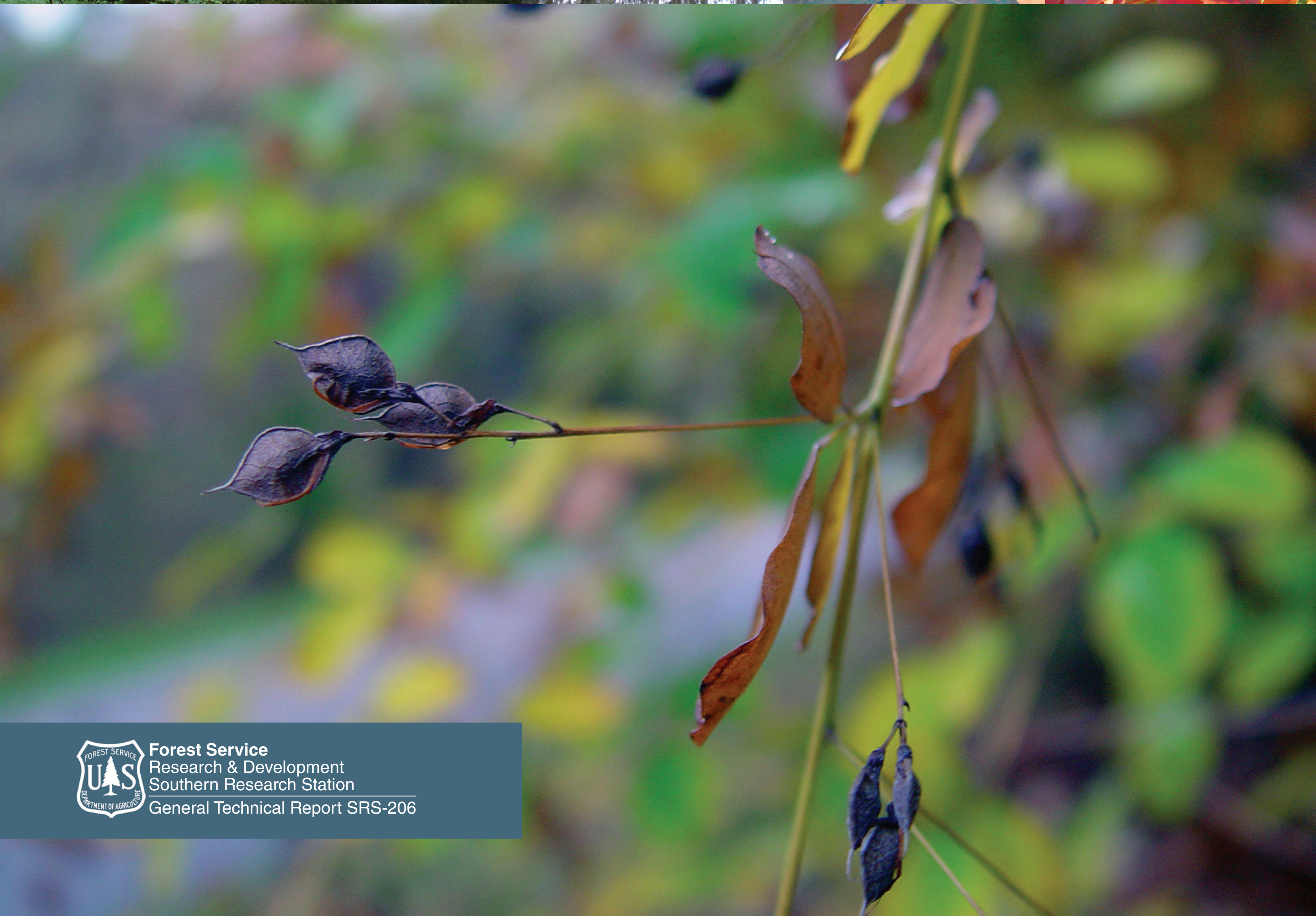
Outlook for Mid-South Forests:

A SUBREGIONAL REPORT from the Southern Forest Futures Project

James M. Guldin, Stephen Hallgren, and James S. Crooks



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Cover photos

MAIN IMAGE: Shrubby lespedeza (Chris Evans, Illinois Wildlife Action Plan). TOP ROW LEFT TO RIGHT: Appalachian mixed hardwoods (Chris Evans, Illinois Wildlife Action Plan); Great Smoky Mountains National Park, Tennessee (Chris Evans, Illinois Wildlife Action Plan); Spanish moss and resurrection fern (Carey Minteer, University of Arkansas); aerial view of Little River, southwest Arkansas (Brian Lockhart, USDA Forest Service); and smooth sumac (Chris Evans, Illinois Wildlife Action Plan). All images from Bugwood.org.

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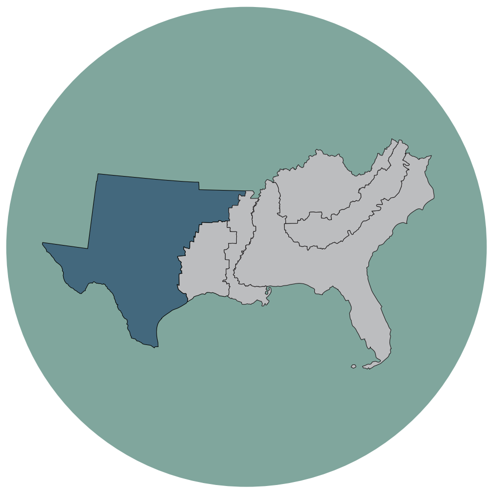

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PROLOGUE

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This report describes a set of likely forest futures and the management implications associated with each for the Mid-South, one of five subregions of the U.S. South. Its findings are based on the findings of the Southern Forest Futures Project, a multi-agency effort to anticipate the future and to analyze what the interaction of future changes might mean for forests and the benefits they provide in the 13 Southern States. The Futures Project investigators examined a labyrinth of driving factors, forest outcomes, and human implications to describe how the landscape of the South might change. Their findings, which are detailed in a 17 chapter technical report (Wear and Greis 2013) and synthesized in a compact summary report (Wear and Greis 2012), consist of analyses of specific forecasts and natural resource issues. Because of the great variations across southern forest ecosystems, the Futures Project also draws out findings and management implications for each of five subregions (fig. P1) including the one addressed in this report.

Why spend several years sorting through the various facets of this complicated puzzle? The reasons are varied but they all revolve around one notion: knowing more about how the future might unfold can improve near-term decisions that have long-term consequences. For example, knowing more about future land use changes and timber markets can guide investment decisions. Knowing more about the intersection of anticipated urbanization, intensive forestry, and imperiled species can guide forest conservation policy and investments. And knowing more about the potential development of

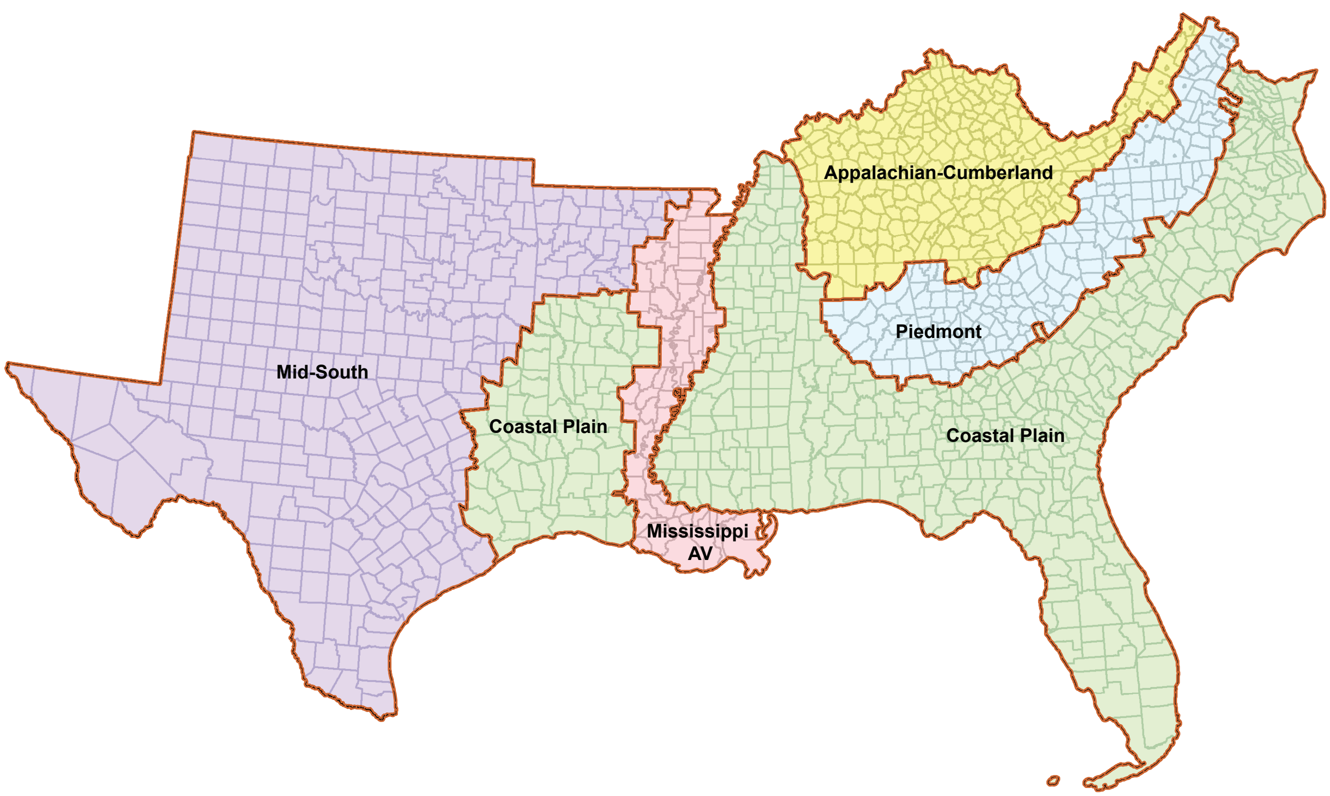

Figure P1—The five subregions of the U.S. South.

fiber markets can inform and improve bioenergy policies. Consequently, the intended users of the Futures Project findings are natural resource decisionmakers, professionals, and policy analysts as well as those members of society who care about natural resource sustainability.

From the dozens of detailed topic-specific findings in the technical report, 10 were identified and discussed in the Futures Project summary report. They are:

- The interactions among four primary factors will define the future forests of the South: population growth, climate change, timber markets, and invasive species.
- Urbanization is forecasted to cause losses in forest acreage, increased carbon emissions, and stress to forest resources.
- Southern forests could sustain higher timber production levels; however, demand is the limiting factor, and demand growth is uncertain.
- Increased use of wood-based bioenergy could generate demands that are large enough to trigger changes in forest conditions, management, and markets.
- A combination of factors, including population growth and climate change, has the potential to decrease water availability and degrade quality; forest conservation and management can help to mitigate these effects.
- Nonnative invasive species (insects, pathogens, and plants) present a large but uncertain potential for ecological changes and economic losses.
- Fire-related hazards in wildlands would be exacerbated by an extended fire season combined with obstacles to prescribed burning that would accompany increased urbanization (particularly in response to air quality and highway smoke issues).
- Private owners continue to control forest futures, but ownership patterns are becoming less stable.
- Threats to species of conservation concern are widespread but are especially concentrated in the Coastal Plain and the Appalachian-Cumberland highland.
- Increasing populations would increase demand for forest-based recreation while the availability of land to meet these needs is forecasted to decline.

The impetus for the Southern Forest Futures Project comes from a desire to understand how a wide variety of dynamics including economic, demographic, and environmental changes might affect forest resources. An assessment of some aspects of forest sustainability (Wear and Greis 2002a, 2002b) was completed a decade ago, but the rapid pace of change and the sudden emergence of new and complex natural resource issues prompted a new study that could take advantage of recent science findings and forecasting methods. In December 2007, the Futures Project got underway under the joint sponsorship of the U.S. Department of Agriculture Forest Service and the Southern Group of State Foresters.

Designing the Futures Project

The Futures Project investigators started by identifying a set of relevant questions and then defining a targeted and robust process for answering them. Their process consisted of enumerating the critical socioeconomic and biophysical changes affecting forests, defining the most important management and policy information needs, and addressing forecasts and questions at the most useful scale of analysis. A series of public information gathering sessions addressed the first two stages of the process: more than 600 participants with a wide array of backgrounds and perspectives—at 14 meetings, with at least one meeting in each of the 13 Southern States—contributed input on what they saw as the important issues and future uncertainties affecting forests (Wear and others 2009). These meetings shaped the thinking about alternative futures and led to the selection and definition of meta-issues, each of which describes an interrelated complex of questions (for example, the bioenergy meta-issue is constructed from a set of questions that address conversion technologies, impacts on sustainability, Federal and State policies, and economic impacts).

The South defines a discernible biological and socioeconomic region of the United States, but also contains a vast diversity of biota and socioeconomic settings within its boundaries. The meta-issues and the forecasts of future conditions were analyzed at the broad regional level, with results broken down to finer grains of analysis where feasible and appropriate. However, the broad-scale approach was not considered adequate to address specific implications that these forecasts and issue analyses hold for forest management and restoration activities in more localized conditions; doing so required a scale that more closely matched the different forest ecosystem types in the South (fig. P2).

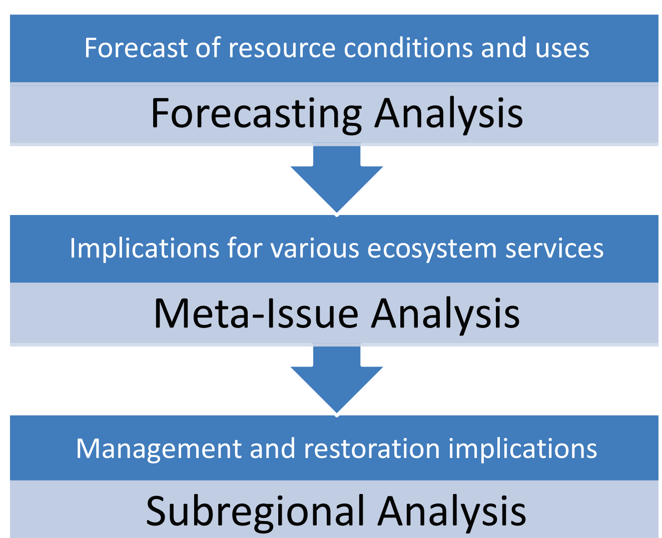

Figure P2—The three phases of the Southern Forest Futures Project.

Thus the second phase of the Futures Project, in which separate efforts examined the management/restoration implications for the five subregions of the South: Coastal Plain, Piedmont, Appalachian-Cumberland highlands, Mississippi Alluvial Valley, and Mid-South (which includes all of Texas and Oklahoma). Still further spatial resolution was provided by breaking the subregions into a number of ecological sections; some issues are discussed at that scale as well.

The analytical centerpiece of the Futures Project is a set of forecasting models contained in the U.S. Forest Assessment System, which was developed for the U.S. Forest Service 2010 Resources Planning Act (RPA) Assessment as a means of conducting national forecasts. The system uses global projections of climate, technological, population, and economic variables to drive the simulation of changes in land uses, forest uses, and forest conditions at a fine spatial scale—thus facilitating subregional and other fine scale analyses. Specific RPA scenarios were chosen that define the set of variables that "drive" the forecasts, linking national economic and climate changes to the worldviews contained in international climate assessments (Intergovernmental Panel on Climate Change 2007).

Although the Futures Project tiered directly to the 2010 RPA Assessment (USDA Forest Service 2012), its investigators developed more specific implications for the South within the bounds of the scientific literature.

Perhaps the only absolute truth about any forecast is that it will be an inaccurate description of future reality to one degree or another and that the best—that is, the most accurate—forecast is not likely to be known ahead of time. As a result, forecasters hedge their expectations of future conditions by including a range of plausible futures and thus addressing the risk of generating precise forecasts of the wrong future.

The Futures Project investigators considered a large number of scenarios based on the 2010 RPA Assessment and public input, and then narrowed them to a half dozen that captured the broad range of potential conditions. These "Cornerstone Futures" define six combinations of climate, economic, population, and forest-products sector projections (fig. P3). The assumption was that unfolding events would be captured by a future that is close to one of the Cornerstone Futures. The validity of this assumption, however, will only be revealed by the course of future events.

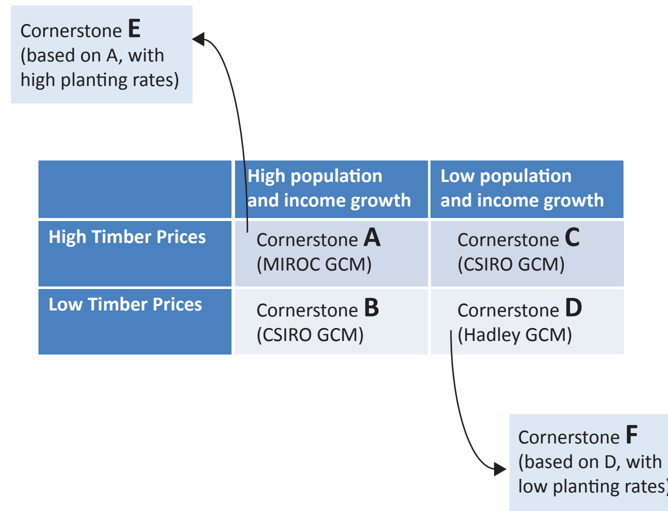

Figure P3—Six Cornerstone Futures, each of which represents a general circulation model (MIROC3.2, CSIROMK3.5, CSIROMK2, or HadCM3) paired with one of two emission scenarios (A1B representing high-population/high-economic growth, high energy use, and B2 representing low growth and use) and two timber price futures; and then extended by evaluating forest planting rates above and below current levels (Sources: Intergovernmental Panel on Climate Change 2007, USDA Forest Service 2012).

Forecasts provide practical insights only when they are examined in the light of specific issues and historical changes. The meta-issues provided specific questions to be addressed using the forecasts along with other available information. For some meta-issues, such as water or fire, additional models helped translate forest forecasts into specific implications. For other meta-issues, such as taxes or ownership, a more qualitative approach linked the analysis of meta-issues to forecasts. But for each meta-issue, the analysis started with a thorough synthesis of historical trends, a description of the current situation, and a summary of the relevant scientific literature.

This report draws together the findings from the 17 chapters of the Southern Forest Futures Project technical report (Wear and Greis 2013) to isolate the findings of most critical consequences for management and policy decisionmaking within the Mid-South. The findings described here also offer an interpretation of the most important findings from the technical report and their implications for forest management and restoration activities within the Mid-South.

THE CORNERSTONE FUTURES

Southern Forest Futures Project investigators developed six Cornerstone Futures (A to F) to describe the factors that are likely to drive changes in southern forests. The Cornerstone Futures were selected to represent the range of findings from a much broader set of possibilities that were developed by combining county-level population/income and climate projections, assumptions about future timber scarcity, and assumptions about tree planting rates (Wear and Greis 2012, 2013).

County-level forecasts of population and income, variables critical to the Cornerstone Futures, were projected within the context of two global perspectives on socioeconomic change—downscaled descriptions of demographic change and economic growth (Intergovernmental Panel on Climate Change 2007)—to construct global forecasts of climate changes and their implications. The first yielded about a 40-percent growth in overall population from 2010 to 2060, and the second yielded a higher rate of 60 percent. The projections vary by county, with the populations of some counties growing substantially and others shrinking.

Timber price futures either describe increasing or decreasing scarcity with an orderly progression of real prices: assumed to be 1 percent per year from a base in 2005 through 2060. Real returns to agricultural land uses were also held constant throughout the forecasts for all Cornerstone Futures.

Each of the population/income projections embedded in the Cornerstone Futures is linked to a worldwide emissions storyline that drives alternative climate forecasts. The result was three climate projections driven by the population/economic projections and downscaled to the county level. Forecasted variables included changes in temperature, precipitation, and derived potential evapotranspiration. One climate forecast was selected for each of the Cornerstone Futures in a way that incorporated the full range of climate projections. These are taken from four downscaled climate models—MIROC3.2, CSIROMK2, CSIROMK3.5, and HadCM3.

Cornerstones A through D are defined by the matrix formed by intersecting low and high population and income forecasts with increasing and decreasing timber price futures as described above:

Cornerstone A—High population/income growth with increasing timber prices and baseline tree planting rates.

Cornerstone B—High population/income growth with decreasing timber prices and baseline tree planting rates.

Cornerstone C—Low population/income growth with increasing timber prices and baseline tree planting rates.

Cornerstone D—Low population/income growth with decreasing timber prices and baseline tree planting rates.

These four Cornerstones assume rates of post-harvesting tree planting that are based on future planting forecasts derived from planting frequencies between the latest two forest survey periods for all States and all major forest types (data from Forest Inventory and Analysis, Southern Research Station, U.S. Forest Service). Because this was a period of rapid expansion in planted pine, perhaps associated with displacement of harvesting from the Western United States, baseline rates were set at 50 percent of the observed frequencies.

Cornerstones E and F depart from the first four, with Cornerstone E increasing planting rates by 50 percent for Cornerstone A (strong economic growth and expanding timber markets); and Cornerstone F decreasing planting rates by 50 percent for Cornerstone D (reduced economic growth and decreasing timber markets).

Forecasts for the Cornerstone Futures provide the foundation for understanding the potential implications of the meta-issues identified by the Futures Project.

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The authors are grateful for the leadership of David Wear and John Greis in the development and implementation of the Southern Forest Futures Project, technical editor Carol Whitlock for an excellent review, and also for hundreds of conversations with resource managers and members of the public in Arkansas, Oklahoma, and Texas that inspired this Mid-South report. We thank several anonymous reviewers for constructive comments and advice. Thanks also to Dr. Ronald F. Billings with the Texas A&M Forest Service, for providing excellent photos of Texas landscapes.

ABSTRACT

This report presents forecasts from the Southern Forest Futures Project that are specific to the Mid-South, which consists of four sections located within Arkansas, Oklahoma, and Texas: the Ozark-Ouachita Highlands, the Cross Timbers, the High Plains, and the West Texas Basin and Range. Ranging from Little Rock, AR to El Paso, TX, it is the most diverse subregion in the South. The Mid-South faces a number of important challenges to management of forests and woodlands over the next 50 years, including population increases, the likelihood for increased drought, increased demand for water and water supply stress, sea level rise along the Gulf of Mexico, and invasive native species. Understanding these challenges, and the implications they could have on management and policy in the region, is critical to maintaining the diversity, health, productivity, and sustainability of Mid-South forests, woodlands, and grasslands.

Keywords: Climate change, Cross Timbers, drought, forest management, High Plains, Mid-South, Ouachita, Ozark, Southern Forest Futures Project, water, West Texas Basin and Range, woodlands.

KEY FINDINGS

- The Mid-South is one of five subregions in the Southern United States, along with the Coastal Plain, Mississippi Alluvial Valley, Piedmont, and Appalachian-Cumberland Highlands. It encompasses the Ozark and Ouachita Highlands in Arkansas and Oklahoma, the Cross Timbers and the High Plains in Oklahoma and Texas, and the West Texas Basin and Range sections. Stretching from Little Rock to El Paso, it is the westernmost, largest, and most diverse subregion in the South, characterized by a combination of geographic range and a unique confluence of rural and highly urban landscapes.

- The projections in the Southern Forest Futures Report (Wear and Greis 2013) were developed using the 2000 U.S. Census. However, rates of population increase in the Mid-South reported by the 2010 U.S. Census were higher than the baseline rates that were used to forecast population through 2060. For example, population growth in some urban counties in northeastern and central Texas was >50 percent from 2000 to 2010. As a result, the findings that depend on population growth, including models of climate, economic activity, land use, and associated stresses on natural resources such as water and forest products, are probably conservative.

- Increases in demand for water in the Mid-South will likely grow as a result of expanding populations, increasing evapotranspiration that is expected under warmer temperatures, and decreases in precipitation; these synergistic effects will likely increase water supply stress over the balance of the 21st century.

- Models predict rising sea levels and coastal inundation along the Gulf of Mexico over the next century; the result could be a loss of ecologically and economically valuable coastal property.

- In the Mid-South, wet and dry periods will continue to be cyclic in association with Pacific Decadal Oscillations, but the cycles will likely become more extreme; some areas will likely experience decreases in precipitation and other areas will experience increases, but models suggest that temperatures will continue to increase overall.

- Changes will be needed in management recommendations for Mid-South forests and woodlands to address expected increases in drought; for example, standard practices may require modification to minimize the loss of investments in tree planting and other costly practices during periods of drought.

- As parcelization of forest and woodland ownership across the landscape increases, resource management practices will need to adapt to increasingly smaller tract sizes, especially in the wildland-urban interface.

- In the forest products industry, the trend is toward increasing mechanization and a homogenization of industrial capability in the woods and at the mills, which does not bode well for development of resource management opportunities from heretofore-unmerchantable standing trees in forests of heterogeneous structure, or for management activities on increasingly smaller tract sizes.

- Because land-based and water-based activities would likely increase more or less constantly with population, expected increases in population densities—especially around the major cities of Texas and to a lesser extent Oklahoma and Arkansas—would mean an increase in demand for outdoor recreation, resulting in competition for opportunities on a static land base of Federal and State lands; expected changes in the pattern of rural versus urban life would also influence recreation activities from consumptive to nonconsumptive uses.

- In the Mid-South, which has abundantly diverse landscapes for wildlife and more species than anywhere else in the South, the combination of increasingly warmer temperatures, increasingly dry conditions, and less water on the landscape would cause changes in existing population numbers and the geographic distribution of plant and animal species; species with a limited geographic range, low genetic diversity, and specialized needs for reproduction and habitat requirements are at higher risk of population decline and even extirpation at local levels.

- Native invasive plant species such as mesquite, juniper, and eastern redcedar are more of a challenge in the Mid-South than nonnative invasives; control or removal of these plants will largely depend on the desire of landowners to engage in control and their ability to afford effective treatments.

- Unlike nonnative plants, invasive insects and diseases are a large-scale threat to Mid-South ecosystems: all ash species are at risk from a devastating infestation of the emerald ash borer, soapberry populations are likely to be lost from infestation by the soapberry borer, red-bay populations are highly susceptible to laurel wilt, and oaks face decline, wilt, defoliators, and canker disease; almost certainly, by the end of the 21st century, other introduced insect and disease pests will threaten other important tree species.

- Increasing temperature, drought, and human population would increase the threat from wildfires, which are expected to occur more frequently and are likely to cover larger areas.

- Many native species that depend on open understory conditions in forests and woodlands would benefit if prescribed burning was extended into Mid-South landscapes; however, the climate changes that are forecasted would reduce the number of days that are suitable for prescribed burning, and the difficulty of prescribed burning would increase because of new smoke management concerns that would arise from the expansion of cities, suburbs, and wildland-urban interface areas.

CHAPTER 1.
The Forests and People of the Mid-South

The Mid-South is the westernmost of the five subregions that make up the Southern United States—along with the Coastal Plain, Mississippi Alluvial Valley, Piedmont, and Appalachian-Cumberland Highlands. It is located to the north and west of the Mississippi Alluvial Valley and western Coastal Plain in Arkansas, Oklahoma, and Texas. For this report, the Mid-South was subdivided into four broad ecologically derived sections—the Ozark-Ouachita Highlands, the Cross Timbers, the High Plains, and the West Texas Basin and Range (fig. 1), after Rudis (1999).

Long-term survey data exist for the forests of the Ozark-Ouachita Highlands and to some extent the Cross Timbers, but the Forest Inventory and Analysis Program of the Forest Service, U.S. Department of Agriculture has only recently extended into the western portion of the Cross Timbers, the High Plains, and the West Texas Basin and Range sections. Thus, some of the analysis that is reported here reflects a less robust database than was used in preparing the other four subregional reports for the Southern Forest Futures Project (Wear and Greis 2013).

