.0-11.3
Sandhills longleaf pine	0.918	1653	94.0	3.39	0.39	0.95	0.30	0.11	0.50	0.05	11.5
Loblolly pine, wiregrass	0.928-0.942	1657-1687	66.5-81.5	1.78-2.31	0.26-0.28	1.19-1.27	0.33-0.42	0.10-0.11	0.45-0.46	0.05-0.07	13.2-15.6
Mixed pine, wax myrtle	0.904	1621	109.4	3.00	0.23	0.83	0.28	0.06	0.38	0.04	10.4
Oak, pine, grass	0.921-0.942	1647-1688	65.9-90.2	1.75-2.26	0.21-0.28	0.97-1.17	0.28-0.36	0.08-0.10	0.40-0.49	0.05-0.06	14.1-14.5
Mixed pine, wiregrass	0.936	1682	73.1	1.99	0.22	0.86	0.23	0.09	0.37	0.09	11.4
Sandhill shrub	0.921	1652	89.7	2.62	0.32	1.01	0.23	0.11	0.47	0.03	11.9
Palmetto, turkey oak	0.938	16.95	71.1	1.65	0.18	1.13	0.49	0.02	0.31	0.05	6.9
Palmetto	0.933	1665	76.4	2.13	0.23	1.12	0.35	0.08	0.45	0.05	15.7
Pocosin	0.935-0.943	1683	64.2-76.4	1.84-2.13	0.23	1.12-1.35	0.36	0.08-0.11	0.46	0.06	15.7-16.7
Sawgrass	0.914-0.97	1635-1752	34.7-98.3	0.90-4.12	0.07-0.59	0.52-1.60	0.21-0.49	0.02-0.23	0.10-0.79	0.02-0.08	9.9-9.1
Wiregrass	0.912-0.936	1626-1681	73.5-99.5	2.16-3.34	0.21-0.44	1.15-1.42	0.25-0.64	0.06-0.20	0.42-0.64	0.05-0.07	9.7-15.3

[a]MCE is modified combustion efficiency, calculated as the $\Delta CO_2/(\Delta CO+\Delta CO_2)$.
Source: Adapted from Urbanski and others 2009.

for six pollutants: ozone, particulate matter, sulfur dioxide, carbon monoxide, nitrogen dioxide and lead (table 17.11). Primary standards are for human health and secondary standards for public welfare, which includes damage to vegetation and crops as well as effects on visibility. Of these six pollutants, only two—sulfur dioxide and lead—are of little concern for prescribed burning. As a result of rapid dilution and its instability, carbon monoxide emissions from prescribed burning are not a concern to the general public (National Coalition of Prescribed Fire Councils 2007). However, carbon monoxide emissions may be a concern to firefighters and prescribed burning crews.

Although nitrogen oxides from prescribed burning are not of concern on a local level (National Coalition of Prescribed Fire Councils 2007), they combine with other emissions (volatile organic carbon, particulates, and carbon monoxide) in a photochemical process (Urbanski and others 2009) and contribute to ozone formation that may be a concern in some areas (National Coalition of Prescribed Fire Councils 2007). Figure 17.13 shows the current status of non-attainment areas in the South for ozone and highlights the relationship of urban areas to non-attainment status. Ozone and particulate levels are generally at their lowest ambient levels during the prescribed burning season in the South, winter and early spring (Southeast Regional Partnership for Planning and Sustainability 2010). But occasionally summer burns are recommended for ecological reasons (Brockway and others 2005), a practice that would be limited in an area designated as non-attainment for ozone and particulates.

After carbon dioxide and carbon monoxide, particulates account for the greatest share of emissions from wildland burning (Urbanski and others 2009) and because particulates are a criteria pollutant, currently they are the greatest concern from prescribed burning. Wood smoke particulates are relatively small but their size distribution can vary greatly, depending on the rate of energy release.