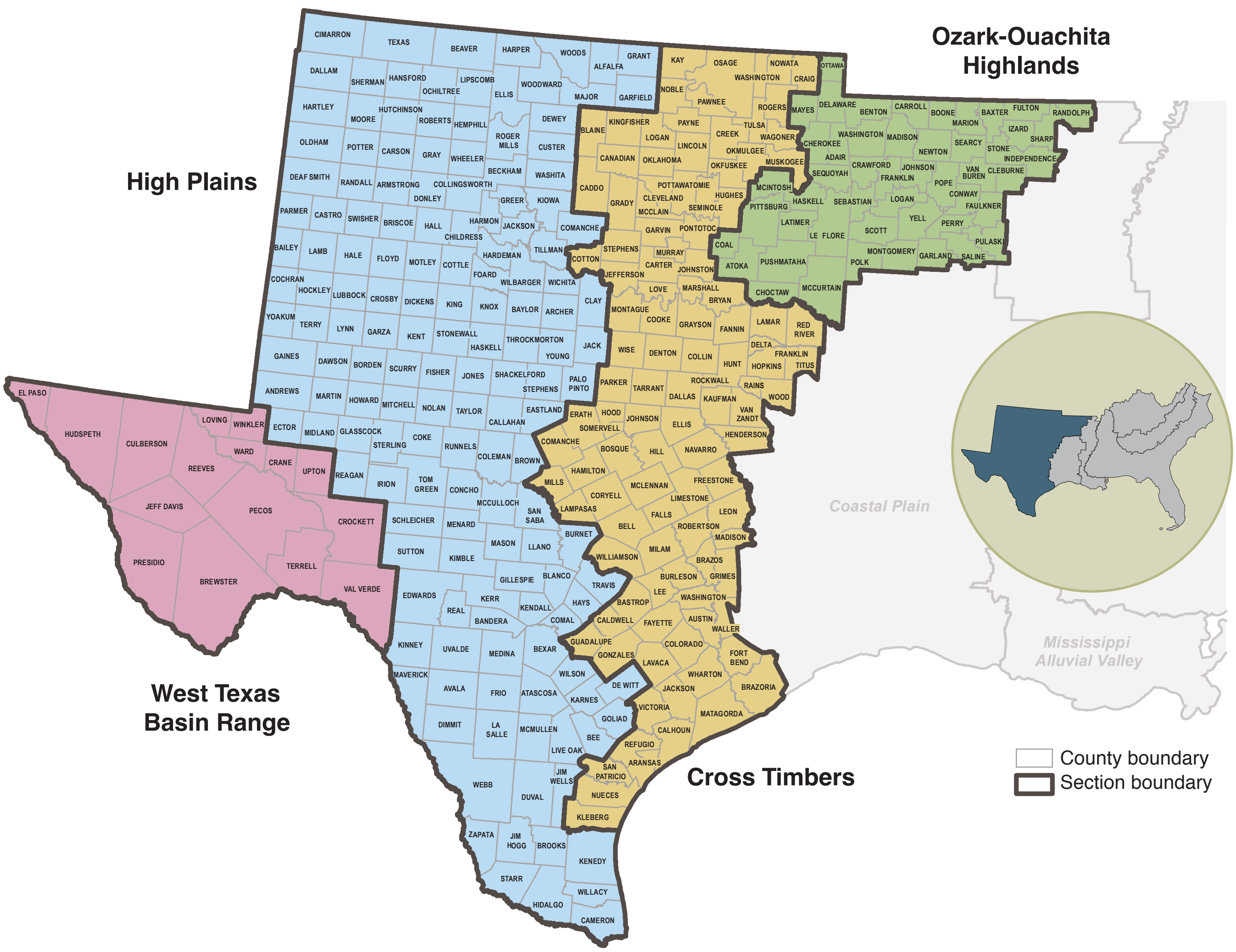


Figure 1—The four sections of the U.S. Mid-South and the counties included in each section.

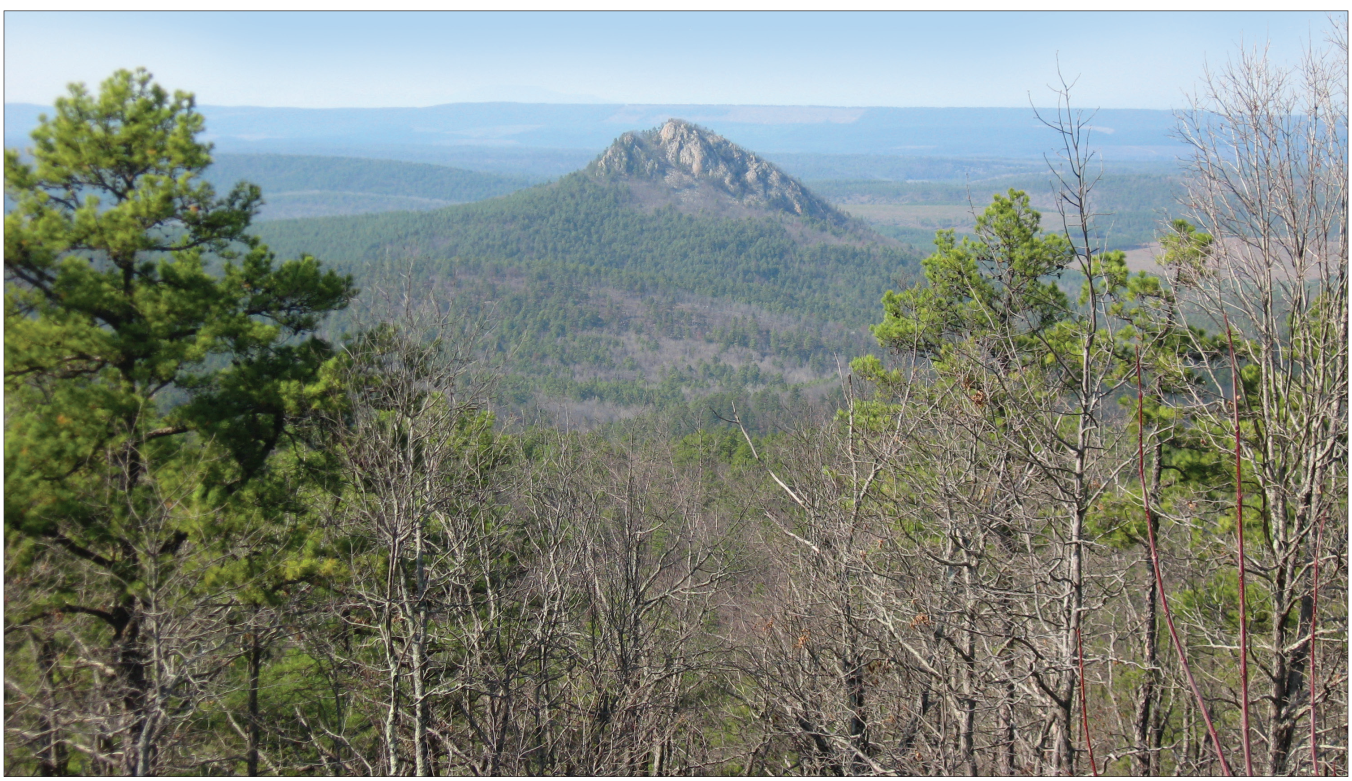
OZARK-OUACHITA HIGHLANDS SECTION

The Ozark-Ouachita Highlands section covers much of the northwestern third of Arkansas and more than a dozen counties in eastern Oklahoma. It is the smallest of the four sections, covering 24.386 million acres or 11.4 percent of the Mid-South (U.S. Census Bureau 2011). According to the nomenclature of Bailey and others (1994) and Keys and others (1995), the section includes the southern part of the Ozark Highlands, the Boston Mountains, the Arkansas River Valley, and the Ouachita Mountains. This is the most heavily forested section in the Mid-South, supporting fully stocked forests of oak and pine. The Ozark Plateau extends well into Missouri, but for purposes of this report the area of analysis is bordered to the north by the Arkansas-Missouri State line. The section is bordered to the east by the Mississippi Alluvial Valley and to the south by the upper west Gulf Coastal Plain. It has no large metropolitan areas, only smaller cities that include Batesville, AR to the northeast; Little Rock and Hot Springs, AR to the southeast; Fayetteville, AR and Tahlequah, OK to the northwest; and McAlester and Idabel, OK to the southwest.

Landforms and Soils

Through most of the Paleozoic Era up to about 320 million years ago, the area of the current Ozark-Ouachita Highlands was under ocean water, during which time organic and inorganic materials were deposited through marine sedimentary processes. But from 286- to 320-million years ago during the Pennsylvanian Epoch, a major tectonic event called the Ouachita Orogen caused what is now North America to collide with a southern landmass, laterally compressing the marine sediments from south to north in ways that resulted in considerable folding, faulting, and subduction from western Texas to central Alabama (Loomis and others 1994, Viele and Thomas 1989). The event exposed what we now call the Ouachita Mountains in a folded and faulted pattern of ridges that are oriented from east to west, and concurrently uplifted and exposed the three major layers of the Ozark Plateau. Over the 280 million years since, the major geological process in the Ozark-Ouachita Highlands has been erosion. The sandstones, shales, and dolomitic limestones that were exposed in the Pennsylvanian Epoch have essentially been reduced through weathering and erosion to their current condition.

South of the Arkansas River, the Ouachita Mountains still bear the imprint of their folded and faulted history, with long ridges oriented from east to west. The terrain reaches maximum elevation of about 2,600 feet, or 1,500 feet above the adjoining valleys. The side slopes of ridges are often steep and rugged in the upper slopes, but gradually flatten in the lower slopes. As a result, hillsides grade into broad U-shaped valleys whose breath and gentle gradient is attributed to millennia of surface-water meanderings, especially along the larger creeks and rivers that flow among the ridges. Cuts in the Ouachita stratigraphy expose a history



Eastern Ouachita Mountains in Arkansas—Forked Mountain in Perry County. (photo by James M. Guldin, U.S. Forest Service)

of rock strata that have been twisted, buckled, folded, and oriented in every position from horizontal to vertical.

Ouachita soils are highly weathered Ultisols (Buckman and Brady 1969). Soil formation is affected by the extremely rocky terrain, the resistance of the rocks to erosion, and the high degree of soil stoniness across the section. For example, Liechty and others (2005) reported that soils in the western Ouachitas are typic Hapludults with loamy surface textures and unusually high rock content in the surface and subsurface. Site productivity closely follows slope position, with poor sites (low moisture and productivity) on ridgetops and upper slopes, and with the topography grading to better sites on lower slopes and floodplains. This common pattern occurs because of colluvial activity that has carried soils from ridgetops to floodplains over the years, resulting in thin soils on upper slopes and deeper soils on lower slopes. Also, because south-facing slopes receive considerably more sunlight than northern slopes, the south-facing ridgetops are drier and less productive, whereas the lower north-facing slopes are more mesic and can be highly productive.

North of the Arkansas River are the three plateaus of the Ozark Mountains—the Salem Plateau, the Springfield Plateau, and the Boston Mountains. Of these, the highest and southernmost is the Boston Mountains, rising just to the north of Interstate 40 between Little Rock and Fort Smith, and consisting of Pennsylvanian sandstones and shales with rugged mountaintops reaching elevations of 1,700 to 2,300 feet. To the north is the Springfield Plateau, consisting of Mississippian limestones and cherts in a less rugged terrain, with hilltops reaching 1,000 to 1,700 feet. Even farther north is the Salem Plateau, of Ordovician dolomite and limestone, varyingly gentle and rugged, with hilltops roughly 900 to 1,400 feet in elevation. Throughout these plateaus, exposed stratigraphy is prominently horizontal, in stark contrast to the Ouachitas.

Because the entire set of plateaus is underlain with carbonate rock, karst features such as exposed glades, sinkholes, caves, and caverns are prominent. More than 250 million years of erosion in these dolomitic hills has resulted in an unusually dissected topography that has a branching pattern, with small creeks running through deep ravines, and hillsides facing nearly all points on the compass. This same interaction of erosion and geology over time has produced some of the most beautiful rivers and creeks in the South, with crystal-clear water flowing through steep vertical bluffs hundreds of feet high.

Variation in the erodibility of substrates leads to variation in topographic and soil conditions on Ozark hillsides, where deposition of soil from above onto resistant parent material on horizontal benches can lead to very moist conditions, and to the counterintuitive observation that some of the best sites for forest growth in the area can be halfway up the hillside. Ozark soils are primarily Ultisols, with everything from new sandy deposits near creeks to well developed silt loams on benches to thin stony soils on the ridgetops.

Upper Boston Mountain area of the Ozark Mountains in Arkansas; view of the Big Bluff on the Buffalo River in Newton County.
(photo by James M. Guldin, U.S. Forest Service)

Major Forest Types and Vegetative Communities

The native forest types in the Ozark-Ouachita Highlands vary from stands heavily dominated by shortleaf pine (*Pinus echinata*) to oak (*Quercus* spp.) and pine mixtures to oak and hickory (*Carya* spp.) stands that are hardwood-dominated with only a minor pine component, if any. Closed canopy forests are typical, but open woodlands were probably more common 200 years ago, when midstories and understories were not subject to the fire controls that have been in place over the past 80 years. In addition, under forest products industry ownership especially in the Ouachitas, large areas of native shortleaf pine-dominated stands have been converted to plantations of loblolly pine (*Pinus taeda*), which is not native to the Ouachita-Ozark Highlands except at the southeastern extremity, more or less south of an imaginary line that crosses Arkansas from DeQueen to Glenwood to Hot Springs to Little Rock.

With respect to species composition, oak-hickory stands are at the opposite end of the silvicultural spectrum from pine-dominated stands in the Ozark-Ouachita Highlands. In the highest elevations, stands dominated by post oak (*Q. stellata*), blackjack oak (*Q. marilandica*), some white oak (*Q. alba*), some black oak (*Q. velutina*), and black hickory (*C. texana*) occupy the ridgetops and upper slopes. Stands that feature white oak, southern red oak (*Q. falcata*), black oak, red maple (*Acer rubrum*), and sweetgum (*Liquidambar styraciflua*) occur in moderately moist conditions on flat or gentle terrain along ephemeral and perennial streams or low north- and south-facing slopes, which in many respects are the most productive sites anywhere in the Ozark-Ouachita Highlands. White oak can become dominant especially on lower slopes where conditions are moderately moist. Red oaks (including southern red oak, black oak, and blackjack oak) also occur, although slightly less commonly than the white oaks. Other common species on lower slopes include winged elm (*Ulmus alata*), sweetgum, red maple, and flowering dogwood (*Cornus florida*).

The five most widely distributed forest types, which cover >70 percent of the forest land in the Ozark-Ouachita Highlands, are white oak/red oak/hickory at 26.9 percent, post oak/blackjack oak at 17.2 percent, shortleaf pine at 11.1 percent, loblolly pine (virtually all in plantations) at 8.5 percent, and shortleaf pine/oak at 7.4 percent.

History

Human use of the Ozark-Ouachita Highlands dates back well into the early Holocene Epoch, when vegetation consisted of species that had retreated from the Wisconsinian glaciation and since have re-occupied the Northern United States. Artifacts of human habitation trace back to 5,000 years ago. Early human residents probably made use of the many bluffs in the Ozarks for protection against weather, but evidence from mounds and middens suggests that humans expanded into shelters and communal groups in the late Archaic Period from 1,000 to 5,000 years ago (Sabo and others 1990); some of these groupings may have permanently settled on terraces of rivers to enable agricultural activity.

The first Europeans entered the southern Ozarks and northern Ouachitas in the late 1600s via the Arkansas

A Ouachita landscape in Arkansas, looking westward from Flatside Pinnacle (Ouachita National Forest) in Perry County; stands are dominated by shortleaf pine on south-facing slopes and by oak-hickory hardwood stands on north-facing slopes. (photo by James M. Guldin, U.S. Forest Service)

River Valley, where they encountered two linguistically related Native American societies—the Osage toward the northwest and the Quapaw toward the southeast. Following the Louisiana Purchase of 1803, these societies were displaced by European fur traders and settlers and by the migration of the Cherokee Nation to lands along the Arkansas River. After an 1817 treaty established the Cherokee Nation along the Arkansas and White Rivers, hostilities continued among the Cherokee, the remnants of the Osage, and the settlers. The hostilities resulted in the final relocation of the Cherokee to territories in Oklahoma in 1828, despite the treaty commitments made in 1817. With that move, the continued presence of Native American society in the Ozark-Ouachita Highlands effectively ended (Sabo and others 1990).

Settlement of the Ozark-Ouachita Highlands in the 18th century consisted of sporadic explorations and isolated outposts occupied by French traders. Other settlements began shortly after the Louisiana Purchase, with several expeditions in 1818 to the northern Ozarks (Schoolcraft 1996) and up through the Arkansas River Valley (Nuttall 1980) to chart and describe the area. The establishment of the Arkansas Territory in 1819 triggered a larger migration. Little Rock was established on the Arkansas River in the early 1800s, and a military post was set up at Fort Smith in 1817. From 1820 to 1840, settlements sprung up along the many tributaries of the Arkansas and White Rivers. The pattern of settlement was initially hunter-herders followed by pioneer farmers (Sabo and others 1990). The rugged topography made this a difficult proposition, and life remained at subsistence level well into the 1800s.

In 1861, Arkansas seceded from the Union but did not play much of a direct role in the Civil War, with no major battles fought. After the Union occupied the State in 1863, widespread lawlessness reigned for the remainder of the war, resulting in a general loss of population (Rafferty 1980). But people returned after the war and a period of developed settlement began, aided by improved roads, expansion of railroads, river traffic, and other advances in transportation. Agricultural activity centered on fruit growing, cotton farming, poultry production, and dairy farming. This period of stability essentially ended the practice of annual burning of forests with concomitant shifts in vegetation of forest understories.

Manufacturing also began in earnest in the 1880s (Sabo and others 1990), and one of the most important raw materials was lumber from the Ozark-Ouachita Highlands (Smith 1988). The high rate of lumbering was, of course, unsustainable in the long term; by the 1920s, virgin timberlands were gone and the practice of scientific forest management had begun.

Despite difficult terrain and topography, the milestones in education and standard of living established during the 20th century govern commercial activity to this day. Schools grew with the town populations, and the University of Arkansas (the State land grant university in Fayetteville) gained in influence. The major development that introduced modern life throughout the section was the establishment of rural electrification immediately after World War II. Before 1930, only 2 percent of Arkansas farms were electrified; 10 years later, 112,050 of the 1.95 million people

Lower Boston Mountains in Arkansas; view south from Pedestal Rocks on the Ozark National Forest in Pope County. (photo by James M. Guldin, U.S. Forest Service)

in Arkansas had electricity. From 1937 to 1945, a power grid was established across the State, and by 1963, 67 percent of Arkansas farms were electrified. The 2010 U.S. Census counted more than a million households in the Ozark and Ouachita Highlands, and electrical service has become universally available for all but the most remote homes.

CROSS TIMBERS SECTION

The Cross Timbers is usually defined as the transition zone between the eastern deciduous forest and the southern Great Plains: a long narrow area extending from southern Kansas through eastern Oklahoma and east-central Texas that almost reaches the Gulf of Mexico. However, for the purposes of this report, its northern boundary is the Oklahoma-Kansas State line, and its southern boundary is the Gulf of Mexico. To the east, the section is bounded by the Ozark-Ouachita Highlands and the western Coastal Plain; to the west, by the High Plains section. It is the second largest section, covering 58.437 million acres or just over a quarter of the land area in the Mid-South (U.S. Census Bureau 2011). According to the nomenclature of Bailey and others (1994) and Keys and others (1995), the section includes the Cross Timbers and Prairies, Blackland Prairies, Oak Woods and Prairies, and the Central Gulf and Southern Gulf Prairies and Marshes. It has the most well developed urban areas in the Mid-South threading from Houston (in the Coastal Plain) to San Antonio (in the High Plains); Oklahoma population centers of Tulsa, Oklahoma City, and Stillwater in the north; and Texas population centers of Dallas, Fort Worth, and Waco in the center and Corpus Christi along the Gulf of Mexico.

Landforms and Soils

The Cross Timbers section is mostly within the southwestern portion of the Central Lowlands physiographic province and its boundary is similar to the local boundary of the physiographic province. Its boundaries with the High Plains to the west and south and with the Coastal Plain to the southeast are not distinct. By comparison, its eastern boundary with the Ouachita and Ozark Highlands is well defined and abrupt.

The Cross Timbers is characterized by the two distinguishing features that typify the Central Lowlands—low elevation and low relief. Elevation ranges from a low of about 500 feet along the Red River to highs of 1,400 feet in the Arbuckle Mountains and 2,500 feet in the Wichita Mountains. The section owes it low relief, which rarely exceeds 600 feet, to the fact that it is in an area that has remained relatively stable for 600 million years and has fewer deformations of the earth's crust than the rest of North America.

The geologic formations underlying the Cross Timbers are almost entirely sedimentary in origin. In Oklahoma and the western Cross Timbers of Texas, the predominant formation

Typical Cross Timbers vegetation in Texas; landscape is the Cross Timbers Research Natural Areas (RNA) in the Lyndon B. Johnson National Grasslands in east Texas. (photo by Don C. Bragg, U.S. Forest Service)

is Pennsylvanian marine shale interbedded with sandstone and limestone, with a smaller portion in Permian red sandstone and shale. Most of the area farther east is underlain by Cretaceous rocks of interbedded sandstone, limestone, marl, and clay. A very small portion is underlain by igneous rocks of Cambrian origin; these include granite, rhyolite, and gabbro in the Wichita Mountains and rhyolite in most of the Arbuckle Mountains. And an even smaller amount of metamorphic rocks in the form of Precambrian gneiss underlie the eastern Arbuckle Mountains.

The Cross Timbers has no natural lakes because the geomorphic processes (such as glaciation) that would create lakes have never occurred. Instead, tens of thousands of farm ponds created in recent times for agricultural use and recreation dot the landscape. The Oklahoma Cross Timbers are entirely within the Mississippi River drainage basin with rivers generally flowing west-to-east into the Arkansas and Red Rivers; the drainage ends just south of the Red River. River systems from New Mexico and Colorado carry snowmelt, much of which evaporates as it traverses the Cross Timbers. Many of the minor streams are intermittent in the dry season and prone to flooding at other times. Stream discharge and number of perennial streams increases from west to east. Most of the Cross Timbers landscape in Texas supplies water to streams and rivers in the Trinity River and Brazos River drainage basins, both of which flow directly into the Gulf of Mexico.

Major Forest Types and Vegetative Communities

Vegetation in the Cross Timbers, currently a mosaic of grassland, savanna, and forest (Dyksterhuis 1948, Rice and Penfound 1959), has experienced major changes during and since the Holocene Epoch as shown by examination of the few pollen deposits that exist in the section (Bryant and Holloway 1985). The initial vegetation soon after the last glaciation was grassland. Oaks began to invade the grasslands 9,000 years ago; over several thousands of years, the vegetation gradually became oak savanna. Oak dominance increased with time; by 5,000 years ago, oak woodlands were prevalent. Pines began to appear at the eastern edge of the Cross Timbers about 2,100 years ago and oak-hickory-pine forests appeared 900 years later. Pine never developed dominance in the Cross Timbers but was restricted to isolated pockets along the eastern edge of the oak-dominated forests. Charcoal was evident in the pollen record since at least 5,000 years ago indicating that fire was an important disturbance factor (Albert and Wyckoff 1981).

Soils, climate, and fire are the dominant forces shaping the vegetation of the Cross Timbers. The savanna and forest vegetation is mostly restricted to the coarse textured soils derived from sandstones or granites (Dwyer and Santelmann 1964, Rice and Penfound 1959), and grasslands are found predominantly on fine textured soil derived from shale and limestone. This suggests that the section has neither a true grassland climate nor a true forest climate, because either vegetation type can be supported depending on the soil texture and its effects on water consumption (Rice and Penfound 1959). The largest effect of climate is the gradient of decreasing moisture, which ranges from >100 cm annual precipitation in the east to 50 cm in the west and is strongly reflected in vegetation that decreases in stature and richness as the forests give way to savannas and eventually to grasslands. Fire was used by Native Americans for thousands of years and more recently by settlers to manipulate vegetation. Fire suppression and prevention over the past century have contributed to an increased component of woody vegetation over the past 60 years (DeSantis and others 2010, DeSantis and others 2011).

Diversity is high, with >37 forest types occurring from moderately moist bottomlands to dry woodlands. The three most widely distributed forest types reflect this variability. The post oak/blackjack oak forest type covers the most area, 4.2 million acres (25.1 percent) (Ridley 2012). Other species occurring in this forest type are black oak, hickory, southern red oak, white oak, shingle oak (*Q. imbricaria*), live oak (*Q. virginiana*), shortleaf pine, blackgum (*Nyssa sylvatica*), red maple, winged elm, hackberry (*Celtis occidentalis*), chinkapin oak (*Q, muehlenbergii*), shumard oak (*Q. shumardii*), flowering dogwood, and eastern redcedar (*Juniperus virginiana*). This forest type tends to be found on dry uplands and ridges (USDA Forest Service 2007).

Each of the two other widespread forest types—the dry mesquite woodlands and the mixture of sugarberry (*Celtis laevigata*), hackberry, elm, and green ash (*Fraxinus pennsylvanica*) on moderately moist sites—covers nearly 1.7 million acres or 10 percent of the Cross Timbers. The bottomland type found along the floodplains includes sugarberry, hackberry, green ash, American elm (*U. americana*), and winged elm; associated species include cedar elm (*U. crassifolia*), slippery elm (*U. rubra*), boxelder (*Acer negundo*), pecan (*C. illinoensis*), blackgum, persimmon (*Diospyros virginiana*), honey locust (*Gleditsia triacanthos*), and red maple. The mesquite woodlands consist of mesquite (*Prosopis glandulosa*) and are associated with a variety of species depending on local conditions (USDA Forest Service 2007).

History

This broad area between the eastern U.S. forests and the southern Great Plains was a landscape shaped by Native Americans for thousands of years. Fire was one of their primary tools for managing forest vegetation and reaping its benefits. It was also used for communication, warfare, hunting, and pasture improvement.

In Oklahoma, settlement became the dominant force in the late 1800s, which marked the first land run after the opening of the Indian Territories. By 1920, >18 million acres of native vegetation had been converted to cropland (DeSantis and others 2011), much of which had been prairie, but some was cleared forest land. Because much of this land was not suitable for agriculture, farm abandonment began very early; by 1950, only 16 million acres were still under cultivation, reduced to only 8 million acres today.

HIGH PLAINS SECTION

The High Plains is the largest section, covering 103.57 million acres, or 48.6 percent, of the Mid-South (U.S. Census Bureau 2011). The northern border is the Oklahoma State line, primarily with Kansas but also with southeastern Colorado (north of Cimarron County at the western end of the Oklahoma panhandle). The western border extends from the New Mexico State line (at Cimarron County) in the north to the eastern edge of the Cross Timbers section. According to the nomenclature of Bailey and others (1994) and Keys and others (1995), the section lies within the Southwest Plateau and Plains Dry Steppe and Shrub Province, and includes a small part of the Southern High Plains in the Oklahoma panhandle, the Texas High Plains in northwestern Texas, the Redbed Plains in southwestern Oklahoma, the Rolling Plains of north-central Texas, and much of the Edwards Plateau in central Texas; for purposes of this report, it also includes several counties bordering the Gulf of Mexico in the Rio Grande Plain of southern Texas. All of the cities in this section—except Enid, OK in the northeast—are in Texas: Amarillo, Wichita Falls, Lubbock, and Abilene in the center; Midland and Odessa in the northwest near New Mexico; Austin and San Antonio in the southeast; and Laredo, McAllen, Kingsville, and Brownsville in the Rio Grande River Valley on the Mexican border.

Landforms and Soils

This is an area of broad rolling plains formed by water-borne and eroded materials from adjacent mountain ranges, and subsequently uplifted and eroded into a moderately dissected topography. The underlying geology consists mostly of Paleozoic and Mesozoic marine deposits of limestone and sandstone. From south to north, the section gradually increases in elevation, from 80 to 100 feet in the Rio Grande Plain, to 600 to 4,000 feet in the Edwards Plateau and Rolling Hills, to 2,500 to 6,500 feet in the Texas High Plains. The northern half of the High Plains includes much of the Llano Estacado, which is almost absolutely flat; it is the largest isolated mountain-free area in North America (Morris 1997). Other features include the scenic Caprock escarpments separating the Rolling Hills from the Texas High Plains, the Edwards Plateau of Cretaceous limestone origin, and a number of river systems that provide locally dissected topography. Examples include the Canadian and Red Rivers in northern Texas and Oklahoma, the Brazos and Colorado Rivers in central Texas, and the Rio Grande River in southern Texas. The Ogallala Aquifer, a huge store of relict water, underlies the northern part of the High Plains. It is the most valuable resource in the section because it provides water year-round for agriculture.

The section also supports >16,000 playa lakes, natural disk-shaped depressions that form ephemeral lakes, not by feeding from streams or springs but rather as a collection from local watersheds. They are lined with heavy clays that prevent percolation into the Ogallala Aquifer. Some 70 percent have been adapted as surface water reservoirs for agricultural use, but they also remain extremely important habitat and sources of water for wildlife (Bolen and others 1989).

Soils vary considerably depending on underlying geology. Alfisols, Mollisols, Inceptisols, and Vertisols are predominant but some areas also include Ustolls, Ustalfs, Usterts, Ochrepts, and Torrerts. Generally, these soils have a mesic-to-thermic temperature regime, a semi-arid moisture regime, and mixed or carbonatic mineralogy. Soils are deep, fine-to-coarse textured, and some (the Torrerts) have so much clay content that they crack during dry periods. Most soils are well drained and have limited moisture for use by vegetation during parts of the growing season. Nevertheless, they are well suited for agriculture, especially when irrigated.

Major Forest Types and Vegetative Communities

The native vegetation of the High Plains was a shortgrass steppe prairie and scattered woodlands that were near rivers and creeks (Drummond 2007). On the Texas High Plains and Rolling Plains, historical documents suggest that most of the area supported shortgrass prairie vegetation, as well as abundant woody vegetation such as cottonwood (*Populus* spp.) and mesquite along watercourses (Wester 2007). Farther south, the Edwards Plateau hill country was a fire-maintained ecosystem principally occupied by live oak (Fowler and Dunlap 1986), but fire prevention and suppression policies have resulted in expanded presence of native species such as Ashe juniper (*Juniperus ashei*) and mesquite (van Auken 2000). And some elements of the Hill Country exhibit spectacular displays of flowers seasonally. In southern Texas, the Rio Grande Plain was largely prairie that disappeared by the end of the 19th century, gradually replaced by forage grasses and the brush species that had always been inhabitants of the area during historical times (Inglis 1964).

This transition from pre-European settlement to current conditions has resulted in changes in fire regime and herbivory, which in turn have produced dramatic changes

Terrain in the northern High Plains of Texas; view of Palo Duro Canyon in the panhandle of Texas. (photo by Ronald F. Billings, Texas A&M Forest Service)

Playa next to irrigated farmland in the High Plains of Texas. (photo by James M. Guldin, U.S. Forest Service)

Terrain in the southern High Plains, on the Edwards Plateau in south central Texas. (photo by Ronald F. Billings, Texas A&M Forest Service)

An example of the renowned scenic beauty in the region, on the Edwards Plateau in south central Texas. (photo by Ronald F. Billings, Texas A&M Forest Service)

in vegetation. Van Auken (2000) described a pattern of overgrazing by domestic animals, which led to reductions in aboveground grass biomass; when coupled with wildfire control efforts, this reduction in biomass decreased the frequency of fire in these ecosystems. Fewer fires favored the encroachment, establishment, survival, and growth of woody plants. The issue is not the encroachment of invasive nonnative plants, which is more common farther east, but rather the expansion of native woody species such as mesquite and Ashe juniper into upland sites that are far beyond the range they occupied 200 years ago.

The three most widely distributed forest types—mesquite woodlands, juniper woodlands, and xeric oak woodlands—cover >25.4 million acres (73.3 percent) of the forest land in the High Plains. Of these, the mesquite woodland type dominates, covering 15.9 million acres (46.1 percent), with mesquite making up the majority of the stocking. The species associated with mesquite vary considerably with changes in climate and soils (USDA Forest Service 2007). The juniper woodland type is also widely distributed, covering 6.26 million acres (18.1 percent). This woodland type is dominated by Ashe juniper, Pinchot juniper (*J. pinchotii*), and oneseed juniper (*J. monosperma*) in the Texas Panhandle (USDA Forest Service 2007).

History

Development of the High Plains falls into three periods—the Spanish exploration from the 1600s to the 1700s; colonization from 1821 to 1863 followed by the Cattle Empire from 1860 to the early 1900s in Texas; and the rise of modern agriculture and ranching.

Early Spanish explorers reported that the southern Texas plains were predominantly a prairie interspersed with mesquite, pricklypear (*Opuntia* spp.), and other woody vegetation. Frequent natural fires kept much of the brush from overtaking the prairie (Fowler and Dunlap 1986, Inglis 1964). Early Spanish explorers traveled through much of the northern area. Coronado crossed the Llano Estacado in 1651 and reported seeing buffalo hunters on foot—these were later identified as ancestors of the Apaches. The Comanche arrived on horseback, displacing the Apaches by 1700, and holding the territory as their own for the next 150 years. In the decade following the Civil War, the U.S. Army led the way in displacing both the Comanche and the buffalo, but not without considerable difficulty (Rathjen 2012). Brownsville, TX was settled in 1846, following the establishment of Fort Brown, the base from which Zachary Taylor and the U.S. Army campaigned during the Mexican War. But the Rio Grande Valley remained sparsely populated until the first years of the 20th century, when the arrival of railroads and the development of irrigation gave rise to agricultural development and the expansion of European and Hispanic population (Vigniss and Odintz 2012).

Early ranchers thought that the grass would last forever in Texas. As a result, pressure from cattle, sheep, and goats increased and fences confined them—and natural fires became more infrequent. Many Rio Grande Valley counties had more sheep than cattle, with a half million sheep being grazed in the three decades after 1867. In 1880, southern Texas supported 45 percent of the State's sheep population. In 1889, the Rio Grande Plains had the four leading sheep producing counties in the State; 10 of the top 15 sheep producing counties were in southern Texas. The peak decade in the Rio Grande Valley was from 1880 to 1890, at times exceeding 2 million head (Vigniss and Odintz 2012).

Similarly, in the northern part of the High Plains, ranching had begun in earnest by 1875. The first herds were sheep, but cattle ranching supported by large-scale commercial interests quickly displaced the sheep. Oil and natural gas were discovered in the High Plains in the 1920s; that industry helped support local economies by building roads for the farm-to-market transportation as well as major highways such as the historic U.S. Route 66 (Rathjen 2012).

The Great Depression was a major blow to agricultural interests in the High Plains. The poor economy and the drought associated with the Dust Bowl led to widespread abandonment of farms and displacement of farmers. Under the New Deal, programs were put in place to develop rural communities, with few as important as the Rural Electrification Act of 1936 (Rathjen 1998). During World War II, a number of new military bases and defense plants helped to further stabilize the economy (Rathjen 2012).

The last major advance in the High Plains was the refinement of farming, primarily using water from the Ogallala Aquifer, which by 1958 was irrigating about 4.5 million acres of farmland in the section. Current concerns are with the long-term sustainability of irrigation water from the Ogallala and the need to refine farming practices so that they use less water (Colaizzi and others 2008).

WEST TEXAS BASIN AND RANGE SECTION

The West Texas Basin and Range section, informally called the Trans-Pecos, consists of 16 counties in western Texas, most of which are west of the Pecos River. It covers 26.8 million acres, or 12.6 percent of the Mid-South (U.S. Census Bureau 2011). To the south, its border is the Rio Grande River on the Mexican border; its northern boundary is the east-west border between Texas and New Mexico; and to east, it abuts the central part of the High Plains

section. According to the nomenclature of Bailey and others (1994) and Keys and others (1995), the section lies in the Chihuahuan Semi-Desert Province and includes the Basin and Range and the Stockton Plateau. Population centers include El Paso at the very westernmost point and the town of Del Rio in the southeastern corner.

Landforms and Soils

The western two-thirds of this section is within the Basin and Range physiographic province and is of relatively recent geologic origin. Faulting in the Oligocene Epoch created the Rio Grande rift in New Mexico and western Texas and initiated volcanic terrain-forming activity (Bailey 1995). Since that time, erosion from uphill resulted in the current landscape of basins that are full of sediments and hills that continue to shed material in transport and deposition activities at the geologic time scale. Geologic strata consist of an undifferentiated mixture of marine deposits across the geologic time scale and volcanic rocks from relatively recent Miocene activity (Bailey 1995).

Elevation in this western area varies from 2,600 to 5,500 feet. Landforms consist of plains with low mountains and a local relief of 1,000 to 3,000 feet, plains with high hills where relief is 1,000 to 3,000 feet, open high hills with a relief of 500 to 1,000 feet, and tablelands with a moderate relief averaging 100 to 300 feet. Soils are primarily Entisols, mostly arid poorly developed Torriorthents, and some Alfisols and Mollisols. These soils have a thermic temperature regime, an arid moisture regime, and mixed or carbonatic mineralogy.

The eastern third of the section, the Stockton Plateau, consists of open hills and tablelands. The area was formed from materials from adjacent mountains, shaped by continued erosion and transport processes. Its underlying geology consists of Paleozoic marine deposits and volcanic rocks of Tertiary origin. Elevations vary from 2,600 to 4,500 feet, and local relief in most of the section ranges from 300 to 1,000 feet. Soils are generally Aridisols—primarily Argids and Orthids in the uplands, and Vertisols such as the Torrerts on the basin floors. These soils have a thermic temperature regime and an arid and well drained moisture regime; they are shallow-to-deep, and of medium-to-fine texture.

Major Forest Types and Vegetative Communities

Vegetation in this section is adapted to arid conditions. Lower elevations support desert grasslands, grading into desert shrublands dominated by creosote bush (*Larrea tridentata*), yucca (*Yucca* spp.), ocatillo (*Fonquieria splendens*), and mesquite (Frye and others 1984, McMahan and others 1984); this type of vegetation appears to be expanding upslope as a

Terrain in the West Texas Basin and Range, showing a view of the Davis Mountains. (photo by Ronald F. Billings, Texas A&M Forest Service)

result of grassland disturbance over the last century (Schmidt 2012). At higher elevations, the desert grassland grades into open woodlands of pinyon—Mexican pinyon (*P. cembroides*), two-needle pinyon (*P. edulis*), and papershell pinyon (*P. remota*)—and juniper in the Davis Mountains, and then into open woodlands of ponderosa pine (*P. ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) in the Guadalupe ranges (Frye and others 1984, McMahan and others 1984). Scattered throughout the section are smaller areas of riparian, holophytic, and other vegetation types adapted to specific site conditions (Schmidt 2012). These woodlands have more in common with the vegetation types of the Rocky Mountains than they do with forest types commonly found across the South.

The mesquite woodland type dominates woody plant cover in the West Texas Basin and Range section, covering 4.38 million acres (54.9 percent) (Ridley 2012). Mesquite and screwbean mesquite (*P. pubescens*) along the Rio Grande River make up the majority of the stocking, with the many mesquite associates varying according to climate and soils (USDA Forest Service 2007). The juniper woodland type is also widely distributed; it covers 2.38 million acres (29.3 percent) and includes Pinchot juniper, redberry juniper (*J. erythrocarpa*), Ashe juniper (but only rarely in easternmost areas), alligator juniper (*J. deppeana*), and oneseed juniper (in western areas). Associates include various woodland oaks, mountain mahogany (*Cercocarpus montanus*), ponderosa pine, Arizona cypress (*Cupressus arizonica*), and Douglas-fir; pinyon is not present. (USDA Forest Service 2007). Together, these woodland types cover >84 percent of the forest land in the West Texas Basin and Range section.

History

Although the El Paso area was partially explored by Europeans beginning late in the 1500s, this area lying west of the Pecos River did not experience any real settlement until Texas became a part of the United States. The El Paso area was an important mountain pass—El Paso del Norte, or the Pass of the North—on the Camino Real that stretched from the Santa Fe Trail to the Mexican interior. Timmons (1990) reports that the position of the town on a major trade route was instrumental in its early development:

> By the middle of the eighteenth century about 5,000 people lived in the El Paso area—the largest population on the Spanish northern frontier. A large dam and a series of acequias (irrigation ditches) made possible a flourishing agriculture. The large number of vineyards produced wine and brandy said to have ranked with the best in the realm. In 1789 the presidio of San Elizario was founded to help in the defense of the El Paso settlements against the Apaches.

With the Mexican independence from Spain in 1821, El Paso became a Mexican town. By then, flooding of the river had become a problem for the expanding agricultural interests in the area. The town officially became part of the United States in 1845, and the Mexican War of 1846 assured that all towns north of the Rio Grande would be part of the United States. But the combination of aridity, isolation, and roving Apache and Comanche bands discouraged rural settlement (Timmons 1990). Fort Bliss was established in 1854 to protect mining interests and otherwise provide a Federal army presence in the area.

The Civil War did not greatly affect the Trans-Pecos, and the arrival of the railroad in 1881 did much to change the future fortunes of El Paso. By the turn of the 20^{th} century, a number of civic improvements were in place to promote manufacturing, mining, agriculture, and international trade with Mexico (Timmons 1990).

The rural counties of the Trans-Pecos (outside the El Paso metropolitan area) are still the least populated areas in Texas, and they are not growing. Of the 16 counties, 10 had population densities <5 people per square mile, compared to the State average of 96 per square mile in 2010. About three-quarters of the rural Trans-Pecos population live in eight or nine small towns. Only the growth of El Paso County, with about 800,000 residents in 2010, differs from this pattern of sparse population and minuscule growth, in no small measure attributable to the economic influence of Fort Bliss, which has grown to be an important Army base. But in general, the cultural landscape of the Trans-Pecos, like the physical one, has more in common with the Southwest than with the rest of Texas.

CHAPTER 2.
The Changing Physical Environment

CLIMATE

From east to west, the Mid-South becomes slightly warmer and dramatically drier, resulting in a prominent increase in potential evapotranspiration. The defining feature throughout is precipitation, specifically the lack of it and the pattern of its distribution. In essence, as one travels west from Little Rock to El Paso, average annual precipitation decreases by roughly 1 inch for every 20 miles—giving rise to a host of ecological variables that define the ecosystems between the two cities.

Coupled with this general trend are the long-term weather patterns conditioned by the oceanic Pacific Decadal Oscillation and the Atlantic Mean Oscillation, both of which in turn depend on variations in ocean temperatures. The Mid-South has experienced extended drought periods in the 1950s and mid-1990s, apparently associated with the warm phase or positive value of the Atlantic oscillation and the cool phase or negative value of the Pacific oscillation (Brown and others 2004). Both have changed again in the past few years with the Pacific oscillation going from warm to cool and the Atlantic oscillation going from cool to warm, a likely indication of increased droughts over the next 15 to 20 years.

Current Climate Trends

Ozark-Ouachita Highlands—From 1940 to 2006, annual temperatures in the Ozark-Ouachita Highlands have been relatively uniform and consistent, averaging about 15.5 °C with an average annual low of 14 °C (1979) and a high nearing 17 °C (1955). County-level patterns in annual temperature from 1997 to 2006 were similar, with an average of 15.5 °C, a low of 14.2 °C, and a high of 17.2 °C (McNulty and others 2013).

Conversely, precipitation has been quite variable from year to year. From 1940 to 2006, average annual precipitation was about 1200 mm. Annual precipitation exceeded 1600 mm in four of those years (1945, 1958, 1974, and 1996), and was less than 900 mm in three of those years (1963, 1980, and 2005). County-level patterns from 1997 to 2006 were similar but with less variation at the extremes (an artifact of the shorter duration of that analysis), with average precipitation of 1151 mm, a high of 1348 mm, and a low of 987 mm (McNulty and others 2013).

Precipitation in the Ouachita Mountains has been about 15 percent higher than the statewide average in Arkansas. This variation is a classic example of the orographic effect that results when moisture-laden clouds approach from the west; as they lift to pass over the Ouachitas, water vapor condenses and falls as precipitation. Precipitation is lowest in August; when combined with high temperatures, this often creates conditions that are favorable for late-season drought. The occurrence of summer droughts is important ecologically, because drought can determine whether tree seedlings and other vegetation have adequate moisture to survive.

Cross Timbers—The climate of the Cross Timbers is humid subtropical. Summers are hot, with maximum temperatures well above 40 °C for many days; winters are generally mild, but cold arctic air can reduce temperatures to -25 °C in the north.

From 1940 to 2006, average annual temperatures have been relatively uniform and consistent, averaging about 18 °C with average annual lows <17 °C in two of those years (1979 and 1983) and average annual highs exceeding 19 °C in four of those years (1954, 1956, 1996, and 2006). County-level patterns in annual temperature from 1997 to 2006 were more varied, with an average of 18.2 °C, a low of 14.9 °C, and a high of 22.6 °C. The reason for this variation is that some counties are near the Gulf of Mexico, whereas others are in Oklahoma at the northern boundary of the Cross Timbers (McNulty and others 2013).

Precipitation has been somewhat variable from one year to the next. From 1940 to 2006, average annual precipitation was roughly 950 mm. Annual precipitation exceeded 1150 mm in five of those years (1941, 1957, 1974, 1991, and 2004) and was < 700 mm in four of those years (1954, 1956, 1963, and 2005). County-level patterns from 1997 to 2006 were similar but with less variation at the extremes (an artifact of the shorter duration of that analysis), with annual precipitation averaging 917 mm, a low of 684 mm, and a high of 1316 mm. Precipitation fluctuations of this magnitude can

result in severe droughts—the most remarkable of which occurred in the 1930s and again in the 1950s (McNulty and others 2013).

Large scale catastrophic disturbances are not common in the region, with one exception—wildfire. Large fires are more likely to occur in dry years. A recent example is the Bastrop Fire in Texas in 2011, which burned more than 34,000 acres, destroyed more than 200 homes and commercial buildings, and caused 2 fatalities. Tornados are rare, with a return interval of about 3,000 years (Meyer and others 2002)—much longer than the 300- to 500-year life span of the major tree species of the Cross Timbers (Therrell and Stahle 1998). Damage from ice storms can be relatively widespread; they cause a lot of breakage, but do not usually kill a tree unless it is uprooted or its stem breaks below the live crown.

High Plains—The climate of the High Plains is humid subtropical, with hot summers and dry winters. From 1940 to 2006, annual temperatures have been relatively uniform and consistent, averaging about 17.5 °C with annual highs of >18 °C in five of those years (1946, 1954, 1956, 1996, and 2006) and annual lows of <17 °C occurring in 10 different years between 1956 to 1988 (but not recurring since). County-level patterns in annual temperature from 1997 to 2006 were considerably more varied, with an average of 17.5 °C, a high of 23.6 °C, and a low of 12.9 °C—again likely because of differences in county averages from the southern tip of Texas next to the Gulf of Mexico to the northern areas of Oklahoma and Texas (McNulty and others 2013).

Annual precipitation for the High Plains has been somewhat variable, but is generally much lower than the sections to the east. From 1940 to 2006, the average annual precipitation was about 600 mm. Annual precipitation exceeded 800 mm in three of those years (1941, 1991, and 2004) and was < 400 mm in two of those years (1954 and 1956). County-level patterns of average annual precipitation from 1997 to 2006 were similar, with an average of 595 mm, an annual high of 891 mm, and an annual low of 338 mm (McNulty and others 2013). Generally, in northern areas, May and September are the wettest months, and the period from October to April is dry (Wester 2007). Similarly, in the Rio Grande Basin, the primary rainfall peak—April, May, and June—occurs because of thunderstorm activity, but the late summer peak—August and September—results from tropical disturbances in the Gulf of Mexico (Box and others 1978).

West Texas Basin and Range—Climate is subtropical and arid, with hot summers and dry winters. From 1940 to 2006, annual temperatures have been relatively uniform and consistent, averaging about 17.6 °C with annual highs of >18.4 °C in three of those years (1950, 1954, and 2006) and annual lows of <17.0 °C in four of those years (1973, 1976, 1979, and 1987). County-level patterns in annual temperature from 1997 to 2006 were slightly more varied, with an average of 18.0 °C, a high of 19.8 °C, and a low of 16.1 °C (McNulty and others 2013).

Precipitation is low. From 1940 to 2006, annual precipitation averaged 350 mm, with highs ≥ 500 mm in five of those years (1941, 1974, 1986, 1991, and 2004) and lows < 200 mm in three of those years (1951, 1953, and 1956). County-level patterns in annual precipitation from 1997 to 2006 were similar, with an average of 331 mm, a high of 500 mm, and a low of 213 mm (McNulty and others 2013).

Forecasts of Climate Change

The analyses in the Southern Forest Futures Project (Wear and Greis 2013) began with the development of two different hypotheses, or storylines, that relate greenhouse gas emissions to economic, demographic, technological, political, and environmental changes (Intergovernmental Panel on Climate Change 2007). The two storylines applied in the Futures report were:

- A1B, featuring very rapid economic growth, a global population that peaks in mid-century and then declines, and makes assumptions about energy futures; and
- B2, featuring a growing population with intermediate economic growth focused on local solutions rather than global integration.

Those storylines were tested with three different global climate circulation models that could prevail over the next century—the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) model, the HadCM3 (“Hadley” model from the United Kingdom Meteorological Center), and the MIROC 3.2 model from the Japanese National Institute for Environmental Studies (Joyce and others 2011).

The emissions storylines were further developed into scenarios for the national Resources Planning Act report (USDA Forest Service 2012) and Cornerstone Futures for the Southern Forest Futures Project. Storyline A1B corresponds to mid-range population growth (a 60-percent increase from 2010 to 2060) and the highest per capita disposable personal income level; under this storyline, the South would support about 160 million people with per capita personal income of about $80,000 (2006 dollars) by 2060. Storyline B2 projects a lower population growth (a 40-percent increase) and lower personal income; under this storyline, the South would support a population of 143 million people with per capita personal income of about $60,000. Thus, the four Cornerstone Futures (Wear and others 2013a) can be broadly summarized as follows:

- Cornerstone A is the MIROC GCM+A1B, characterized by high population growth and a vigorous economy
- Cornerstone B is the CSIRO GCM+A1B, characterized by high population growth and a moderate economy
- Cornerstone C is the CSIRO GCM+B2, characterized by low population growth and a vigorous economy
- Cornerstone D is the Hadley GCM+B2, characterized by low population growth and a moderate economy

The Southern Forest Futures Project then generated forecasts for 17 key issues southwide under each of the four Cornerstone Futures.

The purpose of this report is to dissect those southwide forecasts into forecasts for the Mid-South, and—where possible—to specify the likely effects in its four sections, which differ so markedly. The forecast of climate change for the Southern Forest Futures Project was prepared by McNulty and others (2013). Southwide, they predicted an increase in temperature under all four different Cornerstone Futures, but with more variability in forecasts of precipitation. Climate predictions range from wet and warmer to dry and warmer to dry and hot.

A closer look at the climate change predictions for the Mid-South reveals cause for concern. First and foremost, air temperature is forecasted to increase significantly from historical and current levels (table 1). None of the Cornerstone Futures, nor any of the model outputs published by other climate scientists for that matter, suggest that air temperatures will remain stable or will cool in the 50-year forecasting period (2010 to 2060). Annual increases would vary from a 1.4 °C increase under Cornerstone D to a 2.7 °C increase under Cornerstone A; daily and monthly fluctuations could be larger. A temperature increase of 2.7 °C would make locations in the Mid-South resemble current temperatures 200 miles farther south: Little Rock would be like current-day Baton Rouge, the Dallas-Fort Worth area would be like current-day Houston, which in turn would become more like current-day Corpus Christi.

A county-level analysis from 2010 to 2050 reveals some section-level patterns that could be important (fig. 2). Under Cornerstone A, the entire Mid-South would experience an average temperature increase of >1 °C, and all of the Ozark-Ouachita Highlands and West Texas Basin and Range sections would experience an increase of 2 °C. Under Cornerstone D, most of the northern High Plains and Cross Timbers sections are predicted to have average increases of 1.5 to 2 °C. Under all four Cornerstone Futures, the average temperature of the Ozark-Ouachita Highlands would increase by at least 1 °C. Cornerstone B forecasts an increase of <1 °C in the Rio Grande Valley of southern Texas, but >1.5 °C for northern Texas, Oklahoma, and Arkansas. In other words, although some areas would be less affected, no areas would be totally unaffected.

The forecasts of changes in precipitation are not as severe but are also less conclusive. In the Mid-South, all four Cornerstone Futures predict a decrease in average annual precipitation by 2060 (table 2); that average varies from 13 mm under Cornerstone C to nearly 200 mm under Cornerstone A. By 2090, each of the decreases would be followed by an increase above the 2060 level, from a very small amount under Cornerstones A and C to >150 mm under Cornerstone B.

Table 1—Predited average annual temperature for the U.S. Mid-South as forecasted by four Cornerstone Futures

	Cornerstone[a] prediction of average temperature °C			
Year	A	B	C	D
2010	18.6	18.0	18.5	18.6
2020	19.2	18.4	19.0	19.0
2040	19.9	18.9	19.4	19.4
2060	21.3	20.1	20.0	20.0
2090	22.5	20.7	21.0	20.9

[a] Each Cornerstone represents a general circulation model (MIROC3.2, CSIROMK3.5, CSIROMK2, or HadCM3) paired with one of two emission scenarios (A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use): A is MIROC3.2+A1B, B is CSIROMK3.5+A1B, C is CSIROMK2+B2, and D is HadCM3+B2.

Source: McNulty and others (2013).

Table 2—Predicted average annual precipitation for the U.S. Mid-South as forecasted by four Cornerstone Futures

	Cornerstone[a] prediction of average precipitation mm			
Year	A	B	C	D
2010	721	812	663	784
2020	677	735	710	659
2040	579	837	713	725
2060	525	729	650	717
2090	536	884	666	743

[a] Each Cornerstone represents a general circulation model (MIROC3.2, CSIROMK3.5, CSIROMK2, or HadCM3) paired with one of two emission scenarios (A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use): A is MIROC3.2+A1B, B is CSIROMK3.5+A1B, C is CSIROMK2+B2, and D is HadCM3+B2.

Source: McNulty and others (2013).

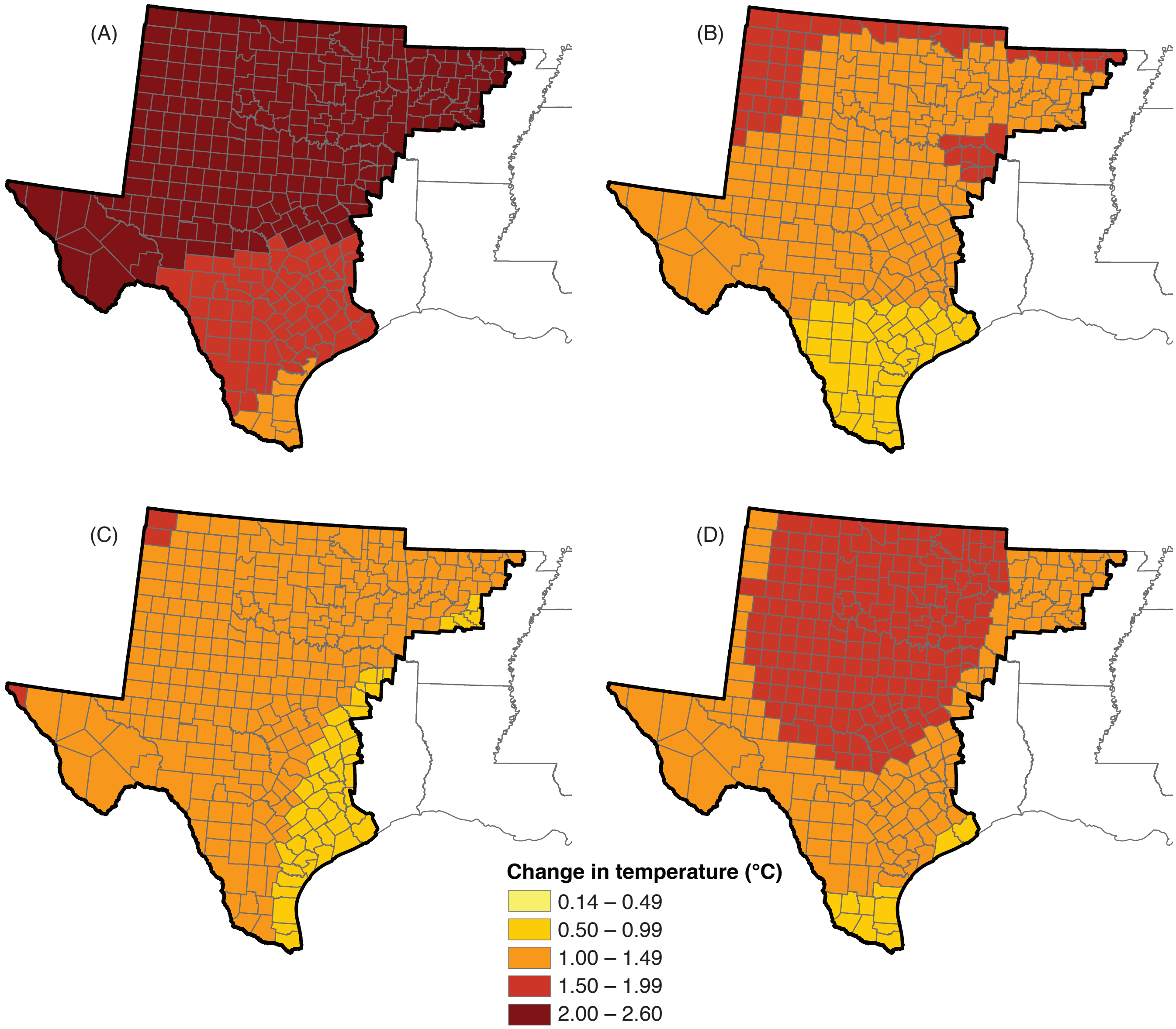


Figure 2—Predicted change in air temperature from 2010 to 2050 for the U.S. Mid-South as forecasted by four Cornerstone Futures; each of which represents a general circulation model paired with one of two emission storylines—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use—(A) MIROC3.2+A1B, (B) CSIROMK3.5+A1B, (C) CSIROMK2+B2, and (D) is HadCM3+B2 (Source: Intergovernmental Panel on Climate Change 2007).

However, monthly average precipitation does not fully represent the number or severity of individual events, nor are differences among months captured that could be ecologically significant (McNulty and others 2013). If the pattern of precipitation changes such that averages remain the same but the majority of precipitation occurs in winter months, the resulting summer droughts could be much more severe. Alternatively, if the major input of annual precipitation occurs in several short but intense events, the effects would be quite different from a distribution that occurred uniformly throughout the year.

The analysis at the county level from 2010 to 2050 also showed diverging geographic patterns of precipitation under the four Cornerstone Futures (fig. 3). Under Cornerstones A and D, a 20-percent reduction in average annual precipitation would occur across southeastern Texas from the Gulf of Mexico to the center of the State; and the rest of the Mid-South (except El Paso under Cornerstone A) would experience a decrease of 1 to 20 percent. Under Cornerstones B and C, more than half of the Mid-South would experience an increase in average annual precipitation: under Cornerstone B, annual rainfall would increase by 10 to 19 percent from southwest to northeast across the entire West Texas Basin and Range section, in the southern High Plains, and in the southern quarter of the Cross Timbers; under Cornerstone C, rainfall would increase from the southern tip of Texas to the north—with increases of >30 percent for the Rio Grande Valley, from 10 to 30 percent from the lower Pecos Valley to Houston, and from 0 to 10 percent in about half the remaining Mid-South counties that stretch from the southern High Plains of west-central Texas into the Cross-Timbers of west-central Oklahoma. Not much relief is expected for the Ozark-Ouachita Highlands, with decreases in annual precipitation forecasted under all four Cornerstone Futures, and two of the Cornerstone Futures forecasting a 10- to 20-percent decrease for the Ouachita Mountains south of the Arkansas River. More rain in western Texas under constant temperatures could be advantageous for agriculture, ranching, and other activities that depend on abundant water, but more rain could also result in increased encroachment by native eastern redcedar, mesquite, and live oak across the western sections of the Mid-South.

To ensure accuracy, changes in precipitation should be evaluated within the context of air temperature changes. As temperatures increase in an ecosystem, water use through evapotranspiration also increases. Therefore, temperature increases would likely offset small increases in precipitation, resulting in more frequent water shortages and streamflow reductions. If precipitation remains at historical levels (or less), water shortage issues would likely increase, especially if rain events become more episodic. Another unknown is whether increased atmospheric activity associated with warmer temperatures will increasingly vary rainfall from one year to the next, thereby increasing the likelihood of significant rain events coupled with more frequent and more severe droughts.