Because of their size (generally, 70 percent are smaller than 2.5 microns in aerodynamic diameter or PM2.5), wood smoke particulates scatter light and reduce visibility (National Coalition of Prescribed Fire Councils 2007). Standards for particulate matter have been on a trend of increasing stringency since 1971 (Southeast Regional Partnership for Planning and Sustainability 2011)—with current thresholds of 35 $\mu g\ m^{-3}$ averaged for any 24 hour-period and 15 $\mu g\ m^{-3}$ averaged over a full year—and there is little evidence to suggest that standards will loosen in future reviews. Recent annual and 24-hour ambient PM2.5

Table 17.11—Current and proposed National Ambient Air Quality Standards

	National Ambient Air Quality Standards	
Pollutant	**Level**	**Averaging time**
Carbon monoxide (CO)	9 ppm (10 mg m^{-3}) 35 ppm (40 mg m^{-3})	8-hour 1-hour
Lead (Pb)	0.15 µg m^{-3}	Rolling 3-month average
Nitrogen dioxide (NO_2)	0.053 ppm (100 µg m^{-3}) 0.10 ppm	Annual (arithmetic mean) 1-hour
Particulate matter (PM_{10})	150 µg m^{-3}	24-hour
Particulate matter ($PM_{2.5}$)	15.0 µg m^{-3} 35 µg m^{-3}	Annual 24-hour
Ozone (O_3)	0.075 ppm (2008 standard) 0.08 ppm (1997 standard) 0.060-0.070 ppm	8-hour 8-hour 8-hour (proposed January 2010)
Sulfur dioxide (SO_2)	0.03 ppm 0.14 ppm 0.5 ppm 0.050 to 0.100 ppm	Annual (arithmetic mean) 24-hour 3-hour 1-hour (proposed December 2009)

Source: Southeast Regional Partnership for Planning and Sustainability 2011.