In short, although the magnitude and temporal and spatial distribution of climate change are unknown, all indications suggest that some change is certain. And although wet and dry periods have always been cyclical, the cycles are becoming more extreme. Changes in precipitation are expected for some areas of the Mid-South, but not for others. Nevertheless, average temperatures will likely continue to increase.

WILDFIRE AND PRESCRIBED BURNING

Stanturf and Goodrick (2013) described the prospective changes that might be expected across the South over the next 50 years, both within the context of wildfire and of prescribed burning under changing climate. They concluded that the hazard of wildfire will likely be higher, big wildfires will be more common, spring and autumn wildfire seasons will be longer, and severity of wildfire will lead to changes in vegetation types. They also predicted a paradoxical situation in which larger and more frequent prescribed burning is needed in a political environment that increasingly constrains the practice in response to health and safety concerns, air quality and smoke management challenges, and changing landscape patterns such as an expanding wildland-urban interface. These issues will likely be especially critical in the four sections of the Mid-South.

Fire is an integral part of the southern landscape. In the Mid-South, evidence points to the importance of fire in the forests and woodlands of the Ouachita-Ozark Highlands, the Cross Timbers, the High Plains, and the West Texas Basin and Range sections. Absence of fire on the landscape is directly responsible for some current forest and woodland management issues confronting the Mid-South. In the Cross Timbers and High Plains, examples include encroachment of native woody vegetation outside its former distribution, and changes in stem density and species composition in woodland communities; in the Ouachita-Ozark Highlands, the absence of fire has led to the dramatic decline of open pine-grassland habitats, and the flora and fauna that depend upon those habitats. But the growth of human populations, changes in societal infrastructure, and land-use shifts over the past century have fundamentally changed the ecological role of fire on the landscape, the scale at which fire can be used, and the potential for economic loss in the event of an uncontrolled wildfire. These changes will likely become more profound in a changing climate.

The relationship between drought and wildfire is well established. The drier conditions expected across the Mid-South under the Cornerstone Futures would result in

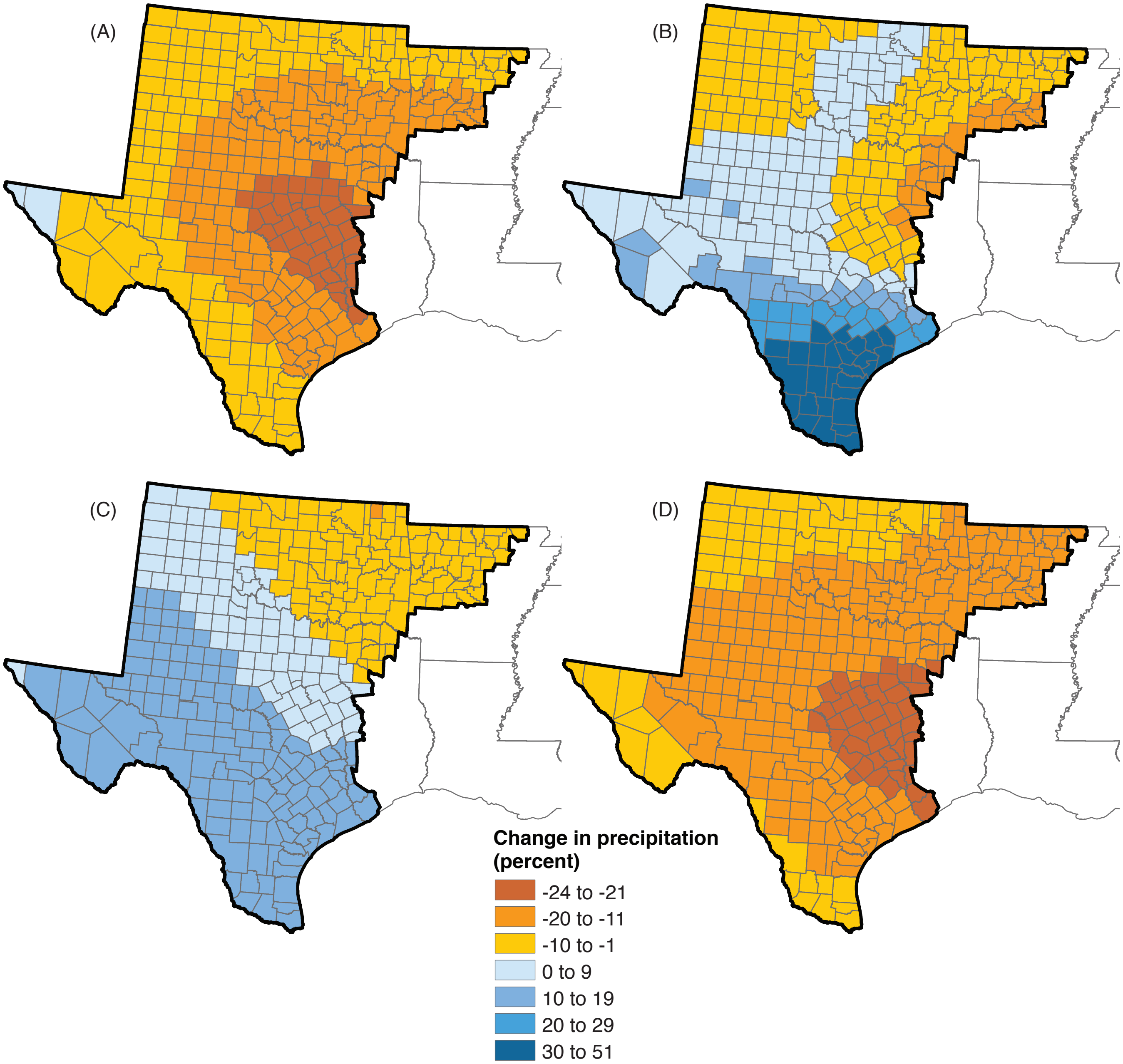


Figure 3—Predicted change in precipitation from 2010 to 2050 for the U.S. Mid-South as forecasted by four Cornerstone Futures; each of which represents a general circulation model paired with one of two emission storylines—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use—(A) MIROC3.2+A1B, (B) CSIROMK3.5+A1B, (C) CSIROMK2+B2, and (D) HadCM3+B2 (Source: McNulty and others 2013).

increased fire potential from 2010 to 2060, and the brunt of these changes would result in an increased wildfire potential—especially in the High Plains and Cross Timbers of Texas and Oklahoma (figs. 4 and 5). Compared to the marked seasonality of wildfire in the Appalachian-Cumberland highlands and the Coastal Plain, wildfires occur during all seasons of the year in the Mid-South (Stanturf and Goodrick 2013). By 2060, however, all four sections of the Mid-South are expected to experience higher wildfire potential, and a dramatic increase in summer wildfire potential is expected (fig. 6).

A prescribed fire (or prescribed burn) is a fire that is deliberately set under suitable weather conditions so that flames will run across a stand or landscape in a controllable and predictable manner; it is used by resource managers to achieve a desired ecological or silvicultural objective. The intensity of the fire depends on a number of factors, including the amount and moisture content of forest fuels (such as needles, twigs, branches, and fallen logs), local weather conditions including wind speed and wind direction within the context of local topography, and the patterns of ignition used to start and sustain the fire across the area being burned.

As conditions change across the Mid-South over the next several decades, the need for prescribed burning in forests and woodlands to reduce fuel and create (or sustain) desired vegetation communities and habitat conditions will probably increase. Conversely, if prevailing air temperatures increase and precipitation decreases as predicted, the windows of opportunity to ignite a safe fire will become more constrained. Other issues revolve around whether the smoke from prescribed burning will be tolerated by an expanding population in an expanding wildland-urban interface, and whether air quality over a wide area will be compromised. Increased urbanization would raise concerns about liability for damage from fires that escape containment, the localized effects of smoke on highway safety and human health, and the degradation of air quality during and after the burn.

Stanturf and Goodrick (2013) modeled the percentage of land area in the driest classes under four Cornerstone Futures (A, B, C, and D) for 2010 and again for 2060. Those data were analyzed in a change detection context—the month-by-month change in land area that is classified as driest under each of the Cornerstone Futures. The changes are predicted to be largest in spring and autumn—especially in Texas, which would experience a 10- to 20-percent increase in land area in the driest classes in those seasons. These results confirm a major concern about the effects of changing climate—that temperature changes would increase aridity earlier and later in the calendar year. Other related concerns include a longer season of conditions that favor wildland fire, a need for more attention to fire weather, and a reduction in the number of days that are suitable for prescribed burning.

Perhaps the most ominous concern for the Mid-South is not strictly the effects on conditions in forests, but rather the implications for growing season and soil moisture in the agricultural sector, especially the croplands of the Cross Timbers and those irrigated by the Ogallala Aquifer in the High Plains.

In summary, the use of prescribed burning as a management tool in forests, woodlands, and grasslands across the Mid-South will likely raise issues of concern that include difficulty in controlling prescribed fire, increasing limits on the weather conditions that are considered safe for burning, and overarching issues of air quality across landscapes. Issues associated with impacts on human health and safety will likely be greater in the highly populated Cross Timbers, as well as in the Ozark-Ouachita Highlands where burning on Federal lands has become a resource management priority.

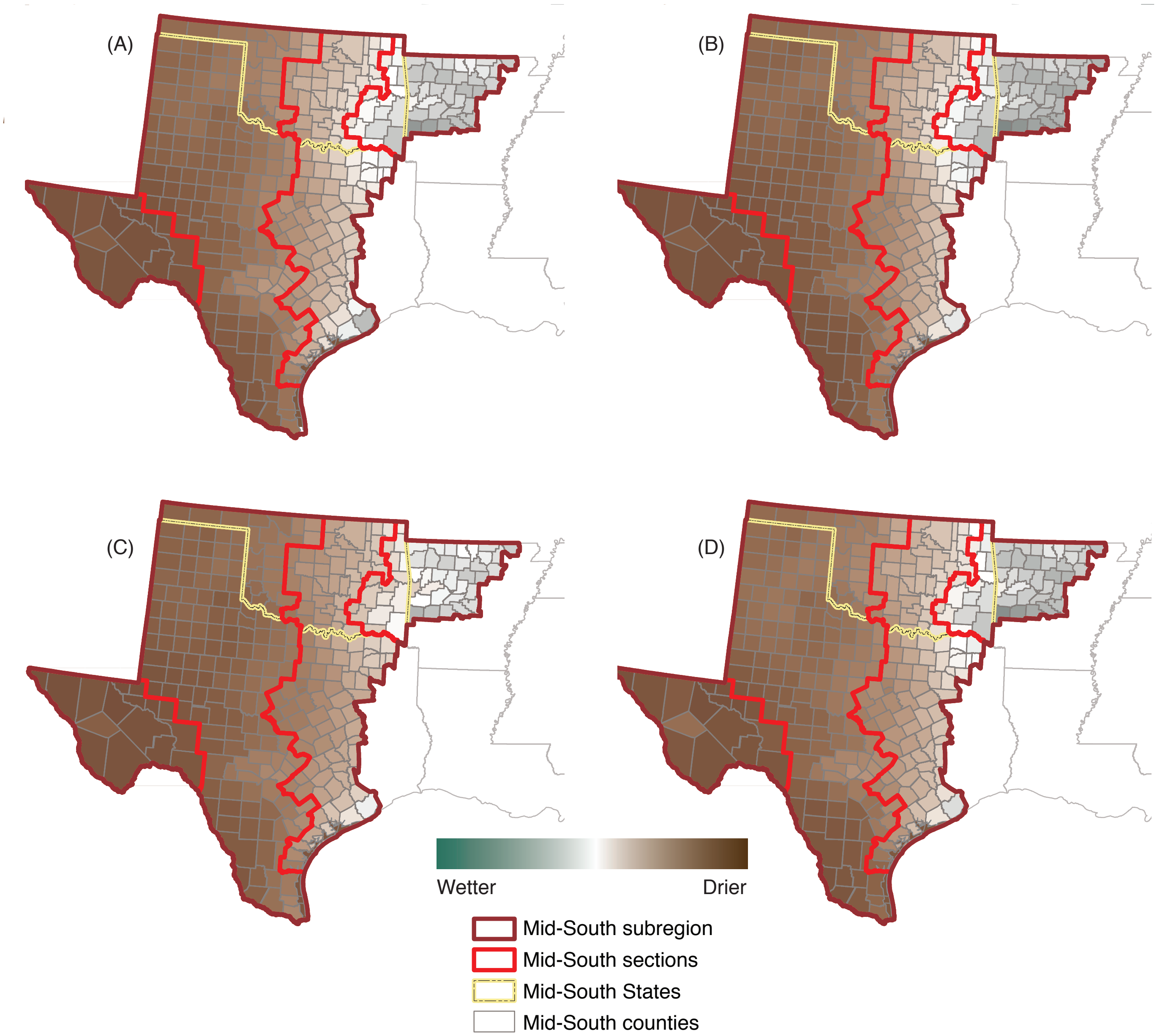


Figure 4—Annual fire potential in the U.S. Mid-South under current conditions in 2010, as simulated by four Cornerstone Futures; each of which represents a general circulation model paired with one of two emission storylines—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use: (A) MIROC3.2+A1B, (B) CSIROMK3.5+A1B, (C) CSIROMK2+B2, and (D) is HadCM3+B2 (Source: Stanturf and Goodrick 2013).

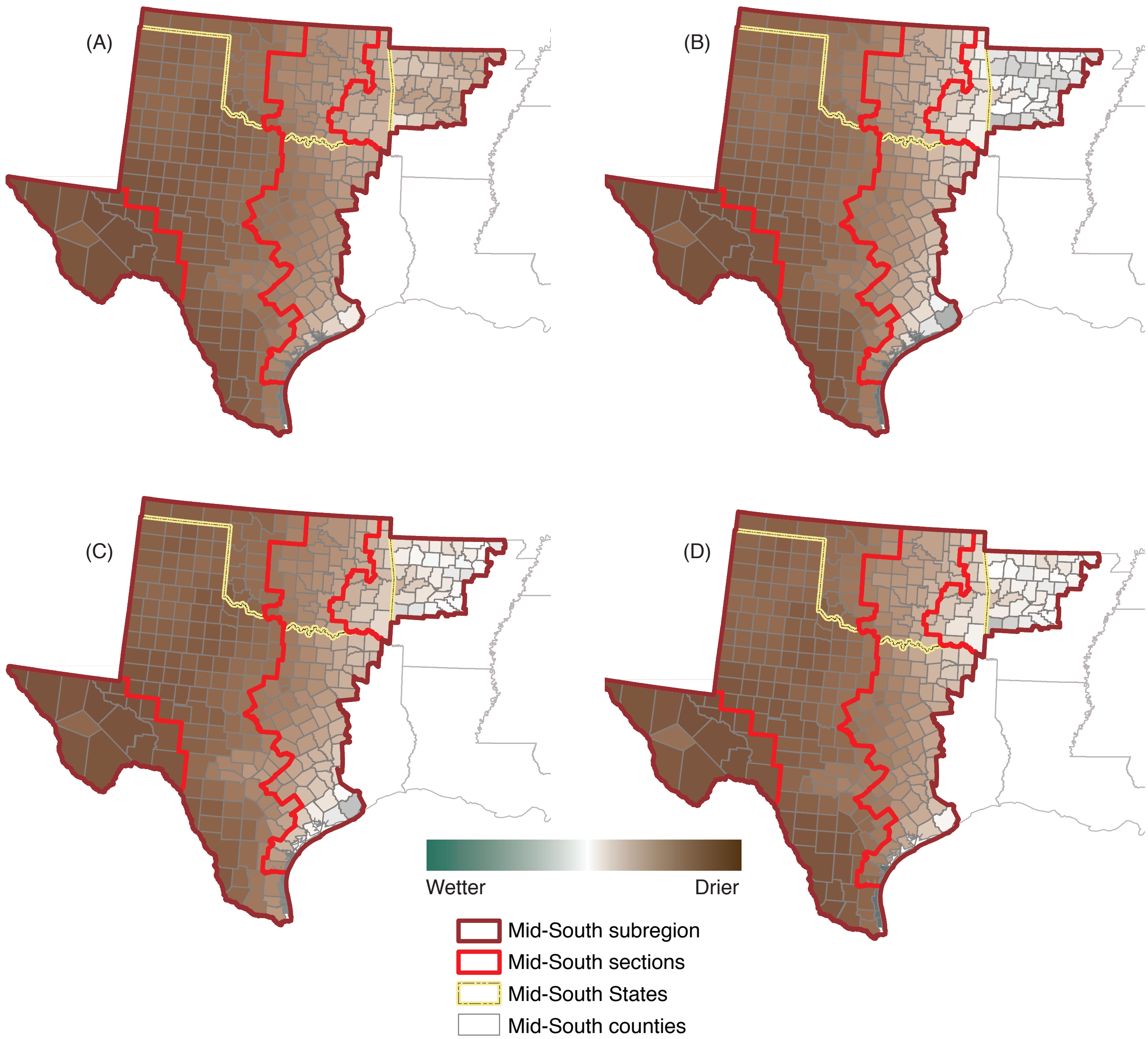


Figure 5—Annual fire potential in the U.S. Mid-South in 2060, as predicted by four Cornerstone Futures; each of which represents a general circulation model paired with one of two emission storylines—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use: (A) MIROC3.2+A1B, (B) CSIROMK3.5+A1B, (C) CSIROMK2+B2, and (D) is HadCM3+B2 (Source: Stanturf and Goodrick 2013).

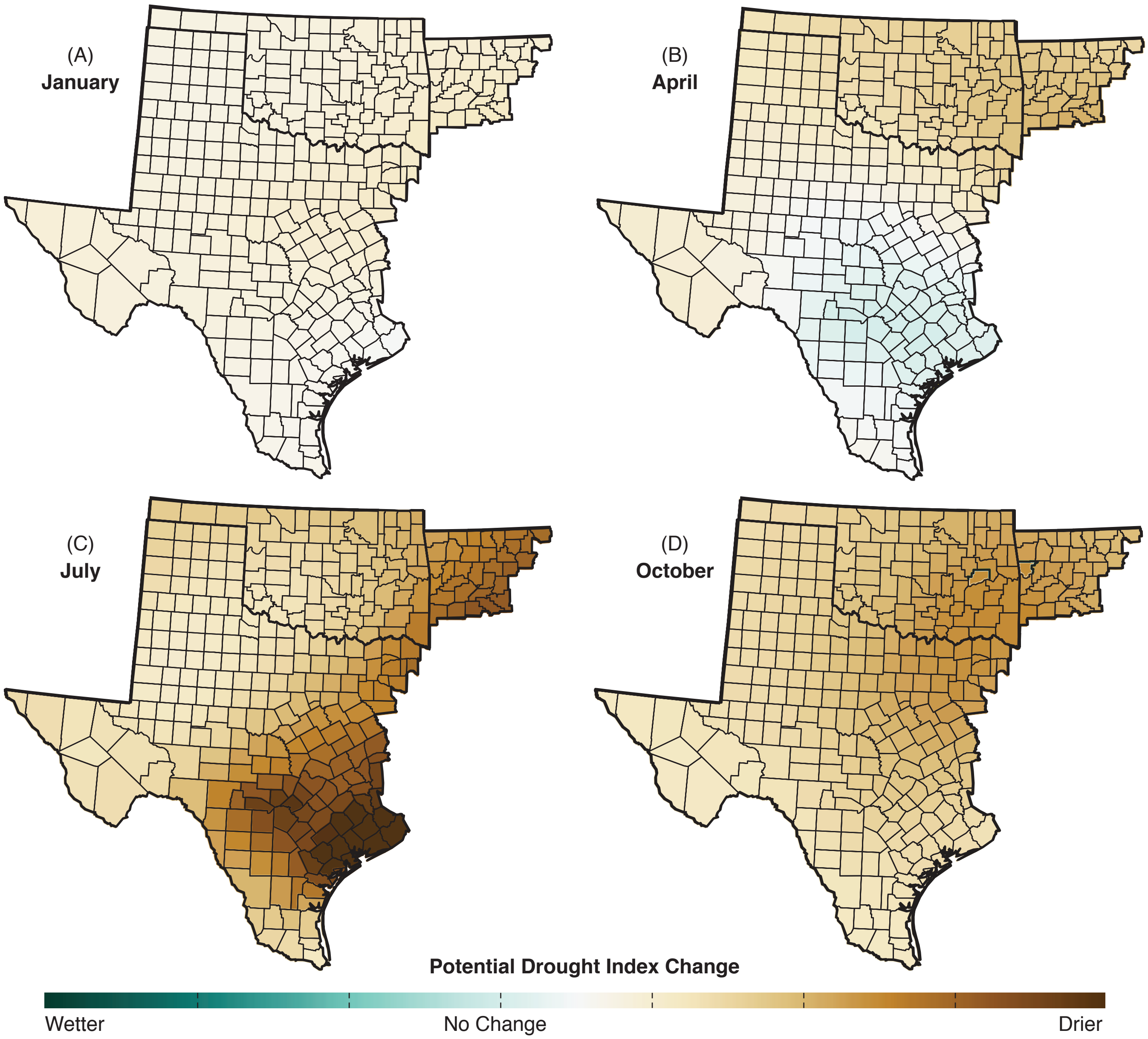


Figure 6—Change in seasonal fire potential, 2060, under Cornerstone A for the U.S. Mid-South during (A) January, (B) April, (C) July, and (D) October; each of the four Cornerstone Futures represents a general circulation model (MIROC3.2, CSIROMK3.5, CSIROMK2, or HadCM3) paired with one of two emission scenarios (A1B representing low-population/high-economic growth, high energy use; B2 representing moderate growth and use). Cornerstone A is MIROC3.2+A1B (Source: Stanturf and Goodrick 2013).

CHAPTER 3. The Human Footprint

POPULATION, DEMOGRAPHY, AND ECONOMIC ACTIVITY

According to the U.S. Census, the population of the Mid-South increased from 20.3 million in 2000 to 24.2 million in 2010—a 15.8-percent increase over the decade (U.S. Census Bureau 2011). That rate of population growth over five decades would result in a 79 percent population increase, with the Cross Timbers and High Plains sections leading both in absolute numbers and in the rate of increase. However, the forecasts in the Southern Forest Futures Project, which were prepared before the 2010 U.S. Census data were released, assumed a southwide population increase of only 59 percent. In 2010:

- The Ozark-Ouachita Highlands section supported 2.29 million people, 13 percent more than in 2000
- The Cross Timbers section supported 13.5 million people, 20 percent more than in 2000
- The High Plains section supported 7.45 million people, 18 percent more than in 2000
- The West Texas Basin and Range section supported 0.93 million people, 16 percent more than in 2000.

Statewide, the largest impacts clearly were in Texas, which supported 25.15 million people in 2010—20.6 percent more than in 2000, more than triple the combined rate of Arkansas and Oklahoma. In the Cross Timbers, 26 of 111 counties grew >20 percent; three counties northeast of Dallas—Denton, Collin, and Rockwall—together increased >50 percent, from 0.98 million to 1.52 million (U.S. Census Bureau 2011).

Ozark-Ouachita Highlands

The population of the Ozark-Ouachita Highlands is distributed in small- to medium-sized cities and towns. This population grew from 1.25 million people in 1970 to 2.29 million people in 2010, an increase of 83 percent; population density in 2010 was 61.8 people per square mile, up from 54.7 a decade ago. Of the 49 counties in the section, 40 gained population and 9 lost population over the last decade. The four with the highest rates of population growth in the past 10 years are Benton County (44.3 percent) and Washington County (28.8 percent) in northwestern Arkansas near Fayetteville, and Faulkner County (31.6 percent) and Saline County (28.2 percent) in central Arkansas near Little Rock (U.S. Census Bureau 2011).

According to U.S. Census reports for 2010, the demographics of the Ozark-Ouachita Highlands mirrored the United States as a whole (U.S. Census Bureau 2011). Per capita income was $21,815, and median household income was $40,359; both of these values are slightly higher than the average for Arkansas, but lower than Oklahoma. Also in 2010:

- **Education**—82.9 percent of the population consisted of high school graduates and 20.5 percent consisted of college graduates, both less than the national average of 85.0 percent for high school graduates and 27.9 percent for college graduates
- **Age**—6.7 percent of the population was <5 years, 24.3 percent was <18 years, and 14.8 percent was >65 years
- **Ethnicity**—8.4 percent was African American, 4.8 percent was Native American, and 7.2 percent was Hispanic
- **Income**—17.3 percent was below the poverty level, slightly higher than the national average of 13.8 percent.

A comparison of economic data from the counties in this section with national averages, all derived from the 2010 U.S. Census (U.S. Census Bureau 2011), was based on the proportional land area of the United States that the section occupies: the Ozark-Ouachita Highlands represented 1.048 percent of the U.S. land area, but only supported 0.74 percent of the U.S. population, 0.54 percent of manufacturing value, 0.44 percent of wholesale sales, 0.67 percent of retail sales, 0.48 percent of accommodations and food services sales, and 0.64 percent of Federal spending (U.S. Census Bureau 2011). These data suggest an area less active in economic development than the national average.

Cross Timbers

The population of the Cross Timbers is concentrated in metropolitan areas. The large current population and expected explosion of population represents one of the biggest challenges to management of natural resources, not only within the Mid-South but also throughout the Southern

United States. The population in this section grew from 6.13 million in 1970 to 13.50 million in 2010, an increase of 120 percent. Of its 110 counties, 93 gained in population (26 of which grew by >20 percent) and 17 lost population over the last decade. Population density was 154.6 people per square mile, up from 128.5 a decade ago.

The Texas State Demographer projected population increases through 2040 (Texas Forest Service 2008). The largest metropolitan area is the Dallas-Fort Worth-Arlington area; its 2000 population of about 5.2 million is expected to grow to 15.3 million by 2040. Similarly, the Houston-Sugarland-Baytown area had 4 million and is expected to range from 8.4 to 11.1 million by 2040. Population and projected growth of metropolitan areas in the Cross Timbers of Oklahoma is much smaller.[1] Together, the Oklahoma City and Tulsa metropolitan areas supported a population of about 2.2 million in 2010, and are projected to be 3.6 million by 2075. Much of this growth would be manifested in urban sprawl and an increase in the wildland-urban interface—both of which would cause a major loss of open space. Over a 5-year period in the 1990s, Texas lost nearly 900,000 acres of open space to development; urban land now occupies almost 10 million acres.

Conservation of the central woodlands was determined to be a high priority by the Texas Statewide Assessment of Forest Resources (Texas Forest Service 2008). Although focused on Texas, these findings apply equally well to the Cross Timbers in Oklahoma. The woodlands of Texas and Oklahoma are a valuable resource for shade, recreation, wildlife, and environmental and watershed protections. Threats to these resources include exploding populations, landscape fragmentation, wildfires, invasive plants, oak wilt, and attacks by other pests. The ownership pattern characteristic of noncommercial hardwood forests is private livestock ranches and residential property.

The Texas A&M Forest Service has an array of programs that address issues such as oak wilt, forest stewardship, forest inventory, and wildfire prevention. But in addition, a new, integrated conservation initiative—the Central Texas Conservation Initiative [http://www.texasconservation.org (Date accessed: September 19, 2014)]—has been established by Texas A&M Forest Service to address other current and emerging problems in land ownership. From 2009 to 2014, this initiative has delivered four regional workshops annually for targeted interface landowners in high-priority counties—including a collaborative "Cross Timbers" initiative delivered with Oklahoma Forestry Services.

According to U.S. Census reports for 2010, the Cross Timbers has an economy that is stronger than the United States as a whole. Per capita income was $26,319, and the median household income was $52,983 (U.S. Census Bureau 2011). Also in 2010:

- **Education**—83.8 percent of the population consisted of high school graduates, and 27.7 percent consisted of college graduates
- **Age**—7.5 percent of the population was <5 years, 26.7 percent was <18, and 10.7 percent was >65 years
- **Ethnicity**—12.4 percent was African American, 2.1 percent was Native American, and 23.4 percent was Hispanic
- **Income**—14.1 percent was below the poverty level, slightly higher than the national average of 13.8 percent.

A comparison of economic data from the counties in this section with national averages, all derived from the 2010 U.S. Census, was based on the proportional land area of the United States that the section occupies: the Cross Timbers represented 2.47 percent of the Nation's land area, but supported 4.37 percent of the U.S. population, 3.85 percent of the manufacturing shipment value, 4.25 percent of wholesale sales, 4.35 percent of retail sales, 3.52 percent of accommodations and food services sales, and 3.15 percent of Federal spending (U.S. Census Bureau 2011).

High Plains

The High Plains section has a number of cities of varying sizes; San Antonio is the largest followed by important urban populations in Austin, Lubbock, Laredo, Midland-Odessa, Amarillo, and Abilene. Population grew from 3.84 million people in 1970 to 7.45 million people in 2010, an increase of 95 percent. From a relatively low overall population density of 46.6 people per square mile in 2010, growth was >20 percent over the past decade in 13 Texas counties that primarily encompassed the hill country from San Antonio to Austin and the Rio Grande Valley along the border from Laredo to Brownsville. Conversely, two counties—Cottle County in north-central Texas, and Cimarron County on the westernmost part of the Oklahoma Panhandle—lost >20 percent of their population in the past decade; both had <2,500 residents in 2010 (U.S. Census Bureau 2011).

According to the U.S. Census reports for 2010, the High Plains section is fairly prosperous. Per capita income was $22,116, and the median household income was $44,662 (U.S. Census Bureau 2011). Also for 2010:

[1] Barker, Steve. 2012. 2012 demographic state of the State report—Oklahoma State and county population projections through 2075. Oklahoma Department of Commerce; Policy, Research, and Economic Analysis Division. 184 p. (http://okcommerce.gov/assets/files/data-and-research/Population_Projections_Report-2012.pdf.) [Date accessed: March 19, 2014].

- **Education**—77.2 percent consisted of high school graduates, and 23.6 percent consisted of college graduates
- **Age**—7.7 percent of the population was <5 years, 27.3 percent was <18 years, and 11.2 percent was >65
- **Ethnicity**—5.1 percent was African American, 0.8 percent was Native American, and 51 percent was Hispanic
- **Income**—20.2 percent of the population was below the poverty level, higher than the national average of 13.8 percent.

A comparison of economic data from the counties in this section with national averages, all derived from the 2010 U.S. Census, was based on the proportional land area of the United States that the section occupies: the High Plains represented 4.52 percent of the Nation's land area, but supported 2.41 percent of the U.S. population, 1.10 percent of the manufacturing shipment value and 1.26 percent of wholesale sales (probably reflecting the importance of its land-based agriculture), 2.26 percent of retail sales, 1.94 percent of accommodations and food services sales, and 2.34 percent of Federal spending (U.S. Census Bureau 2011).

West Texas Basin and Range

This section has the large metropolitan area of El Paso in the western edge and the small city of Del Rio on the eastern edge, with only a few small towns scattered between the two. Population grew from 3.84 million people in 1970 to 7.45 million people in 2010, an increase of 95 percent. By 2010, population density was relatively low at 46.6 people per square mile. Two counties, El Paso and Loving, grew by >15 percent, with population totaling >800,000 in the former and only 82 people in the latter. Seven of the 16 counties in this section lost population in the past decade, with Culberson County decreasing by 19.4 percent since 2000 (U.S. Census Bureau 2011).

According to the U.S. Census reports for 2010, the West Texas Basin and Range section is relatively poor. Per capita income was $16,884, and the median household income was $36,553 (U.S. Census Bureau 2011). Also in 2010:

- **Education**—70.1 percent of the population consisted of high school graduates, and 18.6 percent consisted of college graduates
- **Age**—8.0 percent of the population was <5 years, 29.7 percent was <18 years, and 10.7 percent was >65 years
- **Ethnicity**—3.0 percent was African American, 0.7 percent was Native American, and 80.2 percent was Hispanic
- **Income**—25.1 percent was below the poverty level, nearly double the national average of 13.8 percent.

A comparison of economic data from the counties in this section with national averages, all derived from the 2010 U.S. Census, was based on the proportional land area of the United States that the section occupies: the West Texas Basin and Range section represented 1.18 percent of the Nation's land area, but supported only 0.30 percent of the U.S. population, 0.27 percent of the manufacturing shipment value and 0.13 percent of wholesale sales, 0.25 percent of retail sales, 0.19 percent of accommodations and food services sales, and 0.31 percent of Federal spending—in all, probably reflecting the extraordinarily rural nature of the section (U.S. Census Bureau 2011).

LAND USE CHANGES

The southwide forecast for land use changes in the Southern Forest Futures Project was prepared by Wear and others (2013a). That work was the basis for the changes forecasted for each of the sections in the Mid-South that were developed for this report. The key finding for discussion in the Mid-South is the expansion of urban population centers into forest land in the Cross Timbers, the southern High Plains, and the Ozark and Ouachita Mountains.

As well as describing the effects of urbanization (population and income) on climate (chapter 2), the four Cornerstone Futures (A through D) have underlying assumptions about timber prices that affect forecasts of land use (Huggett and others 2013, Wear and others 2013a):

- Cornerstone A is characterized by increasing timber prices in addition to moderately high population/income growth.
- Cornerstone B is characterized by decreasing timber prices in addition to moderately high population/income growth.
- Cornerstone C is characterized by increasing timber prices in addition to lower population/income growth.
- Cornerstone D is characterized by decreasing timber prices in addition to lower population/income growth.

The land use model developed by Wear and others (2013a) addresses most of the acreage in the 13 Southern States with county-level forecasts. However, for the central and western areas of Texas and Oklahoma, results derive from a land use model developed for the Rocky Mountain/Great Plains; this model, which is sensitive only to changes in population and income, assumes that changes in rural land uses will be proportional to their 1997 levels.

Urban Growth

The growth of urban population centers in the Cross Timbers, High Plains, and Ozark-Ouachita Highlands will continue to be a key issue throughout the 21st century. According to the U.S. Census data, population growth rates from 2000 to 2010 were 15.8 percent for the Mid-South as a whole—13 percent in the Ozark-Ouachita Highlands, 20.3 percent in the Cross Timbers, 18.4 percent for the High Plains, and 15.4 percent for the West Texas Basin and Range

section. Spread forward over a 50-year period (2010 to 2060), this rate of growth considerably exceeds the projection of 60 percent, the most drastic storyline (A1B) used in developing projections for the Cornerstone Futures (Wear 2013).

One effect of increasing population would be a major expansion of urban areas into the wildland-urban interface. Urban growth projections vary across the four sections of the Mid-South. Under Cornerstones A and B, which reflect a 60 percent population growth rate from 1997 to 2060, urban land area across the Mid-South would more than double, occupying >8.5 million acres or 4.1 percent of total land area (table 3). Although all four sections are projected to have expanded urban areas by 2060, the rates of expansion would vary. In the West Texas Basin and Range section, urban land area is projected to expand by 57 percent to 338,500 acres, just >1 percent of total land area. In the High Plains, urban area would more than double to 4.889 million acres, or 4.8 percent of total land area. The Ozark-Ouachita Highlands would have the largest percentage increase of urban land area, more than tripling to 1.62 million acres, or 6.8 percent of total land area, all centered in central and northwestern Arkansas. The Cross Timbers would experience the largest increase in urban land—projected to be 7.59 million acres and occupying 13.9 percent of the section by 2060, more than double that of 1997. Under Cornerstones C and D, which predict lower rates of population growth, urban area across the Mid-South is still expected to nearly double (table 4).

What is non-Federal land?

For the purposes of this publication, non-Federal land includes land held by private organizations, individuals, families, local governments, Indian reservations, and U.S. States. It does not include U.S. military bases or lands managed by the U.S. Department of Agriculture and the U.S. Department of the Interior.

Table 3—Observed (1997) and forecasted (2010–2060) area of urban land in the four sections of the U.S. Mid-South, based on an expectation of large urbanization gains (Cornerstones A and B)

	Area in urban use					Change from 1997 to 2060	
Section	**1997**	**2010**	**2030**	**2040**	**2060**	**Area**	**Percent**
	thousand acres						
Cross Timbers	3,571.32	4,755.67	5,918.31	6,496.88	7,587.58	4,016.26	112.5
High Plains	2,118.25	2,772.43	3,572.02	3,982.05	4,889.50	2,771.25	130.8
Ozark-Ouachita Highlands	715.10	973.87	1,436.92	1,696.06	2,334.79	1,619.69	226.5
West Texas Basin and Range	214.99	241.45	279.75	299.04	338.51	123.52	57.4
Total	**6,619.66**	**8,743.41**	**11,206.99**	**12,474.03**	**15,150.38**	**8,530.72**	**128.9**

Source: Wear (2013).

Table 4—Observed (1997) and forecasted (2010–2060) area of urban land in the four sections of the U.S. Mid-South, based on an expectation of moderate urbanization gains (Cornerstones C and D)

	Area in urban use					Change from 1997 to 2060	
Section	**1997**	**2010**	**2020**	**2040**	**2060**	**Area**	**Percent**
	thousand acres						
Cross Timbers	3,571.32	4,802.41	5,358.32	6,043.35	6,742.91	3,171.59	88.8
High Plains	2,118.25	2,836.53	3,183.58	3,628.00	4,092.01	1,973.76	93.2
Ozark-Ouachita Highlands	715.10	1,026.17	1,216.15	1,467.04	1,792.84	1,077.74	150.7
West Texas Basin and Range	214.99	244.78	261.44	283.21	302.64	87.65	40.8
Total	**6,619.66**	**8,909.89**	**10,019.49**	**11,421.60**	**12,930.40**	**6,310.74**	**95.3**

Source: Wear (2013).

Projected Decreases in Other Land Uses

This urban expansion comes at the expense of the common rural land base in the respective sections, especially under Cornerstone B. Because the largest concentration of forest land occurs in the Ozark-Ouachita Highlands (fig. 7), any urban expansion around Little Rock in central Arkansas and Fayetteville in northwestern Arkansas would occur at the expense of forest area (fig. 8). Under Cornerstone B, forests would lose >868,000 acres, or 8.4 percent (table 5). The other three sections would lose slightly >330,000 acres of forest land area, for a loss of about 8 percent across the Mid-South. Similarly, under Cornerstone B, pasturelands would also decrease in the Ozark-Ouachita Highlands (fig. 8), although the area lost is not very large compared to forest land loss. Cornerstone C, with lower expectations for urban expansion, projects about half of the loss in forest land, but still predicts a loss of slightly >4 percent in the Ozark-Ouachita Highlands and across the Mid-South as a whole (table 6).

For western Texas and Oklahoma, there are differences in the definitions of undeveloped wild lands between the National Resources Inventory (U.S. Department of Agriculture 2009) and Forest Service surveys that somewhat confound predictions about woodlands and rangelands (including forested rangelands). But in the Cross Timbers and the High Plains, any gains in urban area would clearly come at the expense of pastureland and rangeland, including forested rangeland (fig. 8). The impacts of such conversions would be most drastic in the Dallas-Fort Worth metropolitan area, which is already expanding into pastureland toward the southeast and into open and forested rangelands toward the southwest. There would also be projected losses of rangeland and pastureland area in the corridor from Waco to Austin to San Antonio, as well as in projected decreases of rangeland in the Rio Grande Valley. Rangeland would decrease by about 2.5 million acres for Cornerstones C and D and about 3.2 million acres for Cornerstones A and B. These losses would be concentrated in the urbanizing Cross Timbers area of eastern Texas and Oklahoma, especially around Dallas and Austin, and along the Mexican border (Wear 2013).

FOREST OWNERSHIP

History

Ozark-Ouachita Highlands—Initially associated with railroad construction for ties and bridges, commercial logging of virgin shortleaf pine timber began in earnest during the latter part of the 19th century. The larger logging and manufacturing operations in the region, such as the Missouri Lumber and Mining Company mill at Grandin, MO, produced 200,000 board feet of lumber a day (Smith 1988). In 1909, the lumber industry supported nearly 75 percent of Arkansas wage earners (Guldin 2008). The Ouachitas were more completely cutover than the Ozarks for a number of reasons. In the Ouachitas, the shortleaf pine used to mill the valuable yellow pine lumber was (and still is) concentrated on the ridges and south-facing slopes. Compared to the Ozarks, the areas of south-facing slopes in the Ouachitas are vastly larger; this meant that logging could be more efficiently conducted (Smith 1988). In addition, railroad tracks were more easily engineered and built in the Ouachitas than the Ozarks; the long ridges in the Ouachitas are oriented primarily from east to west, and the broad U-shaped valleys that separate the ridges made for easier access than in the uplifted and dendritic Ozark Plateau, especially in the rugged Boston Mountains. Smith (1988) reported that some of the most valuable parcels of land were the few choke points in the mountain gaps of the Ouachitas through which railroads had to travel to open up the lumbering of the next broad ridge. Although the Ozarks supported abundant stands of shortleaf pine and white oak for furniture and stave mills, its terrain limited stand size. Mechanized operations to haul cut timber in the Ozarks were, and still are, much more difficult than in the Ouachitas.

The Ozark-Ouachita Highlands section supports a large area of national forest land, by far a larger proportion of Federal forest land than in the other areas of the Mid-South. President Theodore Roosevelt established the Arkansas National Forest (renamed as the Ouachita National Forest in 1926) in 1907, and the Ozark National Forest in 1908 (Bass 1981), both by proclamation.

Industrial ownership of timberland began in the last years of the 19th century when two Iowa brothers, Hans and Herman Dierks, established the Dierks Lumber and Coal Company in Arkansas and the Choctaw Lumber Company in Oklahoma. They set up sawmills in several towns in Oklahoma (Valiant, Broken Bow, and Wright City) and Arkansas (Dierks and Mountain Pine), and bought a lumberyard in DeQueen, AR (Walker 1991). Their lands were primarily in the Ouachita Mountains of Arkansas and Oklahoma, with some on the Athens-Piedmont Plateau and the upper western Coastal Plain just to the south of the Ouachitas. Within 30 years, the company amassed some 1.8 million acres of forest land in the Ouachitas. In 1968 and 1969, family fortunes suffered a reversal, and the Dierks' forest holdings were acquired by Weyerhaeuser Company, which established its Southern Timberlands headquarters in Hot Springs, AR. In the past decade, these timberlands are once again changing hands, from forest products industry ownership to timberland investment management organizations and real estate investment trusts.

Other Mid-South sections—As directed by Congress, the Forest Service has conducted inventories of the Nation's forest lands since the 1930s; eight national forest survey reports and many more regional and State reports have been

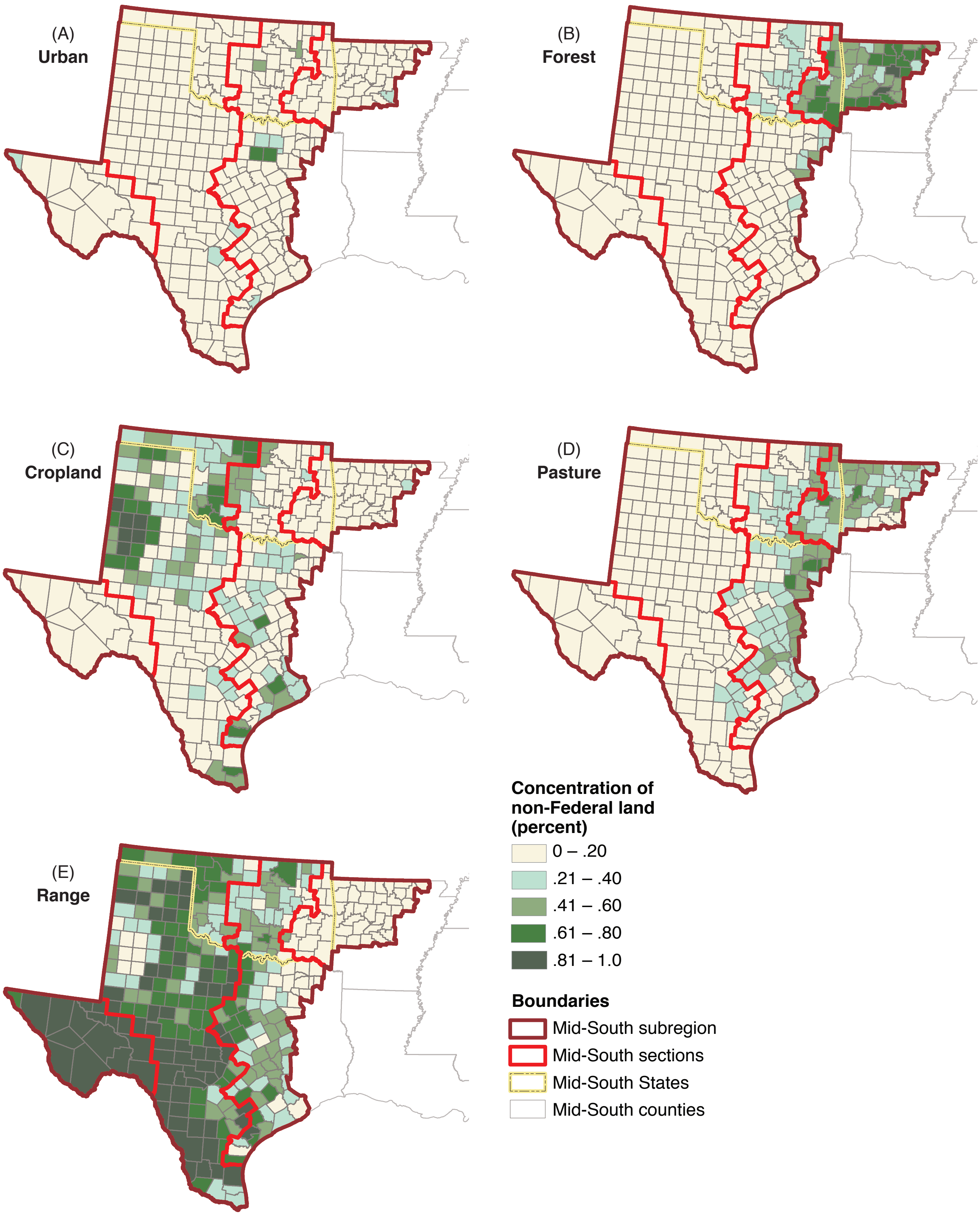


Figure 7—Concentration of non-Federal land in the U.S. Mid-South that is classified as (A) urban, (B) forest, (C) cropland, (D) pasture, and (E) range, as of 1997 (Source: U.S. Department of Agriculture 2009).

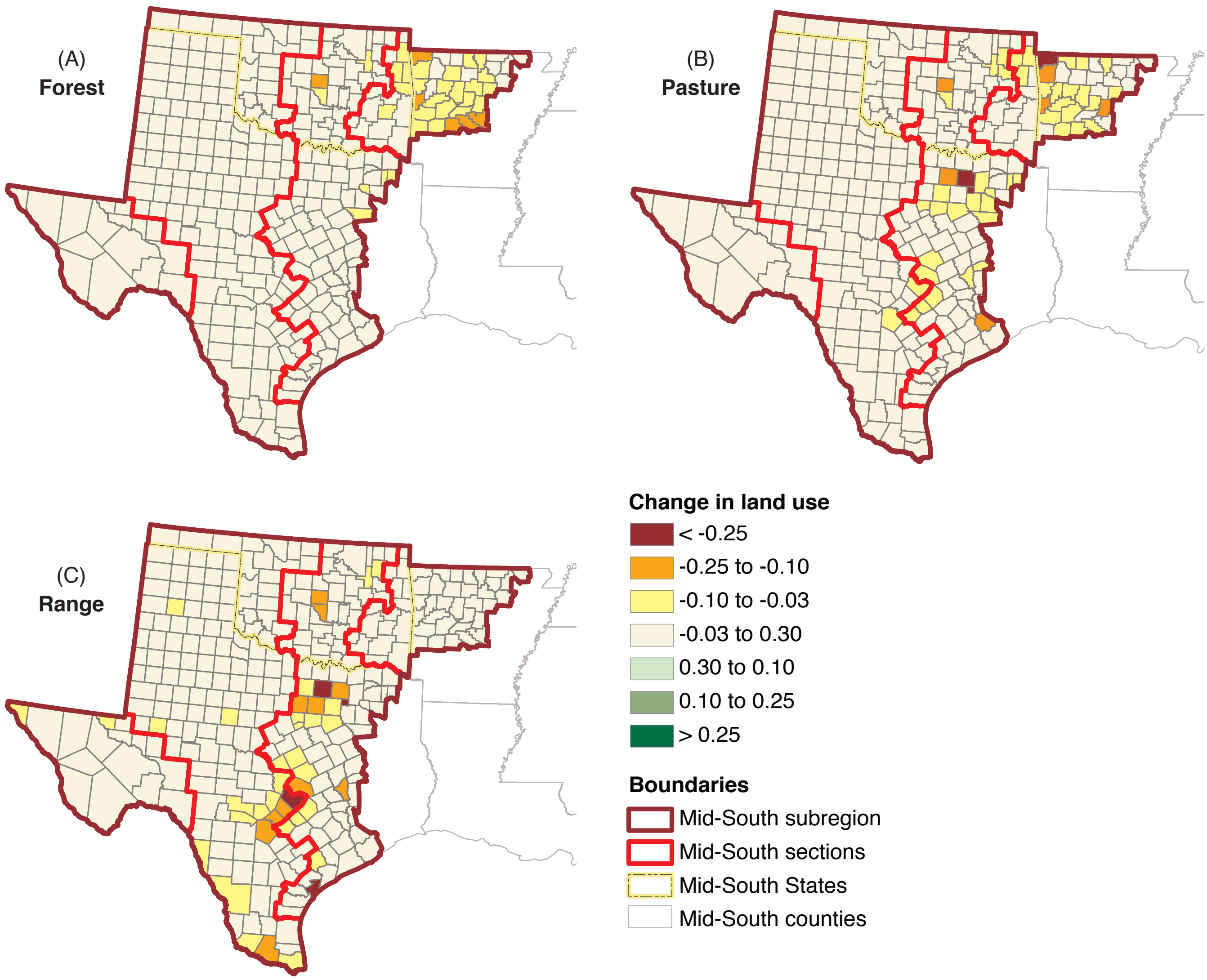


Figure 8—Change in land uses, 1997 to 2060, in the U.S. Mid-South based on an expectation of large urbanization gains and decreasing timber prices, for land that is classified as (A) forest, (B) pasture, and (C) range (Source U.S. Department of Agriculture 2009).

Table 5—Observed (1997) and forecasted (2010-2060) area of non-Federal forest land in the four sections of the U.S. Mid-South, based on an expectation of large urbanization gains and decreasing timber prices (Cornerstone B)

	Area in forest use					Change from 1997 to 2060	
Section	**1997**	**2010**	**2020**	**2040**	**2060**	**Area**	**Percent**
	- - - - - - - - - - - - - - - - - - - thousand acres- - - - - - - - - - - - - - - - - - -						
Cross Timbers	4,582.04	4,500.57	4,447.78	4,338.32	4,250.32	-331.72	-7.2
High Plains	116.34	116.19	115.91	115.32	114.48	-1.86	-1.6
Ozark-Ouachita Highlands	10,355.32	10,216.25	10,086.52	9,826.35	9,486.59	-868.73	-8.4
West Texas Basin and Range	0	0	0	0	0	0.00	0
Total	**15,053.70**	**14,833.01**	**14,650.22**	**14,279.99**	**13,851.39**	**-1,202.31**	**-8.0**

Source: Wear (2013).

Table 6—Observed (1997) and forecasted (2010–2060) area of non-Federal forest land in the four sections of the U.S. Mid-South, based on an expectation of moderate urbanization gains and decreasing timber prices (Cornerstone C)

	Area in forest use					Change from 1997 to 2060	
Section	**1997**	**2010**	**2020**	**2040**	**2060**	**Area**	**Percent**
	- - - - - - - - - - - - - - - - - - - thousand acres- - - - - - - - - - - - - - - - - - -						
Cross Timbers	4,582.04	4,510.84	4,478.97	4,449.96	4,410.01	-172.03	-3.8
High Plains	116.34	116.14	115.95	115.84	115.57	-0.77	-0.7
Ozark-Ouachita Highlands	10,355.32	10,215.68	10,135.17	10,037.04	9,900.33	-454.99	-4.4
West Texas Basin and Range	0	0	0	0	0	0.00	0
Total	**15,053.70**	**14,842.66**	**14,730.08**	**14,602.85**	**14,425.92**	**-627.78**	**-4.2**

Source: Wear (2013).

produced in the past 75 years. The data and interpretations from those reports have been instrumental in economic development and the establishment of policy for management of forest lands at the State, regional, and national level. Among the great advantages of the survey is the opportunity to chart changes in forest conditions over time.

However, in the past, the areas surveyed have been limited to those that support extensive commercial timberlands. In the Mid-South, the only survey units with repeated measurements are in the Ozark and Ouachita areas of Arkansas and Oklahoma. Repeated measurements in Oklahoma were limited to 18 eastern counties that encompass the western Ouachita Mountains. In these counties, forest surveys were conducted in 1956, 1966, 1976, 1986, 1992, and 2008. Consequently, long-term trends in growth, yield, mortality, utilization, and forest conditions in the forests of eastern Oklahoma are well known.

Data from repeated survey measurements are not available for counties outside eastern Oklahoma or from the eastern boundary of the Cross Timbers westward through Oklahoma and Texas, probably because these areas were not a source of raw materials for industrial development. But at the beginning of the 21st century, forestry officials in Texas and Oklahoma found that some issues required technical analyses that employed the kinds of data that are collected in the forest survey. Examples include the encroachment of woody vegetation; the expansion of burgeoning urban population centers into surrounding forests, woodlands, and rangelands (including forested rangelands); and forest and woodland fuel conditions that support increasingly severe wildfires that threaten residential development. What followed was an expanded forest survey in the 211 counties of western Texas (begun in 2004) and the 59 counties of western Oklahoma (begun in 2009). These new surveys are aimed at informing State and Federal agencies and other natural resource professionals about the attributes of all forests and woodlands, regardless of their commercial value.

A single round of the forest survey gives essentially a point estimate in time about the conditions of the vegetation that are sampled on the plot. A second visit to the same plot after 5 or 10 years gives an entirely new kind of data—trends in vegetation growth, removal, mortality, as well as a host of other variables that can only be determined from repeated visits. So although the data from the first survey measurements in western Oklahoma and Texas have been informative, the more valuable trend data will not be available until subsequent visits to the same sample plots have been made.

In the absence of long-term data, literature and historical accounts have provided clues about the ways in which woody plant distributions have changed and the ways in which woody plants were used in the three western sections of the Mid-South. For example, the forests of the Cross Timbers likely provided timber for local firewood and building-construction needs, and larger trees were probably used for railroad ties, although these uses are poorly documented. In general, because trees from Cross Timbers forests are small and somewhat scattered, timber is of low value and quality; very few forests were cleared for agriculture because of the poor quality of the soil, and much of the land was only suitable for grazing. Therefore, the land was put to use for cattle production.

The Cross Timbers in Texas and Oklahoma shared a similar history, although settlement and clearing for cropland began much earlier in Texas. Again, only the best lands were cleared for and remained in agriculture. Much of the Cross

Timbers forest land was not heavily exploited because of the low value of the timber and the poor soil.

The woodlands of the High Plains section in Texas and Oklahoma and of the West Texas Basin and Range section have been expanding largely through changes in fire regime. Before European colonization, grassland fires may have burned extensive areas; trees such as junipers would have been killed outside of floodplains and other moist sites and areas where locally rugged topography would have impeded the spread of grassland fires. However, grassland fires became less frequent after European settlement and have become even less common over the past 60 years with the advent of increased agricultural activity and modern fire suppression. The result has been a gradual expansion of woody vegetation and a slow replacement of native grasslands with woodlands in natural landscapes (van Auken 2000).

Recent Trends

Ozark-Ouachita Highlands—Of the 14.925 million acres of forest land in the Ozark-Ouachita Highlands, a substantial portion occurs in public lands. The two large national forests in this section, the Ozark-St. Francis National Forest and the Ouachita National Forest, combine for a total of 2.7 million acres, 18.3 percent of all forest land in the section. Other Federal lands (Fort Chaffee in western Arkansas and lands managed by the U.S. Army Corps of Engineers along the Arkansas River) total >550,000 acres; and State, county, and municipal holdings add about 270,000 acres. This brings the total public-forest land base to 3.66 million acres, or nearly 25 percent of Ozark-Ouachita Highlands. Of the remainder, 1.29 million acres (8.7 percent) are owned by the forest products industry, and 9.974 million acres (66.8 percent) are held by other (nonindustrial) private forest owners (Ridley 2012).

One way to study the changes in forest ownership patterns is to analyze data collected several decades ago. Two 1988 Arkansas surveys—one in the Ouachitas (Hines 1988a) and the other in the Ozarks (Hines 1988b)—and the 1993 Oklahoma forest survey (Miller and others 1993) contain data for all the counties covered by this report, plus three counties (White in Arkansas, Bryan and Muskogee in Oklahoma) that were stratified into other Mid-South sections for the Southern Forest Futures Project analysis. Those datasets (minus the White/Byran/Muskogee data) approximate the conditions that existed two decades ago and have been termed "1990 data" for the purposes of this report.

Interpreting these data requires an understanding of the distinction among several forest classifications: forest land, which encompasses timberland, woodland, and reserved timberland; timberland, which is capable of producing at least 20 cubic feet of commercial-grade wood per acre per year; woodland, which is limited to producing <20 cubic feet of commercial-grade wood per acre per year because of poor site conditions; and reserved timberland, which has been removed from wood production through Federal or State law (Hines 1988a, Hines 1988b, Miller and others 1993). Additional complexities, including differences in survey design, variables collected, and data processing procedures, make using trend information from past surveys in comparison with the current survey somewhat problematic (Rosson and Rose 2010).

Despite these complexities, ownership of timberland reported in the 1990 survey differed from the 2011 forest survey in a number of ways. First, forest land area appears to have increased from 14.230 to 14.925 million acres over the past 20 years; however, whether the increase is an artifact of the changing survey design or a real difference is difficult to determine. Second, the area of public land appears to have increased from 2.495 to 2.597 million acres, reflecting one of the most important additions to the Federal land base in this section—the 1996 land exchange between the Ouachita National Forest and Weyerhaeuser Company, which transferred about 100,000 acres in Oklahoma and southwestern Arkansas from industry ownership into national forest ownership. In total, publicly owned timberland (including Federal, State, county, and municipal) appeared to increase by >250,000 acres between the two surveys (from 3.130 million acres in the 1990 survey to 3.392 million acres in 2011) (Ridley 2012).

By far the most significant change in forest land ownership has been in the private sector, specifically the change from ownership by the forest products industry to other commercial ownerships. The forest products industry, which held 1.915 million acres of timberland in 1990, decreased its holdings by about 600,000 acres to 1.291 million acres by 2011. Similarly, other commercial owners, primarily focused on timberland investments—timber investment management organizations and real estate investment trusts—have increased their holdings by about 600,000 acres from 0.693 million acres in the 1990 survey to 1.314 million acres by 2011 (Ridley 2012). Caution is required in interpreting these apparently matching losses and gains in the absence of enough data points to calculate reliable long-term trends (described earlier). In addition, differences between forest industry and other commercial ownerships may be misclassified—when determining land ownership, survey crews tend to rely on tax files rather than the more accurate original deed files in county courthouses. For example, forest land under the stewardship of a timber investment group may have tax records still linked to the parent company; in such situations, the ownership category may be incorrectly identified as a forest products industry. But despite these caveats, it appears that a trend common elsewhere in the South is now occurring in the Ozark and Ouachita Highlands—the forest products industry has been selling or transferring timberland to timber investment

groups. The driving forces behind this transition are the high capital value of standing timberlands and the more favorable tax treatment of investment properties than company-owned assets (Hickman 2007).