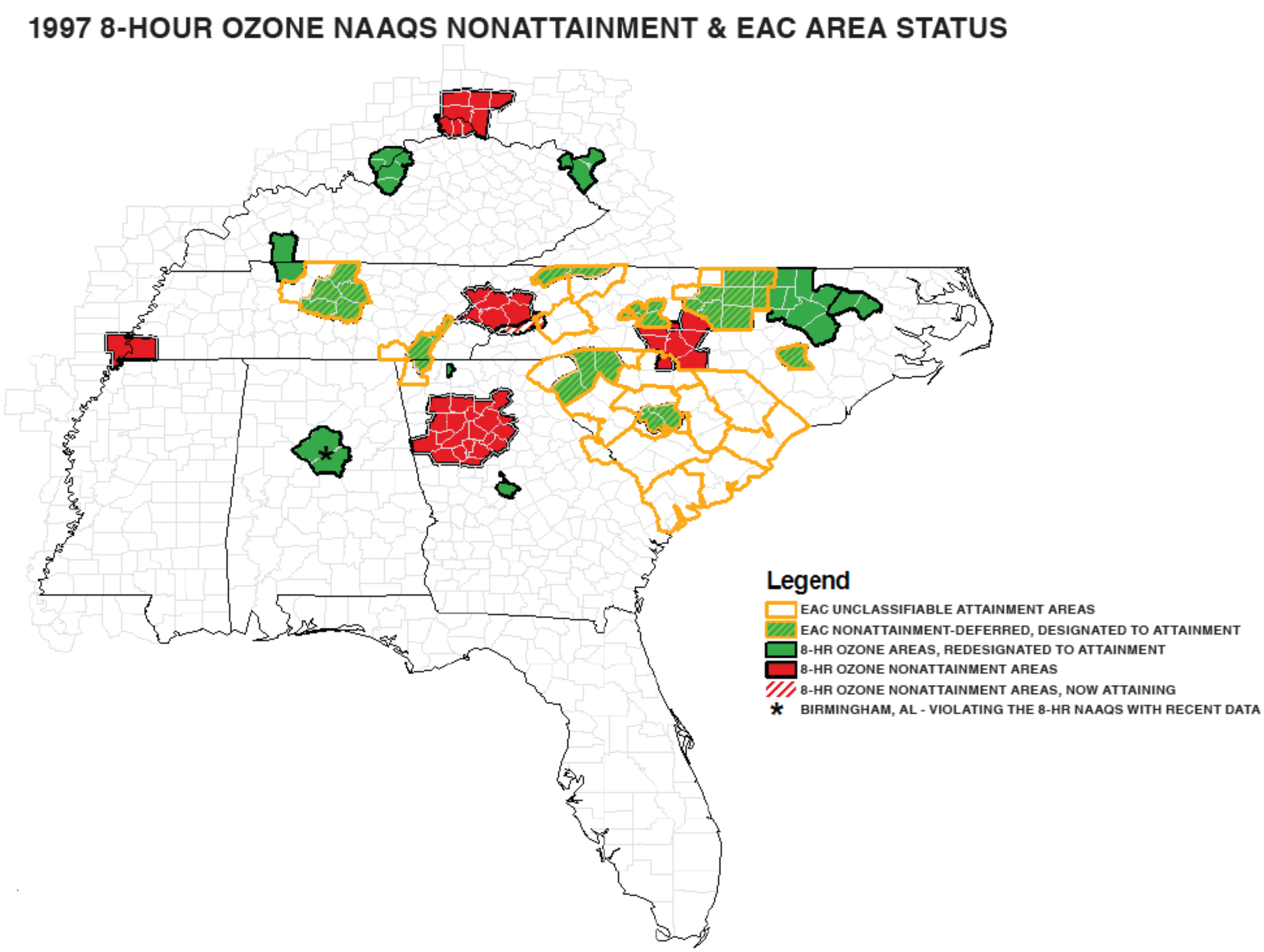

Figure 17.13—Eight-hour ozone non-attainment areas, 2008, in Environment Protection Agency Region 4. (Source: Jane Spann, map created by Nacosta C. Ward; http://www.epa.gov/region04/production/air/modeling/2009%20Workshop/March-19-09/JaneSpan%20Presentation%20wo%20talking%20pts19_4.ppt)

levels for the States east of the Mississippi River and south of Virginia (EPA Region 4) are displayed in figures 17.14 and 17.15. Although current levels for most of the Coastal Plain are below national standards (both the current standards and those being evaluated), the same cannot be said for areas in the Piedmont and Southern Appalachian Mountains.

EPA also monitors visibility in Federal Class I areas (Fox and others, in press), which consist of all international parks, national wilderness areas larger than 5,000 acres, national memorial parks larger than 5,000 acres, and national parks larger than 6,000 acres that were established before 1977. EPA's 1999 Regional Haze Rule (64 FR 35714) provides specific guidance on wildland fire for many Western States but takes a more general approach for the rest of the country (National Coalition of Prescribed Fire Councils 2007), requiring that all States with Class I areas consider the impacts of prescribed burning on visibility. Five Regional Planning Organizations were established to help States develop visibility protection programs; the Central Regional Air Planning Association serves Oklahoma, Texas, Arkansas, and Louisiana and the Visibility Improvement State and Tribal Association of the Southeast for all other Southern States. Their goal for each Class I area is to improve the 20 percent haziest days and ensure that no degradation occurs on the cleanest days.

The Regional Haze Rule requires all States and participating Tribes to develop State Implementation Plans for reducing emissions of visibility degrading aerosols, relative to "natural background conditions." Natural background haze is a complex concept that reflects contemporary, not pre-European settlement conditions (Fox and others, in press). One central issue is whether wildland fire is natural or anthropogenic. The policy developed for the Western States is that any wildfire or any fire being managed to the natural fire frequency is classified as natural; any fire ignited or managed to restore the natural fire frequency is anthropogenic (National Coalition of Prescribed Fire Councils 2007). This policy, which has not been applied beyond the West, would have serious implications for the South, especially in the mountains where prescribed burning for restoration objectives is increasing.

Transportation safety—The extensive transportation system in the South presents a formidable challenge to prescribed burners. Although most burns are carried out without incident, smoke and smoke/fog visibility obstructions on southern highways cause numerous accidents with loss of life and personal injuries. Mobley (1989) reported 28 fatalities, more than 60 serious injuries, numerous minor injuries, and millions of dollars in lawsuits from 1979 to 1988. Comparing three years of accident reports in Florida, Lavdas and Achtemeier (1995) found accidents are more closely associated with local ground radiation fogs (cooling of land after sunset) than with widespread advection fogs (formed when moist air passes over a cool surface) and that most serious accidents occur at night or near sunrise when smoke from smoldering fires is entrapped near the ground and carried by local drainage winds into shallow basins. Near sunset, under clear skies and near calm winds, temperatures in shallow stream basins can drop up to 20 °F in an hour (Achtemeier 1993) and strong, shallow valley inversions can develop. Weak nighttime drainage winds of approximately 1 mile per hour (0.5 m sec^{-1}) can carry smoke more than 10 miles, far enough to carry smoke/fog over a roadway in many areas. An example is the smoke from wildfires in 2000 that drifted across Interstate 10 and caused at least 10 fatalities, five in Florida and five in Mississippi.