Other privately owned timberland has also changed between the two surveys, reported at 7.565 million acres in 1990 compared to 8.082 million acres in 2011. In part, this can be attributed to the success of national efforts such as the Conservation Reserve Program and Wetlands Reserve Program, which were established to reforest marginal agricultural lands, or to the accidental conversion of agricultural land such as pastures to timberland through old-field succession. But it may also be an artifact of the differences in procedures between the two survey periods (Rosson and Rose 2010).

Other Mid-South sections—Agriculture has been the major cause of losses in forest land, woodland, and rangeland. The uses of Cross Timbers forest land include recreation, grazing, hunting, and firewood collection. A recent study of 143 Cross Timbers stands in Oklahoma found that over the past 50 years about 40 percent of the stands were <10 percent disturbed and 65 percent were <50 percent disturbed (Stallings 2008). Forest ownership in the Cross Timbers is mainly private (>90 percent) and mostly in small holdings by individuals, partnerships, and corporations. These forests and woodlands are considered to be valuable resources for shade, recreation, wildlife, environmental, and watershed protection. The biggest threats to their sustainability are population growth, landscape fragmentation, wildfires, invasive species, oak wilt, and attacks by other pests.

In general, water and soils that enable cultivation are more available in the High Plains than in the Cross Timbers or the West Texas Basin and Range sections. Water from the Ogallala Aquifer, the largest U.S. groundwater reserve, supports cropland irrigation, municipal water use, and manufacturing (Drummond 2007).

Forecasts of Forest Ownership

The forest land ownership predictions that Butler and Wear (2013) developed for the Southern United States used existing survey data from repeated measurement plots, and as discussed earlier in this report, do not include results from the survey that was recently begun in the West Texas Basin and Range, the Cross Timbers, or the High Plains. For this reason, many of their forecasts would have only marginal application for much of the Mid-South. The exception is the Ozark-Ouachita Highlands, primarily in the Ouachita Mountains, where changes in ownership to timber investment groups from Weyerhaeuser and other forest products companies likely will have some small effects on the nature of forest holdings.

Combining two different datasets—one from a 2006 survey of southern forest land ownerships[2] and the other from a 2007 survey of woodland and rangeland ownerships in western Texas[3]—showed that the Mid-South is unique among southern landscapes in several aspects of forest ownership, as described in the following paragraphs.

More than 16 percent of forest area in the Mid-South is in public ownership, primarily in the two national forests in Arkansas. By comparison, only 5 percent of woodlands and rangelands is publicly owned. The history of logging virgin forests and recovery of that cutover terrain in the last century prompted legislation that brought some of those cutover forests into Federal ownership. No similar outcry about loss of woodlands and rangelands occurred, even though woodland and rangeland ecosystems underwent similar kinds of exploitation and abandonment during agricultural conversion over the same period.

Private forest ownerships in the Mid-South, and especially family ownerships, have smaller forest holdings than woodland or rangeland holdings. Among all private ownerships, tracts <500 acres make up 54 percent of forest land area, but only 23 percent of woodland and rangeland area (table 7). For larger ownerships, 37 percent of private timberland area is in tracts ≥1,000 acres, compared to 66 percent of woodland and rangeland area. For family-owned properties, tracts <500 acres make up 66 percent of forest land area, compared to 27 percent of woodland and rangeland area in tracts of that size; and 25 percent of family forest lands are in tracts ≥1,000 acres, compared to 62 percent of family-owned woodlands and rangelands. (table 8).

Forest land owners and woodland or rangeland owners in the Mid-South have similar tenure of land ownership and similar reasons for owning their land. Of those responding to the survey, rangeland and woodland owners tended to be more recent owners, with 53 percent having acquired their property within the past 25 years compared to 27 percent of forest land owners (table 9). The percentage of owners with ≥50 years of tenure was about the same, <5 percent, for both sectors. Under the category of family ownership, individual or joint ownerships were by far most common (reported by 89 percent of timberland owners and 94 percent of woodland and rangeland owners), followed distantly by family partnerships at about 3 percent of owners across the board and trusts at about 6 percent of forest land owners and

[2] Butler, B.J. 2010. Family forest owners of the Southern United States. 2006. Unpublished report. On file with: Northern Research Station, Forest Inventory and Analysis, 160 Holdsworth Way, Amherst, MA 01003.

[3] Butler, B.J.; Carraway, A.B. 2011. Results from a survey of families and individuals who own rangeland and woodland in western Texas, 2007. Unpublished report. On file with: Northern Research Station, Forest Inventory and Analysis, 160 Holdsworth Way, Amherst, MA 01003.

Table 7—Percent of land area in all private ownership among forest lands, rangelands and woodlands based on holdings of a given size, across the U.S. Mid-South[a,b]

Size of land holding	Forest land	Rangeland and woodland
acres	*- - - percent of responding landowners - - -*	
1-9	1.5	0.7
10-19	1.4	0.4
20-49	9.0	2.8
50-99	13.0	2.0
100-199	12.4	7.1
200-499	16.8	10.1
500-999	8.6	11.2
1,000-4,999	10.9	29.7
5,000-9,999	3.4	8.8
≥10,000	22.8	27.4
<500	54.2	23.0
≥1,000	37.1	65.9

[a] Butler, B.J. 2010. Family forest owners of the Southern United States. 2006. Unpublished report. On file with: Northern Research Station, Forest Inventory and Analysis, 160 Holdsworth Way, Amherst, MA 01003.

[b] Butler, B.J.; Carraway, A.B. 2011. Results from a survey of families and individuals who own rangeland and woodland in western Texas, 2007. Unpublished report. On file with: Northern Research Station, Forest Inventory and Analysis, 160 Holdsworth Way, Amherst, MA 01003.

Table 8—Percent of land area in private family ownership among forest land, rangeland and woodland based on holdings of a given size, across the U.S. Mid-South[a,b]

Size of land holding	Forest land	Rangeland and woodland
acres	*- - - percent of responding landowners - - -*	
1-9	1.9	0.8
10-19	1.8	0.4
20-49	11.2	3.3
50-99	15.6	2.4
100-199	15.2	8.2
200-499	19.9	11.8
500-999	9.2	11.0
1,000-4,999	12.4	30.0
5,000-9,999	3.8	10.4
≥10,000	8.9	21.7
<500	65.6	26.9
≥1,000	25.2	62.1

[a] Butler, B.J. 2010. Family forest owners of the Southern United States. 2006. Unpublished report. On file with: Northern Research Station, Forest Inventory and Analysis, 160 Holdsworth Way, Amherst, MA 01003.

[b] Butler, B.J.; Carraway, A.B. 2011. Results from a survey of families and individuals who own rangeland and woodland in western Texas, 2007. Unpublished report. On file with: Northern Research Station, Forest Inventory and Analysis, 160 Holdsworth Way, Amherst, MA 01003.

Table 9—Percentage of land held, by years of tenure, for owners of forest land in the Mid-South compared to owners of rangeland and woodland in western Texas[a,b]

Ownership tenure	Forest land	Rangeland and woodland
acres	*- - - percent of responding landowners - - -*	
< 10	11.3	14.8
10-24	16.0	38.1
25-49	68.3	45.7
≥50	4.4	1.3

[a] Butler, B.J. 2010. Family forest owners of the Southern United States. 2006. Unpublished report. On file with: Northern Research Station, Forest Inventory and Analysis, 160 Holdsworth Way, Amherst, MA 01003.

[b] Butler, B.J.; Carraway, A.B. 2011. Results from a survey of families and individuals who own rangeland and woodland in western Texas, 2007. Unpublished report. On file with: Northern Research Station, Forest Inventory and Analysis, 160 Holdsworth Way, Amherst, MA 01003.

2 percent of woodland and rangeland owners. Both sectors also reported similar motivations for owning their property; common reasons included being part of a farm or ranch, passing land to children or heirs, having the opportunity to hunt and fish, and enjoying beauty, scenery, and privacy (table 10).

Most landowners have not done any active management on their lands in the past 5 years. However, of landowners who did report conducting management activities, woodland and rangeland owners seemed to be more active than forest land owners (table 11). Twelve percent of woodland and rangeland owners reported cutting trees, compared to 4 percent of forest land owners. Fire-hazard reduction treatments were applied by 19 percent of woodlands and rangeland owners, and 12 percent of forest land owners. More than 10 percent of rangeland and woodland landowners reported applying chemicals on their property, compared to <5 percent of forest land owners. Fewer than 10 percent of landowners in either group reported they had conducted road and trail maintenance or wildlife habitat improvement activities. Although several questions in the survey were asked of one group but not the other (table 11), responses suggest that forest land owners have concerns about uninvited recreation and trespass that are probably shared by rangeland and woodland owners. Nearly 30 percent of rangeland and woodland owners have conducted invasive plant control activities; this suggests that they have problems not with nonnative species necessarily but rather with encroachment by redcedar, live oak, and other native woody vegetation on upland sites.

Fewer than 15 percent of family private landowners preferred receiving management advice (table 12). Of those who do, woodland and rangeland owners reported more interest in the different approaches to receiving advice than forest land owners. Printed materials were preferred by 14 percent of rangeland and woodland owners, compared to <10 percent of forest land owners. Fewer than 10 percent of landowners preferred online sources, workshops, or video media, all increasingly common tools used by State Extension experts. Talking with other landowners or resource professionals was preferred by about 10 percent of landowners. But talking with contractors, visits to demonstration areas, or membership in a landowner organization were preferred by <5 percent of landowners. Clearly, there are challenges in providing effective technical expertise and management advice to landowners, perhaps foremost among them the scarcity of landowners who are interested in receiving that advice.

Finally, rangeland and woodland owners appear to have higher levels of education than forest land owners in the Mid-South (table 13). Nearly 24 percent have graduate degrees compared to 18 percent of forest land owners, and more than 40 percent have a college degree compared to 27 percent of

Table 10—Reasons reported for owning forest land or rangeland and woodland acreage in the Mid-South by families who ranked objectives as very important (1) or important (2) on a seven-point Likert scale[a,b]

Objective for ownership	Forest land	Rangeland and woodland
	percent of responding landowners	
Enjoyment of beauty or scenery	35.9	40.1
Protection nature and biologic diversity	26.4	30.0
Investment	25.5	34.7
Part of residence or vacation home	39.6	36.3
Part of farm or ranch	24.6	34.3
Privacy assurance	27.9	37.7
Passing land on to children or other heirs	33.1	38.3
Nontimber rangeland and woodland products	5.0	5.4
Production of firewood or biofuel	9.5	1.8
Production of sawlogs, pulpwood, other timber products	2.4	1.6
Hunting or fishing	15.7	26.8
Recreation other than hunting or fishing	13.4	24.4

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[b] Butler, B.J.; Carraway, A.B. 2011. Results from a survey of families and individuals who own rangeland and woodland in western Texas, 2007. Unpublished report. On file with: Northern Research Station, Forest Inventory and Analysis, 160 Holdsworth Way, Amherst, MA 01003.

Table 11—Management activities conducted by family landowners on forest land or rangeland and woodland ownerships in the past 5 years in the Mid-South as reported by responding family landowners[a,b]

Management activity	Forest land	Rangeland and woodland
	- - - - - - percent of responding landowners - - - - - -	
Timber or tree harvest	4.1	11.7
Collection of non-timber forest products	4.0	1.8
Tree planting	3.0	—
Fire hazard reduction	12.0	18.8
Application of chemicals	4.2	12.5
Road/trail maintenance	4.7	7.7
Wildlife habitat improvement	4.1	6.5
Posting land	20.7	—
Private recreation	10.6	—
Public recreation	2.3	—
Insect/disease control	—	3.0
Control of invasive plants	—	29.0

— = Data not available.

[a] Butler, B.J. 2010. Family forest owners of the Southern United States. 2006. Unpublished report. On file with: Northern Research Station, Forest Inventory and Analysis, 160 Holdsworth Way, Amherst, MA 01003.

[b] Butler, B.J.; Carraway, A.B. 2011. Results from a survey of families and individuals who own rangeland and woodland in western Texas, 2007. Unpublished report. On file with: Northern Research Station, Forest Inventory and Analysis, 160 Holdsworth Way, Amherst, MA 01003.

Table 12—Preferred methods for receiving management advice about forest land or rangeland and woodland in the Mid-South as reported by families who ranked each method as very useful (1) or useful (2) on a seven-point Likert scale[a,b]

Preferred learning method	Forest land	Rangeland and woodland
	- - - - - - percent of responding landowners - - - - - -	
Publications, books, or pamphlets	9.2	14.1
Newsletters, magazines, or newspapers	9.5	14.5
Internet/Web	6.5	9.1
Conferences, workshops, or video conferences	3.7	6.3
Video tapes for home viewing	5.5	9.9
Television or radio programs	5.4	9.5
Visits to other woodland ownerships or field trip	6.4	10.5
Talking with a natural resource professional	11.0	10.9
Talking with other woodland owners	9.2	12.5
Talking with a logging contractor	4.7	—
Membership in a landowner organization	1.6	—
Visits to demonstration areas	3.5	5.4

— = Data not available.

[a] Butler, B.J. 2010. Family forest owners of the Southern United States. 2006. Unpublished report. On file with: Northern Research Station, Forest Inventory and Analysis, 160 Holdsworth Way, Amherst, MA 01003.

[b] Butler, B.J.; Carraway, A.B. 2011. Results from a survey of families and individuals who own rangeland and woodland in western Texas, 2007. Unpublished report. On file with: Northern Research Station, Forest Inventory and Analysis, 160 Holdsworth Way, Amherst, MA 01003.

Table 13—Percentage of land ownership by education level of the primary decisionmaker, for owners of forest land in the Mid-South compared to owners of rangeland or woodland in western Texas[a,b]

Education level	Forest land	Rangeland and woodland
	- - - - - - *percent of responding landowners* - - - - - -	
<12th grade	8.5	1.5
High school diploma or equivalent	21.5	9.6
Some college	15.7	15.9
Associate's degree	5.4	4.4
Bachelor's degree	27.0	40.9
Graduate degree	18.1	23.8

[a] Butler, B.J. 2010. Family forest owners of the Southern United States. 2006. Unpublished report. On file with: Northern Research Station, Forest Inventory and Analysis, 160 Holdsworth Way, Amherst, MA 01003.

[b] Butler, B.J.; Carraway, A.B. 2011. Results from a survey of families and individuals who own rangeland and woodland in western Texas, 2007. Unpublished report. On file with: Northern Research Station, Forest Inventory and Analysis, 160 Holdsworth Way, Amherst, MA 01003.

forest land owners. Slightly more than 10 percent have high school degrees (or did not finish the 12th grade) compared to 30 percent of forest land owners.

One might debate whether the higher levels of education for rangeland and woodland owners correlates with ownership of larger tracts; after all, the ability to acquire or maintain larger properties may require more income, which is often associated with higher education. One might also speculate that landowners with higher levels of education might recognize the value of managing their lands, be open to more intensive management, and more aggressively seek sources of information about how to manage their land.

Parcelization

The Southern Forest Futures Project did not show a compelling trend in tract size over time for the Mid-South as a whole, because the survey data upon which that analysis was based was essentially from one sample for three of its four sections—the Cross Timbers, High Plains, and West Texas Basin and Range. Future repeated samples will be useful in estimating ownership trends for forests, rangeland, and pastureland. In the absence of such trend information, anecdotal observations from estate tax law, market trends, and land sales suggest that parcel size is becoming smaller rather than larger. Transferring land from older to younger generations often leads to multiple owners of a given property, or subdivision into smaller parcels that are owned outright. The transfer of commercial property, such as the purchase of forest products industry land by timber investment groups, can also lead to parcelization. New owners often repackage those parts of the purchased property that have a higher, better, or more valuable use as residential or recreational property than as timberland or woodland. Finally, privately owned timberlands, woodlands, and rangelands are often subdivided for industrial or residential development as opportunities to do so arise, especially if the land is near an urban area or if transgenerational ownership forces a land sale to pay estate taxes. Unfortunately, anecdotal examples of the reverse process—assembling many small tracts into one larger tract—are rare.

CHAPTER 4. Biological Threats

INVASIVE PLANTS

Miller and others (2013) described the trends in invasive plants that are expected across the Southern United States. The survey data used to build these trends derived from measurements taken by the Forest Inventory and Analysis Program of the Forest Service; the limitations of those data for western Texas and western Oklahoma have been previously described. As a result, invasive species distribution and trends were described in detail for the Ozark-Ouachita Highlands section, but were not available for the Cross Timbers, High Plains, and West Texas Basin and Range sections.

This is not to say that invasive plants are less of an issue in central and western Oklahoma and Texas than they are in the rest of the South, because they are. Detailed sources of information about them are available from the Oklahoma Invasive Plant Council [http://ok-invasive-plant-council.org/index.html (Date accessed: November 4, 2013)] and Texas Invasives [http://www.texasinvasives.org (Date accessed: November 4, 2013)]. In light of the limitations of survey data, Miller and others (2013) focused on projecting the adverse effects that would occur in eastern Cross Timbers counties if invasive plants migrate westward from the Coastal Plain or the Ozark-Ouachita Highlands.

In preparing this report for the Mid-South, the authors cross-referenced the list of invasive plants that Miller and others (2013) deemed important in the South with the plants database of the U.S. Department of Agriculture Natural Resources Conservation Service (2012) and identified locations reported in the Cross Timbers, High Plains, and West Texas Basin and Range sections. The following are the species that emerged from the cross-referencing effort. For a more detailed description of these species, see Miller and others (2013).

Trees

Tallowtree—Tallowtree, Chinese tallow, or popcorntree (*Triadica sebifera*) is a small tree that forms scattered-to-pure stands in wet prairies, low and flat pastures and woodlands, recently disturbed sites, and other open areas that have moist soils. Planted in urban areas as an ornamental, its seeds are consumed and disseminated by birds. Already a major problem in western Coastal Plain areas that are adjacent to the Mid-South, tallowtree is established in nearly a dozen Texas counties bordering the eastern Texas piney woods in the Cross Timbers, and also occurs in two Texas counties—Nueces and Cameron—along the Gulf of Mexico (USDA Natural Resources Conservation Service 2012). Increases in both range and severity of tallowtree have been predicted with a warming climate; however, Miller and others (2013) concluded that its western limits in Texas appear to have been reached, although some encroachment southward along the Gulf of Mexico may be locally important.

Tree-of-heaven—Tree-of-heaven (*Ailanthus altissima*) occurs mostly along forest roads. From there, it can spread into recently harvested or disturbed sites, where it is exceptionally competitive with native species. It has a very distinctive and unpleasant odor when leaves are rubbed or when twigs and branches are cut. Seeds from this species are wind-disseminated, but the tree also spreads by root sprouts. Nevertheless, it is only of minor concern for the Mid-South (USDA Natural Resources Conservation Service 2012).

Chinaberrytree—Chinaberrytree (*Melia azedarach*) is a traditional widely escaped ornamental that was introduced from Asia in the early 1800s and is now the third most abundant invasive tree in the South (Miller and others 2013). It occurs in a dozen counties in the Ozark-Ouachita Highlands and in >20 counties across the Cross Timbers and High Plains, especially in south-central Texas (USDA Natural Resources Conservation Service 2012). Miller and others (2013) forecasted an additional 28 percent of occupation by 2060.

Mimosa—Mimosa or silktree (*Albizia julibrissin*) is a small tree imported into the South from central Asia. Widely planted as an ornamental across the South because of its pink or white flowers that bloom grandly through the growing season, mimosa reproduces by abundant seeds and root sprouts. It is widely distributed in the Ozark-Ouachita Highlands, but also occurs west of the Ozark-Ouachita Highlands in Oklahoma and in a dozen Texas counties in the Cross Timbers (USDA Natural Resources Conservation

Service 2012). Miller and others (2013) forecasted a 22-percent increase over the next 50 years under current climate.

Brazilian peppertree—Brazilian peppertree (*Schinus terebinthifolius*) is a subtropical species from South America, brought to the United States in the 1800s. It is a member of the Anacardiaceae family, along with cashew, poison ivy, and poison oak; some people experience allergic dermatitis similar to the effects of contact with poison ivy and poison oak. The berries of Brazilian peppertree are widely dispersed by birds and mammals; the tree can completely replace native vegetation with its tangled infestations (Miller and others 2013). It is well established in Florida, has been reported in three coastal counties in southern Texas (USDA Natural Resources Conservation Service 2012), and has the potential to seriously threaten other native ecosystems in the Mid-South.

Paulownia—Paulownia or princesstree (*Paulownia tomentosa*) is a native of China. It was brought to the United States via Europe as an ornamental in the mid-1800s, became naturalized in the South by the late 1800s (Miller and others 2013), and is still a popular ornamental. Producing abundant seed that is dispersed long distances by the wind, it can be found occasionally in upland hardwood stands of the Ozark-Ouachita Highlands. However it is not common farther west and is therefore only a minimal threat in the Mid-South.

Shrubs

Invasive privets—In the 19th century, at least eight species of invasive privet (*Ligustrum* spp.) were introduced as ornamentals from Asia and Europe; today it is the second most abundant invasive plant in the South (Miller and others 2013). Privets are most frequently found in bottomland forests, but have begun to appear in upland forests, fencerows, rights-of-way, and special habitats throughout the region. In the Mid-South, Chinese privet (*Ligustrum sinense*) is the most invasive, widely dispersed in the Ozark-Ouachita Highlands, but it also occurs west of the Ozark-Ouachita Highlands in Oklahoma and in more than a dozen counties in the Cross Timbers (USDA Natural Resources Conservation Service 2012).

Invasive roses—Multiflora rose (*Rosa multiflora*), Cherokee rose (*Rosa laevigata*), and especially Macartney rose (*Rosa bracteata*) are the most invasive of the nonnative rose species in the Mid-South, occurring along forest margins and stream banks and spreading into pastures, woodlands, and rangelands (Miller and others 2013). Multiflora rose is most common in the Ozark-Ouachita Highlands, but also occurs sporadically in northeastern and north-central Oklahoma, whereas the other species are of greater concern in the Cross Timbers and also have been found in the High Plains (USDA Natural Resources Conservation Service 2012).

Invasive lespedezas—Several species of nonnative nitrogen-fixing lespedezas (*Lespedeza* spp.) were introduced in the 19th century as food for wildlife, forage for grazing animals, and erosion control (Miller and others 2013). Chinese or sericea lespedeza (*Lespedeza cuneata*) is the most widely distributed; it has already spread westward into the Great Plains and is established in the Ozark-Ouachita Highlands and Cross Timbers (USDA Natural Resources Conservation Service 2012). Unlike most invasive plants, several native species (*Lespedeza capitata* and especially *Lespedeza virginica*) are as widely distributed as the Chinese lespedeza.

Saltcedars—Miller and others (2013) did not include the saltcedars (*Tamarisk* spp.) in their projections, but this Asian shrub includes several species that are well established in the West Texas Basin and Range section, in northern areas of the High Plains section, and in scattered areas of the southern High Plains and Cross Timbers sections (USDA Natural Resources Conservation Service 2012). A fire-adapted, drought-tolerant plant with a deep taproot, saltcedar colonizes riparian areas, displacing native species such as cottonwood and willow, and adversely affecting arid land hydrology and streamflow.

Nandina—Nandina (*Nandina domestica*), or sacred bamboo, was imported to the United States as an ornamental early in the 19th century and is still valued for suburban landscaping. By the 1960s, the species was recognized as a potential invasive in forests and woodlands (Radford and others 1964). It is still widely sold and cultured to yield new hybrids, some of which are seedless. However, older cultivars, whose seed can be bird-disseminated in the wildland-urban interface, probably have the highest potential for invasiveness.

Vines

Japanese honeysuckle—Miller and others (2013) described Japanese honeysuckle (*Lonicera japonica*) as "the most occupying forest invasive in the region," usually coexisting with both native and invasive plants but also capable of blocking the establishment of native plants in a wide range of forests over a wide range of sites. Brought to the United States in the 1800s, it quickly became a very popular plant for homestead beautification, soil stabilization, and wildlife food plots. It occurs in nearly every Arkansas county and is scattered throughout the Cross Timbers of Oklahoma and Texas.

Kudzu—Arguably the poster child for invasive plants, kudzu (*Pueraria montana)* conjures mental images from the Coastal Plain and Mississippi Delta of locations where the plant has completely covered forest openings, old sheds, telephone poles, and tree snags. A nitrogen-fixing woody vine, kudzu was originally brought to the United States from China with the (largely erroneous) expectation that it would control erosion and serve as forage for livestock. In the Mid-South, it occurs in most counties in the Ozark-Ouachita Highlands, but less extensively than in Coastal Plain sites, and is scattered in a few counties of the Cross Timbers (USDA Natural Resources Conservation Service 2012).

Invasive wisterias—Chinese (*Wisteria sinensis*) and Japanese wisterias (*Wisteria floribunda*) are woody vines often associated with old home sites that are now abandoned and reclaimed by forests. They are climbing, twining, and trailing woody vines. Like kudzu, they are nitrogen-fixing members of the legume family and can be found sporadically in the Ozark-Ouachita Highlands and the Cross Timbers (USDA Natural Resources Conservation Service 2012).

Japanese climbing fern—Japanese climbing fern (*Lygodium japonicum*) is rapidly becoming one of the most common invasive plants in Coastal Plain areas along the Gulf of Mexico. It is a climbing and twining, perennial fern that grows to 90 feet, often forming mats of shrub- and tree-covering infestations that erode plant diversity and that have no known value to wildlife. In addition to colonizing by rhizomes, Japanese climbing fern also spreads rapidly by wind-dispersed spores. It is predicted to occupy >500,000 acres of southern forests by 2060 (Miller and others 2013). Northward spread from the Coastal Plain is likely with warming trends.

Grasses

Tall fescue—Tall fescue (*Schedonorus phoenix*) is an important forage crop for cattle and sheep that can be an aggressive invasive in other situations. In addition to its value for forage, it is also an important species in managed landscapes for soil stabilization and reclamation of disturbed sites. The species tends to out-compete native grasses, forming extensive monocultures that are generally poor habitat for wildlife (Miller and others 2013). Tall fescue occurs in scattered counties across the eastern half of the Mid-South (USDA Natural Resources Conservation Service 2012).

Cogongrass—Cogongrass (*Imperata cylindrica*), a native of Japan introduced early in the 20th century, is among the most aggressive invasive grasses as well as the most difficult to control. Because cogongrass is considered to be one of the "world's worst 10 weeds" (Holm and others 1977), Federal- and State-funded control programs have been underway in all infested States; the strategy is to stop the spread by eradicating outliers and to treat the advancing fronts and selected epicenter infestations along the Gulf of Mexico (Miller and others 2013). Cogongrass is disseminated by windblown seed and by rhizomes, which can be transported in mud on logging equipment—thus diminishing prospects for long-term control. Cogongrass has been reported—and reported to have been eradicated—in Tyler County of southeastern Texas,[4] but vigilance by State forestry and highway employees in Texas, Oklahoma, and Arkansas will be needed to find and eradicate this highly aggressive species.

King's Ranch (KR) bluestem—Miller and others (2013) did not include KR Bluestem (*Bothriochloa ischaemum* var. *songarica*) in their analysis, but this Old World bluestem grass was once widely planted by ranchers for forage and by highway departments for erosion control. If not controlled, it disrupts native arid grassland ecosystems, crowds out native plants, and reduces native species diversity. It is now widely established across central and southern Texas, and is difficult to control (Gabbard and Fowler 2007).

Implications

This description of invasive species in the Mid-South builds on forest survey data (Miller and others 2013), and as such is best interpreted as limited to the invasives whose ranges are expected to expand into the Mid-South from Coastal Plain sites to the east. Several hundred other invasives, both nonnative and native, are expanding in the Cross Timbers, High Plains, and West Texas Basin and Range sections; although they are beyond the scope of this report, they could very well be far more important under the conditions that are likely to occur in the future: increased urban development, loss of forest and woodland area, and changing weather and climate. Fortunately, extension offices and agencies in Texas and Oklahoma have aggressive efforts underway to help landowners identify and manage invasive species.

Regardless of whether the species were reported by Miller and others (2013) or by Oklahoma and Texas agencies, invasive plants are an active threat that will require adaptive management and suppression across ownerships. Not all will have the same effect on stand development and regeneration dynamics of forest and woodlands. Active management to control these invasive species is the only proactive option in most situations. Failure to act would undoubtedly result in significant loss of plant species diversity and productivity over time.

[4] Billings, R.F. 2010. Hello cogongrass: goodbye Texas forests and grasslands! Texas Forestry. August: 8-10. http://texasinvasives.org/resources/publications/HelloCogongrass.pdf. [Date accessed: October 2, 2012].

INSECT AND DISEASE PESTS

Duerr and Mistretta (2013) described trends in insect infestations and diseases that are expected across the forests of the Southern United States. They observed that the number of significant pests has risen from 21 to 30 species over the past decade, and that some of the recently introduced pests have the potential to cause catastrophic losses. Existing insect and disease pests are likely to continue to affect southern forests at rates similar to historical activity, and there will certainly be previously undocumented pests to deal with in the future. However, scientific literature and expert opinion are not at all clear as to what to expect under a changing climate. Table 14 lists the 30 high priority pests in the South (Duerr and Mistretta 2013) and projects the likelihood of each becoming an issue in the four sections of the Mid-South.

Insect Pests of Softwoods

Southern pine beetle—The southern pine beetle (*Dendroctonus frontalis*) has the well deserved reputation of being the most damaging insect in southern pine forests. The fact that the Ouachita-Ozark Highlands section has not experienced an outbreak in more than a decade is historically unusual. Nevertheless, continued vigilance and periodic thinning treatments will be needed to ensure that the hazard remains low (Guldin 2011).

Secondary pine bark beetles—Unlike southern pine beetles, secondary bark beetles, especially the three species of engraver beetles—the six-spined engraver (*Ips calligraphus*), the southern pine engraver (*Ips grandicollis*), and the small southern pine engraver (*Ips avulsus*)—and the black turpentine beetle (*Dendroctonus terebrans*), have become more prominent in the past decade across the Ozark-Ouachita Highlands and the scattered pines of the Cross Timbers. Whether these patterns reflect normal activity associated with increasingly mature stands or an epidemiological response to changing climate is unclear, but the concern is that climate may be a factor. Again, vigilant observation is needed along with additional research to quantify the hazard and risk of bark beetle activity.

Nantucket pine tip moth—The Nantucket pine tip moth (*Rhyacionia frustrana*) and other species of pine reproduction weevils are primarily pests of planted pines, where they can reduce the return on landowner investments in timber production. As such, they could be a concern in shortleaf and loblolly pine plantation management in the Ozark-Ouachita Highlands. However, these pests are currently a larger problem elsewhere in the South, especially in plantations on the Coastal Plain.

Sirex wood wasp—As no major outbreak of Sirex wood wasp (*Sirex noctilio*) has yet occurred in North America, concern about this introduced pest in southern pines largely stems from the substantial impact it has had in North American pines that were planted in Australia, South Africa, and South America (Carnegie and others 2006). Because this perceived hazard is limited to areas stocked with pine, the only vulnerability in the Mid-South would be in forests dominated by native shortleaf and planted loblolly in the Ozark-Ouachita Highlands section, in pine stands scattered in the Cross Timbers section, and possibly in pinyon and ponderosa pine stands in the West Texas Basin and Range section.

Texas leafcutting ant—This species of ant (*Atta texana*) will continue to be an issue in the central Cross Timbers and northern High Plains—not so much as a threat to young pine plantations as it is in the Texas Coastal Plain, but rather as a threat to woodland and agricultural plants. It is constrained by a requirement for well-drained, deep sandy soils. The potential effects of changing climate are somewhat uncertain; a shorter dormant season might aggravate the damage it causes to hosts, but increased drought incidence might adversely affect its foraging activity. This species is likely to remain a local concern rather than a concern for the Mid-South as a whole.

Insect Pests of Hardwoods

In contrast to softwoods, the risk of damage from nonnative insect species is much higher in hardwoods, threatening not only forest and woodland hardwoods but also hardwoods in urban settings. Two introduced Asian species in particular, the Asian longhorned beetle (*Anoplophora glabripennis*) and the emerald ash borer (*Agrilus planipennis)*, have been very destructive in Northern States. Both are wood-boring insects whose larvae live under the bark, girdling the tree with their feeding activity.

Asian longhorned beetle—This wood borer, which has a wide range of hosts but prefers trees in the maple family, has been a serious pest especially for cities in the northern part of the continent. Although it extends its range slowly, the movement of infested firewood can accelerate its distribution. Control efforts include chipping and burning infested trees and enforcing quarantines against the movement of infested wood products. In all likelihood, the Mid-South will not experience wide damage from this pest in the next few decades.

Emerald ash borer—A tiny green jewel-like beetle, the emerald ash borer threatens all U.S. ash species regardless of their size and vigor. Estimates are that 50 million ash trees have already been lost in both urban and forested conditions.

Table 14—Insect and disease pests of importance across the southern region of the United States and the likelihood they will become an issue in each of the four sections of the Mid-South subregion

	Sections of the U.S. Mid-South			
Pest	Ozark-Ouachita Highlands	Cross Timbers	High Plains	West Texas Basin and Range
Insect pests of conifers				
Balsam woolly adelgid	–	–	–	–
Hemlock woolly adelgid	–	–	–	–
Nantucket pine tip moth	Y	–	–	–
Secondary bark beetles	Y	Y	Y	Y
Pine reproduction weevils	Y	–	–	–
Sirex woodwasp	Y	–	–	–
Southern pine beetle	Y	–	–	–
Texas leafcutting ant	–	Y	Y	–
Insect pests of hardwoods				
Asian longhorned beetle	Y	Y	Y	Y
Baldcypress leafroller	–	–	–	–
Emerald ash borer	Y	Y	Y	–
Forest tent caterpillar	Y	Y	Y	–
Gypsy moth	Y	Y	Y	–
Hardwood borers	Y	Y	–	–
Soapberry borer	Y	Y	Y	Y
Diseases of conifers				
Annosum root disease	–	–	–	–
Brown spot needle disease	–	–	–	–
Fusiform rust	–	–	–	–
Littleleaf disease	–	–	–	–
Loblolly pine decline	–	–	–	–
Diseases of hardwoods				
Beech bark disease	–	–	–	–
Butternut canker	Y	–	–	–
Chestnut blight	Y	–	–	–
Dogwood anthracnose	Y	Y	–	–
Dutch elm disease	Y	Y	Y	–
Laurel wilt	–	–	–	–
Oak decline	Y	Y	Y	–
Oak wilt	Y	Y	Y	–
Sudden oak death	Y	Y	Y	–
Thousand cankers disease	Y	Y	Y	Y

Y = the species is likely to become a threat for in the section; "–" indicates that the species is either not found or unlikely to be a threat in the section.

Source: Duerr and Mistretta (2013).

Given what is known about the biology of this species, the Mid-South will probably lose millions of ash trees over the next 50 years (Duerr and Mistretta 2013).

Soapberry borer—Similar to the emerald ash borer in appearance, the soapberry borer (*Agrilus prionurus*) is a Mexican import that has been the cause of widespread mortality of soapberry in the Cross Timbers and High Plains of Texas. Although soapberry borer has not been found outside Texas, this damaging insect has the potential to decimate soapberry trees throughout their natural range, which extends into the Missouri Ozarks and farther westward into Arizona.

Gypsy moth—The gypsy moth (*Lymantria dispar*), the notorious nonnative defoliator of oak-dominated forests in the Northeastern United States, is slowly advancing to the South. Although still centered in the North Central States, this voracious species could wreak havoc on the oak forests of the Ozark-Ouachita Highlands and on oak woodlands in Oklahoma and Texas. At its current rate of natural spread, it will probably require several decades to become established in the Mid-South. However, isolated long-distance dispersal events, such as transport of egg masses on firewood or recreational vehicles, have been known to occur; the response to any detected isolated infestations in the Mid-South would be to attempt eradication.

Native hardwood borers and tent caterpillar species—These species will continue to be locally important. Outbreaks are often controlled by the natural predators that have evolved with them over time, but populations occasionally expand to the point of substantial ecological and economic impact. This happened a decade ago in the Ozark-Ouachita Highlands, when populations of the native red oak borer (*Enaphalodes rufulus*) reached epidemic status, contributing to an oak decline complex that affected >340,000 acres. But just as quickly, red oak borer populations returned to their previous levels. Nevertheless, similar unexpected outbreaks could be expected to occur under changing climate.

Disease Pests

Duerr and Mistretta (2013) list several important diseases of southern softwoods, many of which are associated with intensive pine plantation management or are the result of choosing unfavorable sites or conditions for planting. The etiology of these diseases, combined with available host species and site conditions, would not be favorable for large outbreaks in the softwood forests of the Mid-South. In contrast, a number of hardwood diseases—most nonnative in origin, but not all—have the potential to become serious issues in the Mid-South.

Diseases of the walnut family—Butternut canker (*Sirococcus clavigignenti-juglandacearum*) is a stem canker fungus that is killing butternut (*Juglans cinerea*) trees throughout the Appalachians from Alabama to Virginia, and westward into Kentucky and Tennessee. Because butternut trees that are infected do not appear to have any genetic resistance to the disease, experts conclude that it is probably an introduced disease of unknown origin. Butternuts in the Ozark Mountains will certainly be a victim of this fungus.

A new pest complex called thousand cankers disease, which is caused by a fungus (*Geosmithia morbida*) and vectored from infected to healthy trees by the walnut twig beetle (*Pityophthorus juglandis*), has the potential to cause widespread mortality in several species of walnut, including the highly prized black walnut (*Juglans nigra*) found across the Eastern United States. Walnut species across the Mid-South may well be susceptible to this fungus.

Chestnut blight—Chestnut blight (*Cryphonectria parasitica*) virtually annihilated mature American chestnut (*Castanea dentata*) from eastern forests early in the 20th century. The only survivors are sprouts from rootstocks, which ultimately succumb at an early age. An ambitious restoration program that uses advanced genetics and breeding techniques is underway to restore the species in the field (Rhoads and others 2009), but widespread success is decades away. American chestnut is not native west of the Mississippi, but its close relative—Ozark chinkapin (*Castanea pumila*)—is scattered through the Ozark-Ouachita Highlands. Like chestnut, the chinkapin is susceptible to the blight, but persists through resprouting. Although this vegetative propagation could survive a changing climate, the prospects for long-term recovery of Ozark chinkapin in the Mid-South are bleak for the foreseeable future.

Dogwood anthracnose—A disease of flowering dogwood (*Cornus florida*) called dogwood anthracnose is caused by a nonnative fungus (*Discula destructiva*), and has inflicted substantial mortality in this small but highly valued tree species across the Appalachian Mountains. Flowering dogwood is also common in the Ozark-Ouachita Highlands and in the northern Cross Timbers. However, the current distribution maps for dogwood anthracnose suggest that the spread of the fungus may be limited by high temperatures, which means it will likely not be an important disease west of the Mississippi.

Dutch elm disease—The infamous Dutch elm disease, caused by two related species of fungi and vectored by one of two elm bark beetle species, can attack all elm species including two commonly found in the Mid-South, winged elm and cedar elm. But the disease is far less destructive in the Mid-South, especially in Oklahoma and Texas, than in forests farther northeast.

Laurel wilt—Red-bay (*Persea borbonia*) populations along the Gulf of Mexico in Texas are at considerable risk from a disease called laurel wilt, caused by an introduced fungus (*Raffaelea lauricola*) transmitted by an introduced ambrosia beetle (*Xyleborus glabratus*). This disease has decimated populations of red-bay across the Atlantic Coastal Plain and is headed west. Projections based on the current rate of spread are that the disease will reach Texas by 2040 if not sooner, and that the loss of the Texas red-bay populations along the coast is likely. The disease could also cause substantial mortality of sassafras (*Sassafras albidum*) throughout the Mid-South, although the impacts on sassafras populations are usually less severe than the impacts on red-bay.

Oak diseases—Finally, the oak forests of the Mid-South are at varying risk from three diseases. Two of these, oak decline and oak wilt, are currently active; and the third, sudden oak death, is currently only a potential threat, although it could eventually become quite destructive.

A significant problem in the Ozark-Ouachita Highlands over the past several decades, oak decline is a term that describes a variety of tree stressors that include drought, insect pests, poor site conditions, and declining vigor associated with old age. Decline is manifested as a gradual loss of the crown until the leaves that remain can no longer support the tree. If changing climate increases drought as predicted, oak decline events may become more pronounced.

Oak wilt, a vascular disease caused by a fungus (*Ceratocystis fagacearum*) similar to Dutch elm disease, occurs in 21 Eastern States. All oaks are susceptible to varying degrees; red oaks are most susceptible, white oaks least susceptible, and the susceptibility of live oak falls between red and white oaks. Infection causes trees to wilt and eventually succumb. The disease has become quite active in central Texas, and is likely to persist over time.

Finally, a rather ominous disease in oaks called sudden oak death, caused by a fungus (*Phytophthora ramorum*), is a canker disease that currently has a limited range in oaks on the West Coast. However, it could become quite severe if it becomes established in eastern forests.

Implications

Whether discussing insect or disease pests or their impacts on pines or hardwoods, the future is clouded with uncertainty. Scientists do not know how changing climate will affect insect and disease pests, or which pests will become scourges of forests and woodlands in 50 years. Current trends suggest that all of the ash species, soapberry, and red-bay could be lost, that the threat is considerable for walnut and butternut, and that oaks face decline, wilt, defoliators, and canker disease. The best advice for landowners and the professional foresters who advise them is to maintain healthy forests and woodlands full of vigorous trees and shrubs that are well adapted to the sites they occupy. But even those measures may not stop insect and disease pests, either those already known or those that have not yet been introduced.

CHAPTER 5.
Effects of Changes on Forests and their Values

FOREST CONDITIONS

This report summarizes forest survey data for the counties included in each of the sections in the Mid-South (Ridley 2012). Although data from Arkansas were prepared using inventory year 2011 (field data collected from 2007 to 2011), and data from Oklahoma and Texas were prepared using inventory year 2010 (field data collected from 2008 to 2010), all are lumped together and identified as 2011.

Ozark-Ouachita Highlands

Forests cover slightly >14.92 million acres (61.2 percent) of the Ozark-Ouachita Highlands in Arkansas and Oklahoma. Of that, 96 percent is considered productive forest land (producing or capable of producing at least 20 cubic feet of commercial-grade wood per acre per year) and the balance is classified as unproductive woodland.

The average acre in the Ozark-Ouachita Highlands has a density of 568 trees per acre (24 percent of which are >5 inches d.b.h.) and basal area of 86 square feet per acre (81 percent of which is in trees >5 inches d.b.h.). Stands are relatively mature: 50.8 percent of forest land area supports large-diameter trees, 32.1 percent supports medium-diameter trees, 16.6 percent supports small-diameter trees, and 0.4 percent is unstocked. The average stand has a volume of 1,299 cubic feet per acre, average annual growth of 28.1 cubic feet per acre, aboveground biomass (dry weight) of 37.1 tons per acre, and aboveground weight of carbon of 18.6 tons per acre. Pine-dominated forest types occur on 21.8 percent of forest land; of those, 38.2 percent are plantation stands, which reflects the past importance of the timber industry and of intensive forest practices in the Ozark-Ouachita Highlands. Because of its favorable climate, this section supports the most productive sites of the four Mid-South sections; 57.0 percent of its forest land area is capable of growing >50 cubic feet per acre annually, and 95.7 percent is capable of growing >20 cubic feet per acre annually.

Cross Timbers

Forests cover 16.75 million acres (27.3 percent) of the Cross Timbers land area in Oklahoma and Texas. Of that, 40.9 percent is considered productive forest land (producing >20 cubic feet of commercial-grade wood per acre annually), and the balance is classified as unproductive or nonforest but would probably be more accurately classified as woodland.

The average acre in the Cross Timbers has density of 389 trees per acre (25 percent of which are >5 inches d.b.h.) and basal area of 61.6 square feet per acre (81 percent of which are in trees >5 inches d.b.h.). Forest land area is fairly equally divided by tree size: 37.2 percent supports large-diameter trees, 32.0 percent supports medium-diameter trees, 27.5 percent of supports small-diameter trees, and 3.3 percent is unstocked. The average stand has a volume of 691 cubic feet per acre, average annual growth of 4.6 cubic feet per acre, aboveground biomass (dry weight) of 20.45 tons per acre, and aboveground weight of carbon of 10.2 tons per acre. Pine-dominated forest types are found on only 9 percent of forest land in the section; of those, only 5.8 percent are planted, suggesting that active timber management is not common or productive in the Cross Timbers. Only 16.9 percent of the forest land area is capable of growing >50 cubic feet per acre annually, whereas 73.0 percent is classified as unproductive, growing <20 cubic feet per acre.

High Plains

Forests and woodlands cover slightly >34.5 million acres, almost exactly a third of the land area, of the High Plains section in Oklahoma and Texas. Of that, >99 percent is classified as unproductive as commercial timberland, growing <20 cubic feet of commercial-grade wood per acre annually.

The average acre of forest land in the High Plains has density of 239 trees per acre (27.3 percent of which are >5 inches d.b.h.) and basal area of 37.3 square feet per acre (81 percent of which are in trees >5 inches d.b.h.). Less than a third (31.3 percent) of forest land area is in large-diameter trees, 21.0 percent is in medium-diameter trees, 40.1 percent is in small-diameter trees, and 7.2 percent of forest land area is unstocked. The average stand has volume of 256 cubic feet per acre, aboveground biomass (dry weight) of 7.6 tons per acre, and aboveground weight of carbon of 3.8 tons per acre. Nearly a fifth (19.7 percent) of forest land is dominated by pines, all of natural origin in the pinyon-juniper forest type.

Less than 1 percent of the forest land area in the High Plains is capable of growing >20 cubic feet per acre annually; 99.2 percent is classified as unproductive (growing <20 cubic feet per acre annually).

West Texas Basin and Range

Forest land covers slightly >7.92 million acres, or slightly <30 percent, of the land area in the West Texas Basin and Range section. Of that, <1 percent is considered productive forest land (capable of producing >20 cubic feet of commercial-grade wood per acre annually); the remaining 99 percent is classified as unproductive.

The average acre of forest land in the West Texas Basin and Range section has density of 151 trees per acre (23.8 percent of which are >5 inches d.b.h.) and basal area of 18.1 square feet per acre (74.4 percent of which are in trees >5 inches d.b.h.). About an eighth (12.3 percent) of forest land area is in large-diameter trees, 14.9 percent is in medium-diameter trees, 66.3 percent is in small-diameter trees, and 6.5 percent of forest land area is unstocked. The average stand has volume of 69.4 cubic feet per acre, aboveground biomass (dry weight) of 2.1 tons per acre, and aboveground weight of carbon of slightly >1 ton per acre. Nearly a third (31.8 percent) of forest land in the section is dominated by pines, all of natural origin in the pinyon-juniper forest type. Only 0.1 percent of the forest land area in the West Texas Basin and Range is capable of growing >20 cubic feet per acre annually; 99.9 percent is classified as unproductive (growing <20 cubic feet per acre annually).

WILDLIFE AND FOREST COMMUNITIES

Trani Griep and Collins (2013) described the wildlife species and forest communities that inhabit or occupy the 13 States included in the Southern Forest Futures Project. The major species groups that Trani Griep and Collins (2013) analyzed were birds, mammals, reptiles, amphibians, and vascular plants. Their analysis included species that are native to the Mid-South, either living in forests or in other habitats, with species locations queried and tallied at the county level from the NatureServe (2011) database.

The Mid-South featured prominently because of its size and the diversity of its landscapes, which stretch from the Ozarks to the Guadalupes, and because it figures prominently in the analyses of three key issues.

First, the Mid-South is an unusually diverse landscape, supporting 115 ecosystems (NatureServe 2010). It also supports 856 native terrestrial vertebrate species (NatureServe 2011)—more than anywhere else in the South (fig. 9). This richness stems from the confluence of species distributions, with many species that are centered in eastern forests, western rangelands and woodlands, or the Mexican deserts extending their ranges into the Mid-South. Added to this mix of species is the influence of the centers of native species diversity in the Big Bend National Park and in the counties along the Gulf of Mexico.

Secondly, the key stressors of wildlife populations and their associated habitats will likely be urban development, forest and woodland loss, and climate change. Management will not likely be effective in changing these stressors, but will likely invest in considerable effort to respond to them.

Finally, species vary in their response to stressors, and those most at risk will likely be those with small geographic ranges, patchy distributions, more demanding resource needs, more specialized requirements for reproduction (such as limited seed production or dispersal capabilities), marginal physiological tolerance for the conditions they occupy, and low genetic diversity.

Current Trends

Mammals—Trani Griep and Collins (2013) reported that terrestrial, marine, and freshwater habitats in the Mid-South are home to 148 mammal species (fig. 10), with diversity highest for rodents (68 species), bats (38 species), and carnivores (22 species). Especially important for providing habitat are the High Plains section with 105 species and the West Texas Basin and Range section with 88 species. Together, the four Mid-South sections support a high level of richness for rodents ranging from 57 species in the High Plains to 27 species in the Ozark-Ouachita Highlands (table 15). Bat richness is highest in the High Plains (25 species) and West Texas Basin and Range sections (24 species). Carnivore richness is highest in the High Plains and Cross Timbers; unique carnivores in these two sections include the ocelot (*Leopardus pardalis*), western spotted skunk (*Spilogale gracilis*), and white-nosed coati (*Nasua narica*).

Birds—The Mid-South supports 469 bird species, including 241 species of perching birds and 28 species of raptors (Trani Griep and Collins 2013). This impressive diversity is due to its size, to the heterogeneity of its habitats, and especially to the wetlands and coastlines along the Gulf of Mexico (fig. 11). The pattern across the southernmost portions of eastern Texas includes species typical of Latin America (Stein and others 2000), and diversity is further increased by numerous southwestern species that range eastward into the West Texas Basin and Range section. Of particular prominence is the Southern Gulf, which encompasses the portions of the Cross Timbers and High Plains that form the Texas eastern coastline. Each of these two sections supports habitat for >360 species of birds, including more than 35 species of shorebirds and more than 30 species of waterfowl (table 15).

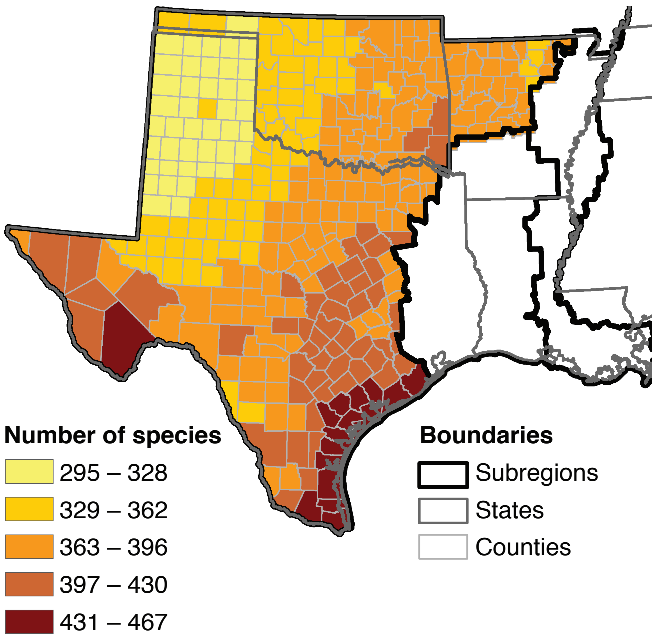

Figure 9—County-level counts of native terrestrial vertebrate species in the U.S. Mid-South (Source: NatureServe 2011).

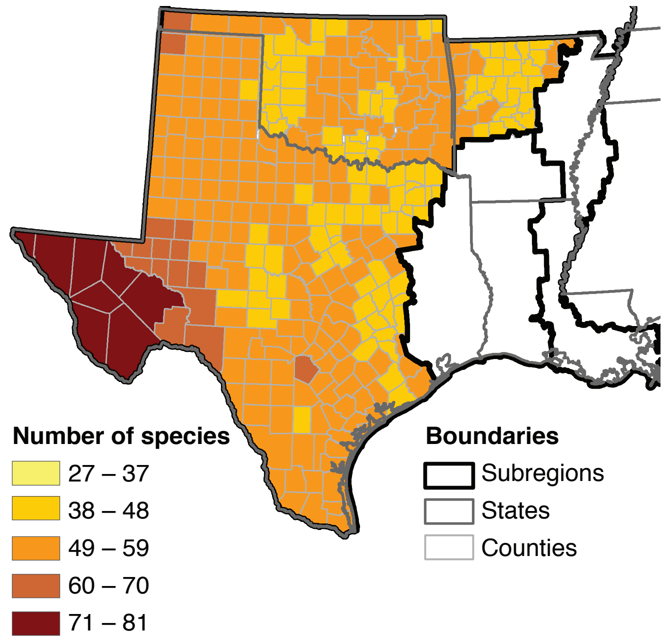

Figure 10—County-level counts of all native mammal species in the U.S. Mid-South (Source: NatureServe 2011).

Table 15—Number of vertebrate species in the four sections of the U.S. Mid-South

	Sections of the U.S. Mid-South			
Species	**Ozark-Ouachita Highlands**	**Cross Timbers**	**High Plains**	**West Texas Basin and Range**
Mammals				
Bats	16	16	25	24
Carnivores	12	17	20	14
Other mammals	14	18	16	15
Rodents	27	41	57	46
Birds				
Other birds	49	86	92	66
Perching birds	143	184	208	171
Raptors	15	21	28	21
Shorebirds	20	37	38	22
Wading birds	12	17	17	10
Waterfowl	25	34	31	25
Reptiles				
Crocodilians[a]	1	0	0	0
Lizards	13	25	38	35
Snakes	38	58	64	43
Turtles	17	24	21	10
Amphibians				
Frogs and toads	29	38	37	19
Salamanders	29	26	18	4

[a] Although NatureServe does not report crocodilians in the Texas Cross Timbers and High Plains, which for purposes of this report includes the Texas counties on the Gulf of Mexico, Elsey and Aldrich (2009) and others have reported that the American alligator (*Alligator mississippiensis*) has been documented in Texas.

Source: NatureServe (2011).

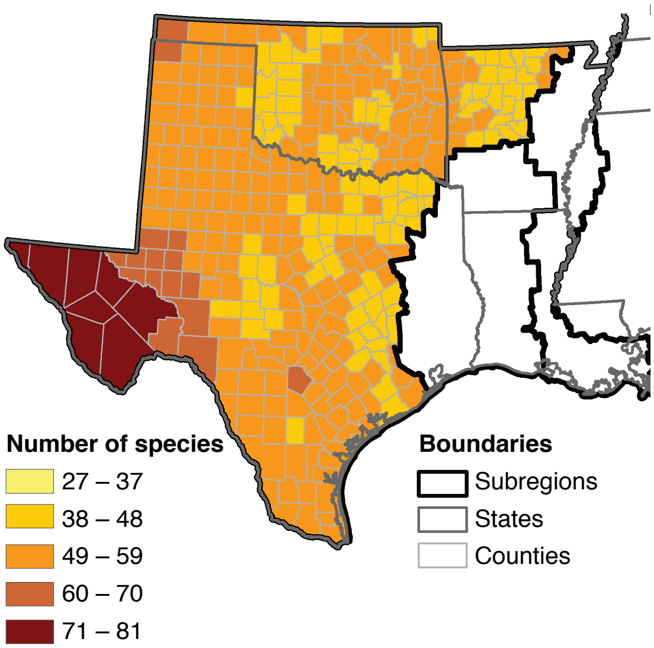

Figure 11—County-level counts of all native bird species in the U.S. Mid-South (Source: NatureServe 2011).

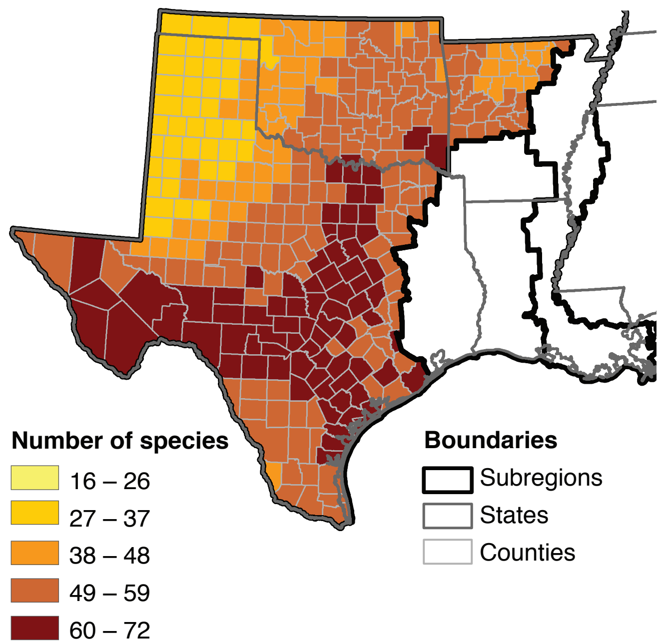

Figure 12—County-level counts of all native reptile species in the U.S. Mid-South (Source: NatureServe 2011).

Reptiles—The Mid-South supports 148 species of reptiles, including 74 species of snakes and 45 species of lizards (Trani Griep and Collins 2013). This diversity reflects its profoundly different habitats from east to west (fig. 12), as well as its location at the crossroads of several distinct reptilian species (Stein and others 2000). Snake and lizard richness is highest in the three western sections of the Mid-South (table 15), reflecting the availability of arid habitats. Similarly, two sections support ≥20 turtle species—the Cross Timbers with 24 and the High Plains with 21. The American alligator (*Alligator mississippiensis*) occurs only rarely in the Ozark-Ouachita Highlands and mostly along its borders—the upper western Coastal Plain to the south and the Mississippi Delta to the east. Although NatureServe (2011) does not list the alligators in either the Cross Timbers or High Plains, they have been documented along the Gulf of Mexico in southern Texas (Elsey and Aldrich 2009).

Amphibians—The Mid-South supports 91 species of amphibians (fig. 13), including 46 species of frogs and toads and 45 species of salamanders (Trani Griep and Collins 2013). The Cross Timbers (38 species) and High Plains (37 species) each supports >35 species of frogs and toads, the Ozark-Ouachita Highlands section supports 29 salamander species, and the Cross Timbers section supports 26 salamander species (table 15). In the Ozark-Ouachita Highlands, a handful of the woodland salamander species are very locally distributed on north-facing moderately moist hillsides; they sometimes occur within 75 miles of one another and yet have different species names based on the mountain that they occupy—such as the Caddo Mountain salamander (*Plethodon caddoensis*), the Rich Mountain salamander (*Plethodon ouachitae*), the Fourche Mountain salamander (*Plethodon fourchensis*), and the Kiamichi Mountain salamander (*Plethodon kiamichi*).