Achtemeier (2006, 2008, 2009) demonstrated that under certain conditions, fog combined with smoke from prescribed burning can produce a "superfog" that reduces visibility to less than 10 feet (3 m, the definition of zero visibility). Motorists have no defense when driving from unlimited visibility to zero visibility in a manner of seconds. Because most prescribed burns take place in the winter when dry surface fuels overlay wet fuels, they often provide considerable moisture release both from the combustion and from heated soil and underlying wet fuels that do not ignite. At night, moisture from residual smoke can increase ambient relative humidity to 100 percent and contribute to the formation of superfog (Achtemeier 2009). Because we are just beginning to recognize the conditions for superfog formation, the full significance of this extremely hazardous phenomenon is yet to be realized or mitigated by the public safety community.

Human health—The greatest health threat from wood smoke appears to come from fine particles although a number of other constituents have health effects (Naeher and others 2007). Fine particles in wood smoke (less than 100 µg m^3) that penetrate far into lung tissue have toxic effects (Naeher and others 2007). Because ultra-fine particles (PM2.5) can be transported long distances from the combustion site and may form later through condensation and atmospheric chemical reactions, they can pose a health hazard to vulnerable populations at considerable distance from a prescribed burn. According to the World Health Organization, vulnerable groups are the very young, pregnant women, the elderly, and individuals with pre-existing respiratory (asthma, chronic obstructive pulmonary diseases) and cardiac diseases (Schwela and others 1999).

Other groups may be more susceptible due to higher exposures: outdoor workers, firefighters and emergency response workers ("Guidelines on vegetation fire emergencies for public health protection" also contains a review of studies linking health effects to biomass burning. Available online at http://www.who.int/docstore/

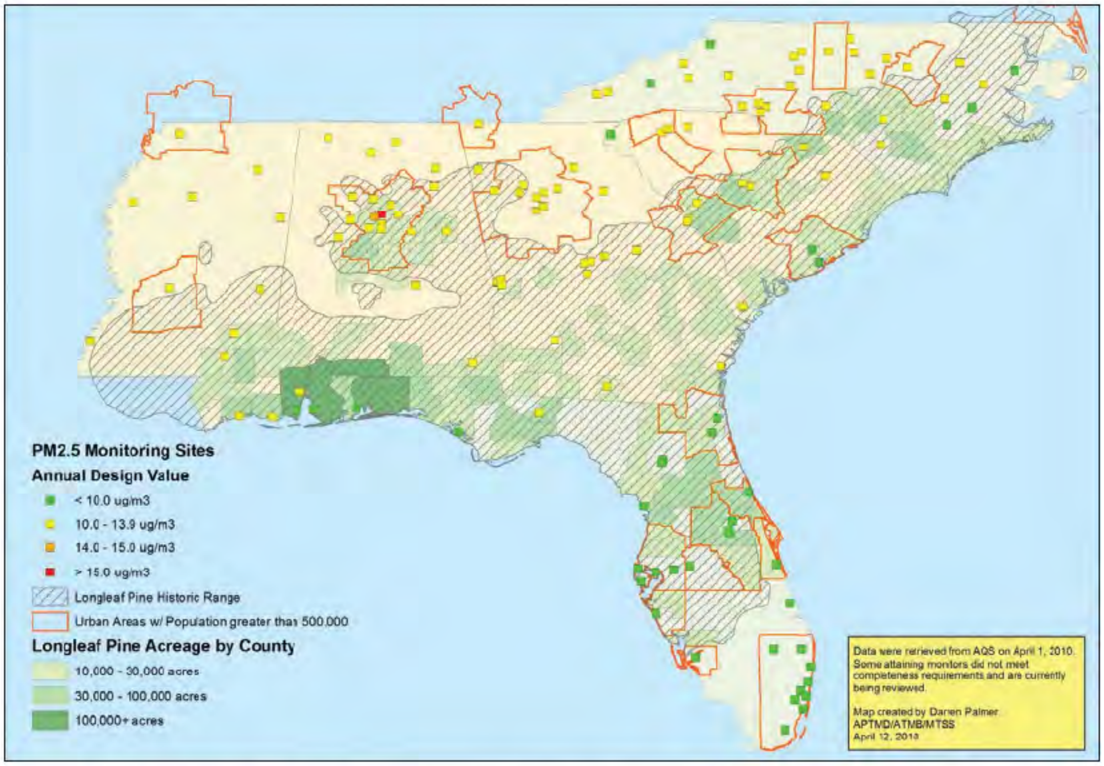

Figure 17.14—Annual average ambient air concentrations at particulate-matter (PM2.5) monitoring sites, 2007 to 2009, for States participating in the Southeast Regional Partnership for Planning and Sustainability; concentrations calculated according to the Clean Air Act regulations for comparison to the National Ambient Air Quality Standards. (Source: Southeast Regional Partnership for Planning and Sustainability 2010; map created by Darren Palmer)

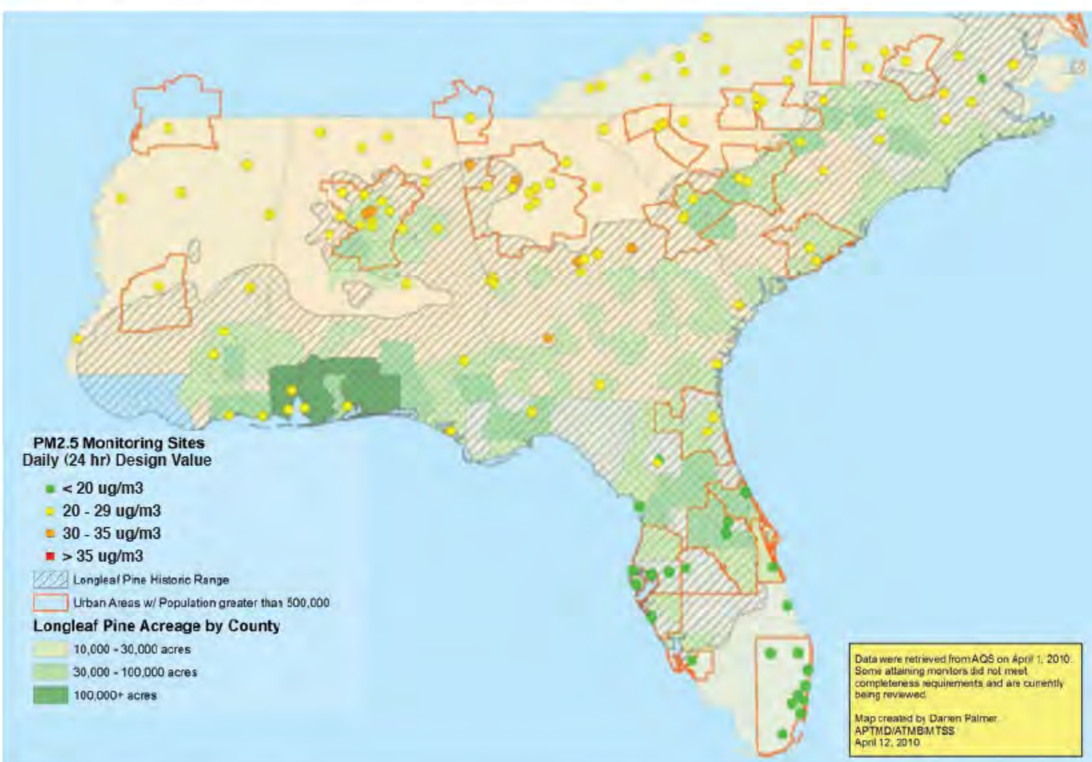

Figure 17.15—Twenty-four-hour average ambient air concentrations at particulate-matter (PM2.5) monitoring sites, 2007 to 2009, for States participating in the Southeast Regional Partnership for Planning and Sustainability; concentrations calculated according to the Clean Air Act regulations for comparison to the National Ambient Air Quality Standards. (Source: Southeast Regional Partnership for Planning and Sustainability 2010; map created by Darren Palmer)

peh/Vegetation_fires/Health_Guidelines_final_3.pdf , last accessed on 9 December 2010). Recent studies have shown that wildfires and prescribed burns expose fire personnel to smoke levels high enough to present potential occupational health concerns (Carlton and others 2004, Naeher and others 2007, Yanosky 2001). Naeher and others (2006) also found that current exposure standards for dust inhalation, although not intended to apply to wildland fire personnel, would be inadequate if applied to protect fire personnel from harmful particulate exposures.

A number of other wood smoke constituents have health effects (Naeher and others 2007). Although carbon monoxide's instability and rapid dilution preclude any threats to the general public (National Coalition of Prescribed Fire Councils 2007), carbon monoxide emissions may be a concern to firefighters and persons on prescribed burning crews. At least five chemical groups with known carcinogenic properties are present in wood smoke along with 26 chemicals considered hazardous air pollutants by EPA (Naeher and others 2007). Currently EPA is focusing on acetaldehyde, acrolein, 1,3 butadiene, formaldehyde, and polycyclic organic matter (Southeast Regional Partnership for Planning and Sustainability 2010). Naeher and others (2007) found that even limited exposure to wood smoke can reduce resistance against infections, that most effects are associated with the particle phase, and that an associations exists between wildfires and increased emergency room visits for upper and lower respiratory illnesses and decreased lung functioning (Naeher and others 2007).

Alternatives to Prescribed Burning

Various mechanical and chemical alternatives to prescribed burning are used or have been proposed and recent reviews provide details (Guldin 2010, Marshall and others 2008, Mercer and Prestemon 2008, O'Brien and others 2010, Outcalt 2009, Reilly and others 2009, Schwilk and others 2009). Equipment such as mowers, mulchers and choppers are used to cut, chop, or sever mostly midstory and understory fuel layers (Outcalt 2009). This equipment is most effective where large stems are widely spaced and is often used in areas with high fuel loads. Mechanical methods change fuel configurations but do not remove fuels from the site and may not completely mitigate the wildfire threat. Most often they are used as a pre-treatment prior to prescribed burning. Although slope limitations have traditionally hindered usage of mechanical methods in the mountains, increasingly smaller crawler units are now available for steep slopes (Reilly and others 2009). Harvesting with mechanized equipment is a normal forestry operation and clear-cutting or thinning for fuels management or restoration is increasingly utilized especially in pine types (Guldin 2010, Outcalt 2009). Harvesting to remove unwanted species or to reduce stem density is often followed by prescribed burning to maintain stand structure and composition.

Herbicides that target broadleaved trees have been a standard treatment in pine plantation management for more than 30 years. Managers also use herbicides for fuel reduction (Outcalt 2009). Similar to mechanical fuel reduction methods, herbicides are often the precursor to prescribed burning in stands with dense shrub-layer vegetation. Herbicide application followed by burning can be more effective than burning alone (Outcalt 2009).

Prescribed burning remains the most widely used fuel treatment in the South although significant acres are treated with mechanical means, mostly on Federal lands in the wildland-urban interface zone (Outcalt 2009). Each method has benefits and drawbacks (table 17.12) with prescribed burning often costing the least and providing the most ecosystem benefits (Glitzenstein and others 2003, Kirkman and others 2004a, b).

Carbon and Climate

Wildfire can affect climate through emitting carbon dioxide and aerosol particles into the atmosphere (National Academy of Sciences 2010). The greenhouse gas effect is one of the major contributors for climate change at long-term (decade and century) scale. Greenhouse gases in the atmosphere can absorb long-wave radiation emitted from the ground, which prevents heat energy from radiating into space. As a result, the temperature of the earth-atmosphere system increases. A number of atmospheric general circulation models have projected that greenhouse gases will increase global temperature by 4 to 6 °C by the end of this century, accompanied by significant changes in precipitation. It is estimated that average annual global fire carbon emissions were about 2 Pg (petagrams) in the recent decade, about a third of all carbon emissions. This indicates that wildfire emission is one of the major sources of atmospheric carbon dioxide and therefore an important contributor to future climate change, even though they comprised only 4 to 6 percent of anthropogenic emissions in the United States (Wiedinmyer and Neff 2007).

Charlson and others (1992) showed that smoke from wildfires can affect global climate by scattering and absorbing short-wave (solar) radiation (direct radiative forcing) and modifying cloud microphysics (indirect radiative forcing). These processes can further modify clouds and precipitation and atmospheric circulation (Ackerman and others 2000, Liu 2005a). In contrast, smoke aerosols (including black carbon or soot) have a shorter life span, but greater spatial variability and the potential for long-range transport (Kopp and Mauzerall 2010). Thus, they mainly affect short-term (daily, monthly, or seasonal) regional climate variability.

For example, figure 17.16 shows the role of the smoke aerosols from the Yellowstone National Park wildfires in the development of the 1988 drought in the Northern United States (Liu 2005b). The precipitation change in response to radiative forcing of smoke aerosols was mostly negative in the Northwest, with the largest negative response of about -30 mm found in the northeastern portion of the Midwest. This was accompanied by positive responses in the Southwest, Northeast, and southeastern portion of the Midwest; and negative response in the South. This simulated pattern was similar to the observed pattern of precipitation anomalies, suggesting that the smoke particles from the wildfire might have exacerbated the drought.

Although much about the interaction between wildfire and climate has yet to be understood and great uncertainty surrounds U.S. policy and regulatory approaches, smoke from prescribed burning clearly will receive increased attention from the scientific and policy communities. Recent studies have called for a more complete accounting of fire in carbon budgets (Hurteau and others 2008) and have emphasized the need to consider black carbon in climate change projections (Kopp and Mauzerall 2010). If climate change increases the potential for wildfire and alters fire regimes (Running 2006), the ability of forests to sequester carbon as a mitigation strategy could be compromised; instead of a carbon sink, forests could become a carbon source. Although it is generally agreed that fuel management through prescribed burning emits less carbon into the atmosphere compared to more intense wildfires, only a few studies have quantified this comparison (Wiedinmyer and Hurteau 2010) or demonstrated how forest management techniques can significantly alter the emissions from prescribed burning (Tian and others 2008).

CONCLUSIONS AND DISCUSSION

The potential for an extended wildfire season magnifies the importance of effective fuels management. However, the same drying that is extending the wildfire season could also limit the ability to use prescribed fire because the dry conditions will likely increase the potential for escaped fires and harm to resources. Dry conditions promote increased fuel consumption and consequently increased emissions. If air quality standards continue to tighten, these added emissions could result in further constraints on use of prescribed fire to protect the health of the growing population. Air quality issues could have the largest impact on prescribed fire by restricting burning over large areas, not just within the wildland-urban interface.

Prescribed burning is an important forest management tool in the South, used to manage fuels and promote wildlife habitat. Because natural wildfires have been limited both by effective fire suppression to protect other resources and by forest fragmentation, prescribed burning plays a critical ecological role in restoring and maintaining the integrity of fire-dependent forest and grassland communities.

Nevertheless, the near-term future of prescribed burning in the South is problematic. Changing land use and demographics have increased the numbers of people and value of structures in close proximity to wildlands, the so-called wildland-urban interface. In this interface zone,

Table 17.12—Advantages, disadvantages, and costs of fuel treatment options in use in the South

Attributes	Treatment			
	Prescribed burn	Mechanical	Manual	Harvesting
Pros	Low cost	Facilitates burning	Selective	Selective
	Ecological benefits	Use in urban areas	Use in urban areas	Produces revenue
	Minimal soil disturbance			
Cons	Smoke	Can be costly	Can be costly	Fuel created
	Potential escapes	Fuel created	Fuel created	Potential site damage
	Resource damage	Equipment breakage		
		Potential site damage		
Cost (dollars per acre)	23 to 121[a]	120 to 350[b]		
		35 to 1000[c]		

[a]Cleaves and others 2000.
[b]Rummer and others 2002.
[c]Wolcott and others 2007.
Source: Outcalt 2009.

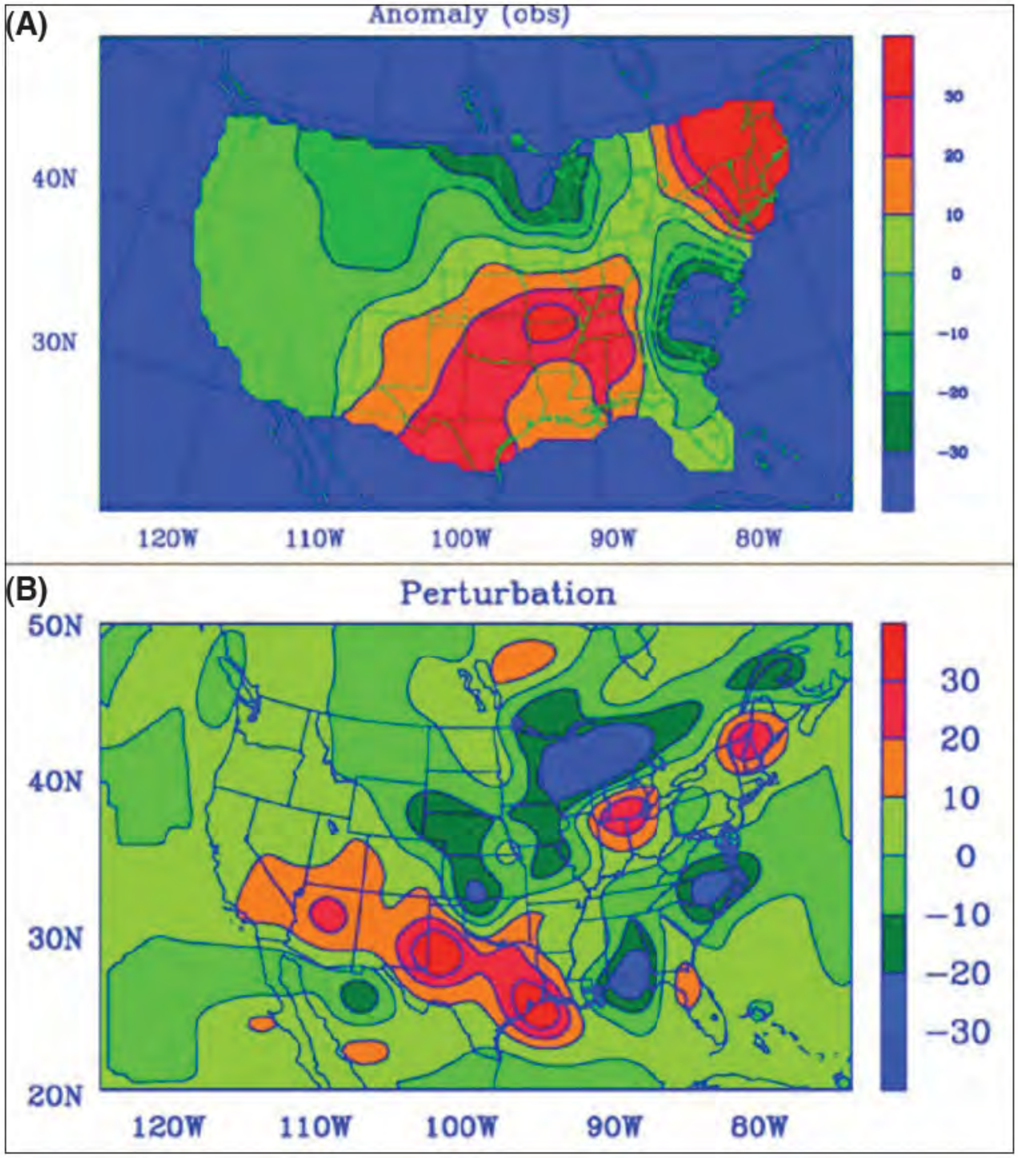

Figure 17.16—Following the Yellowstone National Park wildfires of July 1988, (A) observed U.S. precipitation anomalies and (B) differences in regional climate model simulations of U.S. precipitation with and without smoke particles. (Source: Liu 2005b)

prescribed burning requires greater skill and more attention to communication with the public, both of which increase costs (State of Georgia 2010). State legislatures have established limits on liability from responsibly conducted burns that escape, but laws can be changed. The greatest threat to continued use of prescribed burning comes from the effects of smoke on public health, transportation safety, and air quality; and from new regulations on carbon and greenhouse gas emissions to mitigate climate change. Air quality issues, including caps on carbon and greenhouse gas emissions, would have the greatest impact as they could restrict prescribed burning over large areas, not just the wildland-urban interface. Alternatives to prescribed burning are neither cost-effective nor do they provide the ecological benefits of fire in adapted ecosystems, (Glitzenstein and others 2003, Kirkman and others 2004a, 2004b) and do not achieve the same level of health and safety benefits to human communities.

Over the longer term and factoring in the effects of climate change, the need for prescribed burning will likely grow at the same time that obstacles, complexity and cost will increase. Restrictions on the use of prescribed burning to manage fuels would exacerbate potential climate change effects, particularly in the Coastal Plain and western Appalachian Mountains where wildfire potential is expected to increase. Fuels buildups combined with more intense wildfires under a changed climate potentially would have drastic consequences for fire-dependent communities that often support one or more threatened, endangered, or sensitive species. Drier conditions with more variability in precipitation could cause vegetation ranges to begin shifting, which could be initially resisted by active management, particularly in production conifer forests where reforestation through planting currently is the norm. Over longer time than the projections used here, the combination of climate change, extreme weather events, and severe wildfires could disrupt successful regeneration and result in new species assemblages, so-called novel ecosystems, with possibly novel fire regimes (Williams and Jackson 2007).

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