Effects on Wildlife from Forecasts of Urban Growth, Forest Loss, and Climate Change

Among the possible futures outlined in Wear and Greis (2013), Trani Griep and Collins (2013) emphasized the effects that would occur under Cornerstone B, which predicts the biggest loss of forest acreage and the highest level of urban growth. In the Mid-South, the two areas of concern are the Ozark-Ouachita Highlands and a swath of land from south-central Texas eastward to the Gulf of Mexico.

Forest loss and urban growth in the Ozark-Ouachita Highlands threaten concentrations of plant and animal species along the southern border of the section and in the northwestern corner of Arkansas. Around Hot Springs and Little Rock, AR, urban areas are expected to grow 10 to 20 percent, with a corresponding loss of forest area. Although this area is somewhat protected by its proximity to the Hot Springs National Park and the Ouachita National Forest, adverse effects are likely to be concentrated on private lands that are under development in the wildland-urban interface. Plant species at risk, especially on private lands, include Kentucky lady's slipper (*Cypripedium kentuckiense*) reported by Case and others (1998), the clasping twistflower (*Streptanthus maculatus*), and least trillium (*Trillium pusillum)* reported by Timmerman-Erskine and others (2003).

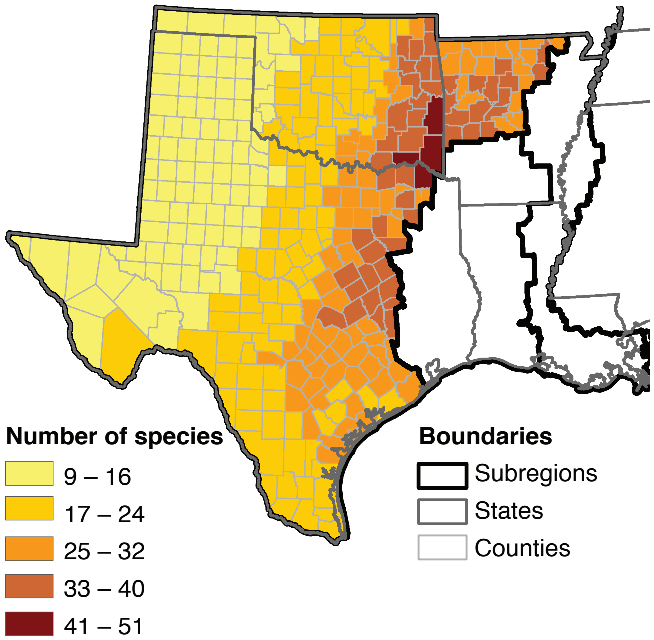

Figure 13—County-level counts of all native amphibian species in the U.S. Mid-South (Source: NatureServe 2011).

Trani Griep and Collins (2013) reported that similar rates of urban growth and associated loss of forest cover could affect species such as the Ozark big-eared bat (*Corynorhinus townsendii ingens*) and Oklahoma salamander (*Eurycea tynerensis*) in the northwestern part of the section.

Similarly, urban development from south-central Texas to the Gulf of Mexico could impact many reptiles and birds (Trani Griep and Collins 2013). Urban growth and associated loss of woodlands in southern Texas between Houston and San Antonio could impact a number of reptiles such as Cagle's map turtle (*Graptemys caglei)* and other turtles. This area also lies on the Central Flyway, a band of especially high avian richness that occurs along the Gulf of Mexico in Texas. Finally, if sea levels rise as predicted, coastal birds and other species whose ranges are limited to coastal areas would be vulnerable.

Species at Risk

The Mid-South supports 28 federally listed (as endangered or threatened) species and subspecies of vertebrates (table 16), with most occurring in the High Plains and Cross Timbers and fewer occurring in the Ozark-Ouachita Highlands and the highly diverse Big Bend area of the West Texas Basin and Range section. Four species of amphibians are federally listed including three salamanders, each of which has a highly restricted geographic range and requires moist habitats that would be adversely affected by drought conditions and urban development. Of the 12 listed bird species, 10—including the Eskimo curlew (*Numenius borealis*) (Oberholser 1974) and Bachman's warbler (*Vermivora bachmanii*), both of which may well be extinct—are endangered. Nine of these bird species are found in the High Plains, and 10 are found in the Cross Timbers, especially in the coastal prairies near the Gulf of Mexico. Moreover, the entire breeding range of the endangered golden-cheeked warbler (*Dendroica chrysoparia*) lies within Mid-South landscapes of Texas. Eight species of mammals are federally listed, four bats and four carnivores, but two of the carnivores—the mountain lion (*Puma concolor*) and American black bear (*Ursus americanus*)—are only listed because they are similar in appearance to the endangered Gulf Coast jaguarundi (*Puma yagouaroundi cacomitli*) and the Louisiana black bear (*Ursus americanus luteolus*) of the Mississippi Deltaic Plain. Three of the listed bat species are in the Ozark-Ouachita Highlands, and one—the Mexican long-nosed bat (*Leptonycteris nivalis*)—migrates from Mexico to the West Texas Basin and Range section, where populations tend to congregate in the Big Bend National Park. Finally, four reptiles are federally listed (table 16); they include two sea turtles and a water snake whose habitat is restricted to the Concho River.

In addition, 29 species of plants are federally listed as endangered or threatened (table 17). Eight are cacti; seven occur in the West Texas Basin and Range section, four of which primarily or only occur in the Big Bend National Park in Brewster County: Nellie's cory cactus (*Escobaria minima*), Davis' green pitaya cactus (*Echinocereus viridiflorus* var. *davisii*), Chisos Mountains hedgehog cactus (*Echinocereus chisoensis* var. *chisoensis*), and Lloyd's Mariposa cactus (*Sclerocactus mariposensis*). Whether the natural range of the Pima pineapple cactus (*Coryphantha scheeri* var. *robustispina*) in Arizona actually extends into El Paso County (Poole and others 2007) is unclear.

Federally listed herb species (table 17) are scattered across all four sections of the Mid-South. A few—such as the western prairie white-fringed orchid (*Platanthera praeclara*), which at one time was reported in northeastern Oklahoma—may already be extirpated. Finally, the four endangered trees and shrubs of the Mid-South all occur along the Rio Grande River from the Big Bend National Park to Brownsville.

Implications

The major reasons for concern about the ability to maintain existing populations and distributions of plant and animal species in the Mid-South are habitat loss, urban development, and the likelihood of changing climate. For species with limited geographic ranges or those that have specific and narrow habitat requirements that may or may not be known, monitoring will be important to quantify changes in their status, especially if they are federally listed.

Table 16—The terrestrial vertebrate species that are federally listed as threatened or endangered in the four sections of the U.S. Mid-South

		Sections of the U.S. Mid-South[a]			
Species name	Status	Ozark-Ouachita Highlands	Cross Timbers	High Plains	West Texas Basin and Range
Frogs and toads					
Houston toad (*Bufo houstonensis*)	**E**	–	X	–	–
Salamanders					
San Marcos salamander (*Eurycea nana*)	**T**	–	–	X	–
Texas blind salamander (*Eurycea rathbuni*)	**E**	–	–	X	–
Barton Springs salamander (*Eurycea sosorum*)	**E**	–	–	X	–
Wading birds					
Whooping crane (*Grus americana*)	**E**	–	X	X	–
Raptors					
Northern Aplomado falcon (*Falco femoralis septentrionalis*)	**E**	–	–	X	–
Shorebirds					
Piping plover (*Charadrius melodus*)	**T**	–	X	X	–
Eskimo curlew[b] (*Numenius borealis*)	**E**	–	X	X	X
Perching birds					
Golden-cheeked warbler (*Dendroica chrysoparia*)	**E**	–	X	X	–
Bachman's warbler (*Vermivora bachmanii*)	**E**	–	X	–	–
Black-capped vireo (*Vireo atricapilla*)	**E**	–	X	X	X
Other birds					
Red-cockaded woodpecker (*Picoides borealis*)	**E**	X	X	–	–
Least tern (*Sternula antillarum*)	**E**	X	X	X	–
Interior least tern (*Sternula antillarum athalassos*)	**E**	X	X	X	–
Mexican spotted owl (*Strix occidentalis lucida*)	**T**	–	–	X	–
Attwater's greater prairie chicken (*Tympanuchus cupido attwateri*)	**E**	X	X	–	–
Bats					
Ozark big-eared bat (*Corynorhinus townsendii ingens*)	**E**	X	–	–	–
Mexican long-nosed bat (*Leptonycteris nivalis*)	**E**	–	–	X	–
Indiana bat (*Myotis sodalis*)	**E**	X	–	–	–
Gray bat (*Myotis grisescens*)	**E**	X	–	–	–
Carnivores					
Ocelot (*Leopardus pardalis*)	**E**	–	–	X	–
Mountain lion (*Puma concolor*[c])	**S**[d]	–	X	X	X
Gulf Coast jaguarundi (*Puma yagouaroundi cacomitli*)	**E**	–	X	X	–
American black bear (*Ursus americanus*)	**S**[d]	X	X	X	X
Reptiles					
American alligator (*Alligator mississippiensis*)	**S**[d]	X	–	–	–
Concho watersnake (*Nerodia paucimaculata*)	**T**	–	X	X	–
Loggerhead (*Caretta caretta*)	**T**	–	X	X	–
Kemp's Ridley sea turtle (*Lepidochelys kempii*)	**E**	–	–	X	–

[a] An X indicates that the species is found in the Mid-South section; an "–" indicates that the species is not found in that section.

[b] Oberholser (1974) reported that Eskimo curlew is a spring migrant through most of Texas, but has been on the verge of extinction since 1905. Five records document its persistence: two for the Cross Timbers (Cooke County and Nueces County), two for the High Plains (Kendall County and Cameron County), and one for West Texas Basin and Range (Pecos County).

[c] All except *coryi.*

[d] Listed as endangered or threatened because of similarity of appearance.

Status: **E** = Endangered, **T** = Threatened, and **S** = Similar.

Source: U.S. Department of the Interior, Fish and Wildlife Service (2011).

Table 17—The vascular plant species that are federally listed as threatened or endangered in the four sections of the U.S. Mid-South

		Sections of the U.S. Mid-South			
Species name and range	**Status**	**Ozark-Ouachita Highlands**	**Cross Timbers**	**High Plains**	**West Texas Basin and Range**
Graminoids					
Texas wild wice (*Zizania texana*)	**E**	–	–	X	–
Cacti					
Star cactus (*Astrophytum asterias*)	**E**	–	–	X	–
Pima pineapple cactus (*Coryphantha scheeri* var. *robustispina*)	**E**	–	–	–	X
Chisos Mountains hedgehog cactus (*Echinocereus chisoensis* var. *chisoensis*)	**T**	–	X	X	X
Davis' green pitaya cactus (*Echinocereus viridiflorus* var. *davisii*)	**E**	–	–	–	X
Nellie's cory cactus (*Escobaria minima*)	**E**	–	–	–	X
Sneed pincushion cactus (*Escobaria sneedii* var. *sneedii*)	**E**	–	–	–	X
Shorthook fishhook cactus (*Sclerocactus brevihamatus* ssp. *Tobuschii*)	**E**	–	–	X	X
Lloyd's Mariposa cactus (*Sclerocactus mariposensis*)	**T**	–	–	–	X
Herbs					
Large-fruit sand-verbena (*Abronia macrocarpa*)	**E**	–	X	–	–
South Texas ragweed (*Ambrosia cheiranthifolia*)	**E**	–	X	–	–
Texas poppy-mallow (*Callirhoe scabriuscula*)	**E**	–	–	X	–
Terlingua Creek cat's-eye (*Cryptantha crassipes*)	**E**	–	–	–	X
Tiny Tim (*Geocarpon minimum*)	**T**	X	–	–	–
Pecos sunflower (*Helianthus paradoxus*)	**T**	–	–	–	X
Slender rushpea (*Hoffmannseggia tenella*)	**E**	–	X	–	–
Prairie dawn (*Hymenoxys texana*)	**E**	–	X	–	–
Missouri bladderpod (*Lesquerella filiformis*)	**T**	X	–	–	–
Zapata bladderpod (*Lesquerella thamnophila*)	**E**	–	–	X	–
Walker's manihot (*Manihot walkerae*)	**E**	–	–	X	–
Western prairie white-fringed orchid (*Platanthera praeclara*)	**T**	–	X	–	–
Little aguja pondweed (*Potamogeton clystocarpus*)	**E**	–	–	–	X
Harperella (*Ptilimnium nodosum*)	**E**	X	–	–	–
Navasota ladies'-tresses (*Spiranthes parksii*)	**E**	–	X	–	–
Ashy dogweed (*Thymophylla tephroleuca*)	**E**	–	–	X	–
Trees/shrubs					
Texas ayenia (*Ayenia limitaris*)	**E**	–	–	X	–
Johnston's frankenia (*Frankenia johnstonii*)	**E**	–	–	X	–
Hinckley's oak (*Quercus hinckleyi*)	**T**	–	–	–	X
Texas snowbell (*Styrax platanifolius* ssp. *Texanus*)	**E**	–	–	X	X

X = the species is found in the section; an "–" indicates that the species is not found in that section.

Status: **E** = Endangered and **T** = Threatened.

Sources: Federal listings by the U.S. Department of the Interior, Fish and Wildlife Service (2011); location data from NatureServe (2011); species names follow the USDA Natural Resources Conservation Service PLANTS database (2012).

Within a larger context, the vulnerability of each of these plant and animal species will vary in response to habitat loss, urban development, and changing climate. Ensuring their survival will require that government agencies take these factors into account when developing future conservation and management activities.

WATER RESOURCES

Lockaby and others (2013) described water trends that are expected across the Southern United States over the next decades. Changing patterns of precipitation in the Mid-South will likely result in more water supply in some areas and less in others. However, expected increases in temperature would result in more evapotranspiration, which in turn would cause lower streamflow and decreased water supply, degraded aquatic communities, and diminished water quality. Extreme rainfall events increase the severity and frequency of flooding, negatively affecting both human safety and welfare and the functioning of aquatic communities. And without doubt, more people will use more water, and the larger urban areas in which they live will adversely affect downstream water quantity and quality.

The key findings pertinent to the Mid-South are the adverse effects on water yield and water quality from conversion to urban uses, a marked increase in water stress, and the threats associated with predicted sea level rise.

Water Quantity and Quality

Variation in annual precipitation within a single year or from one year to the next is a natural phenomenon controlled by large-scale global climate patterns such as the Pacific Decadal Oscillation cycle. Prevailing precipitation patterns can be predicted under the four Cornerstone Futures with some variations across the Mid-South, but the timing and spatial distribution of extreme events on an annual basis are difficult to predict. Despite this uncertainty, recent experience with droughts and low flows in many areas of the United States suggests that even small changes in drought severity and frequency will have major societal impacts, among them a reduction in drinking water supplies (Easterling and others 2000, Luce and Holden 2009).

Another major water issue will likely be associated with increasing population densities in the Cross Timbers and the High Plains, given the ongoing expansion of urban areas into the wildland-urban interface in these sections. Generally, forest or woodland conversion to agriculture or urban use leads to increased variability of streamflow and increased discharge, peak flow, and velocity of streams; in addition, sediment, water chemistry indices, pathogens, and other substances often become more concentrated. These effects, in combination with climate variability, can result in a decreased supply of water that is available for human consumption, degraded stream habitats, poor water quality, and increased threats to human health through vectors such as mosquitoes, which transmit West Nile virus and other human diseases (Lockaby and others 2013).

Whether adverse hydrological effects, such as higher peak flows and lower baseflows and hydroperiods that are predicted for systems farther east (Amatya and others 2006), will occur in the Mid-South is unknown. For example, Cuffney and others (2010) reported that the conversion of forests to urban uses had adverse effects on benthic macroinvertebrates in several southern cities, but that those effects were not as severe after similar conversions near Dallas, TX, where stream ecosystems on former grasslands had already been degraded through recent conversions.

Despite these confounding effects, a watershed that is downstream from an urban area in the Mid-South will provide a different habitat and support a different composition of aquatic (and riparian) communities from similar watersheds in undeveloped areas (Lockaby and others 2013). A key element of this is attributable to impervious cover such as buildings, parking lots, and roads. For example, in Houston just to the east of the Cross Timbers in southeastern Texas, impervious surfaces were responsible for about 20 percent of the increase in peak flows, and slightly more than half of the increase in annual runoff since the 1970s (Olivera and DeFee 2007). Similarly, in Dallas, varying precipitation intensities increased peak flows in the White Rock Creek watershed by 20 to 118 percent—the result of increased impervious cover (Vicars-Groening and Williams 2007). Stream hydrographs of urban watersheds have revealed a flashy hydrology with larger pulses and faster attainment of peak flows during storm events (Beighley and others 2003, Boggs and Sun 2011, Calhoun and others 2003, Crim 2007, Schoonover and others 2006). However, arid areas have precipitation regimes that produce a naturally flashy hydrology, so the effects of urban development may not be as dramatic in the Cross Timbers, High Plains, and West Texas Basin and Range sections as they are in moister environments (Grimm and others 2004).

Water Supply Stress

Lockaby and others (2013) also prepared forecasts of water supply stress, calculated using a water supply stress index (WaSSI) accounting model analysis (Sun and others 2008). This index examines future changes in water stress induced by humans, biological factors, and climate. It is defined as water demand divided by water supply, both of which have been quantified under different climate conditions and historical data.

On average, water supply model projections for the South predict that water stress resulting from population and land use change will increase 10 percent by 2050. However effects are forecasted to be more severe in the Mid-South under all of the four Cornerstone Futures. Average baseline water stress (1995 to 2005) in the South is low (WaSSI = 0.16) but high in southern and western Texas (WaSSI >0.90) because of naturally low precipitation and high evapotranspiration (fig. 14). In the absence of changing climate, water stress is expected to increase 10 to 100 percent across the Cross Timbers especially and in parts of southwestern Texas (fig. 15). The highest levels of water stress would occur during the growing season when ecosystem water use and human water withdrawal for uses such as irrigation, domestic purposes, and generation of electricity are the highest.

When projected climate change is added to population and land use changes, forecasts become more drastic. Water stress would increase dramatically relative to historical levels across the Mid-South by 2050 (fig. 16), especially under Cornerstones A and D. For example, the water supply stress model predicts that each of the capital cities in the Mid-South—Oklahoma City, Little Rock, and Austin—will experience significant increases in water stress (fig. 16). These changes could shift the timing of peak water supply stress from late summer to early autumn, with effects that would extend across the landscape on natural systems, agricultural land, rangelands, woodlands, urban areas, and ultimately, the people in the region.

Sea Level Rise

About 5,000 miles of southern coastline are highly vulnerable to sea level rise. Climate-induced changes in sea level would have significant and direct effects on ecosystem processes in forested wetlands (Amatya and others 2006), and potentially devastating impacts on human welfare in urban and rural areas. Sea levels could rise from 0.4 to 2.0 m by the end of the 21st century (Rahmstorf 2007, Soloman and others 2009). Along the Gulf of Mexico, about 13,605 square miles (about 8.7 million acres) of land are at an elevation of <1.5 m (Louisiana and Texas have the most coastal area <1.5 m), with an additional 6,430 square miles (about 4.1 million acres) of coastal land between 1.5 and 3.5 m (Hammar-Klose and Thieler 2001, Titus and Richman 2001). This would affect all elements of coastal ecosystem ecology, management, and development, varying from the loss or shrinkage of national seashores and wildlife refuges to reductions and erosion of highly valuable developed coastal properties.

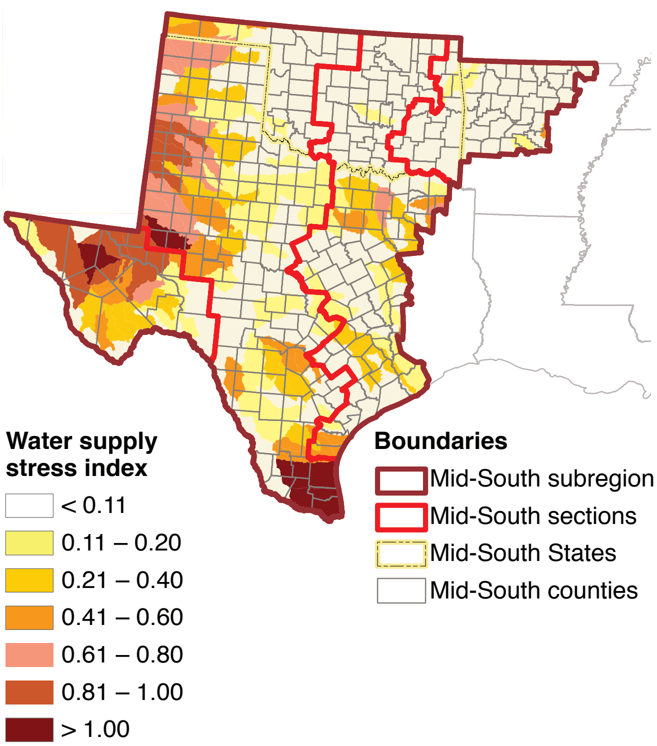

Figure 14—Water supply stress index (defined by the Water Supply Stress Index (WaSSI) and calculated by dividing water supply into water demand) in the U.S. Mid-South under baseline, 1995 to 2005, conditions (Source: Lockaby and others 2013).

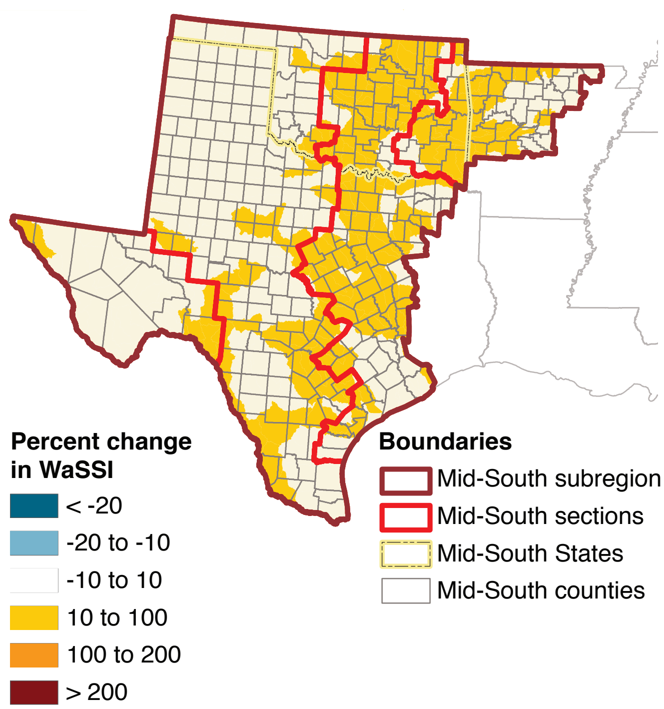

Figure 15—Predicted change in water supply stress (defined by the Water Supply Stress Index (WaSSI) and calculated by dividing water supply into water demand) by 2050 in the U.S. Mid-South under the combined effects of population growth and a shift of land to urban uses (Source: Lockaby and others 2013).

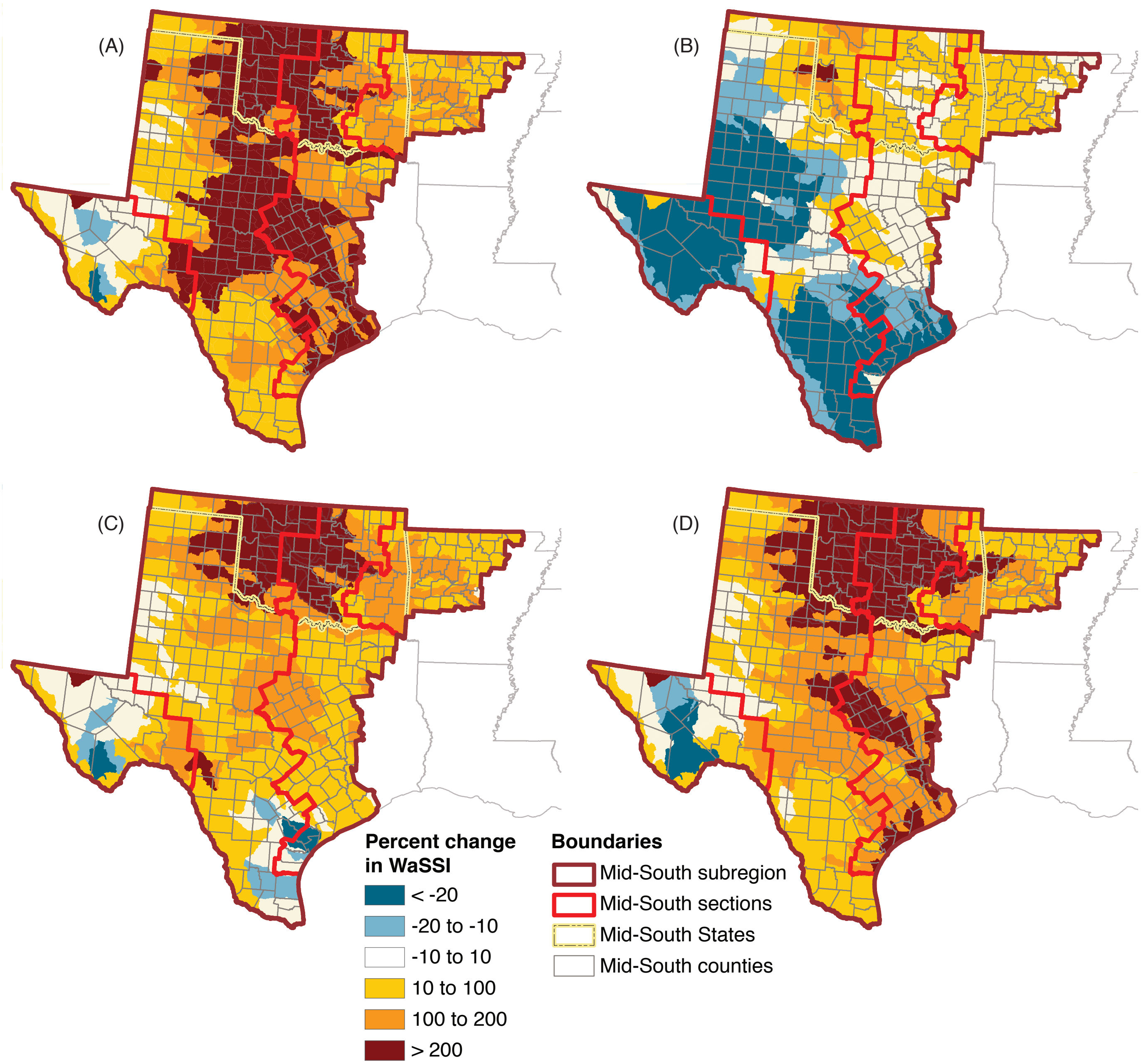

Figure 16—Predicted change in water supply stress due to climate change (defined by the Water Supply Stress Index (WaSSI) and calculated by dividing water supply into water demand) by 2050 under four climatic scenarios: (A) Cornerstone A, MIROC3.2+A1B, (B): Cornerstone B, CSIROMK3.5+A1B, (C): Cornerstone C, CSIROMK2+B2, and (D): Cornerstone D, HadCM3+B2 (Sources: Intergovernmental Panel on Climate Change 2007, Lockaby and others 2013).

Implications

Forecasts from the Southern Forest Futures Project predict that demand for water will grow with expanding populations, warmer temperatures will increase evapotranspiration, and water availability in the form of precipitation will decrease. Stream flows and water supply are expected to decrease and become more variable over the next 50 to 100 years. The magnitude of changes in stream flows resulting from climate change will likely vary considerably among sections in the Mid-South. Some small areas, such as western Texas, would experience increases in water supply under some forecasts. Other areas, especially Oklahoma and northern Texas, are likely to experience decreases regardless of the conditions that ultimately occur.

Overall, climate-induced decreases in water supply and increased demand from a growing human population will likely result in an increase in water supply stress into the next century. This is predicted under all four Cornerstone Futures, largely because of higher air temperatures that cause increases in water loss by evapotranspiration, but also because of decreasing precipitation in some areas.

The result might be an unexpected change in the way society uses and pays for water. If demand outstrips supply, households and business would have to pay more for the water that they consume. If society begins to view water as an ecosystem service, utilities might begin to pay landowners for the surface water that flows from their forests and woodlands, and best management practices (BMPs) to optimize freshwater flow could become more common. Increases in the cost of freshwater aboveground and belowground could favor the economics of desalinating water from the Gulf of Mexico. And certainly, increases in the cost of water could change attitudes and practices for residential, commercial, and agricultural consumption.

The Southern Forest Futures Project also predicted a higher risk of sea level rise and coastal inundation, as coastal dry lands begin to experience episodic inundation and wetlands change from episodically inundated (during high tides and storms) to permanently inundated. A higher risk of sea level rise is predicted for many coastal areas. Thermal inertia dictates that once the waters rise, reductions in future greenhouse gas emissions would not produce a quick reversal. Therefore, unlike precipitation-driven flood events, flooding caused by rising sea levels would have long-term consequences. Coastal inundation is one of the most visible impacts of rising sea levels. Areas that were once dry further inland would gradually shift to episodically inundated (during high tides and storms) and then to permanently inundated. The impact of sea level rise to the point of inundation would be obvious, less so for other impacts.

An example is the salt-water marshes that currently exemplify an ecosystem in balance between fresh water and saline environments. These unique places provide important breeding habitat for many terrestrial and aquatic animal species. Rapidly rising sea levels would permeate nonsaline forests and grasslands, causing losses of existing vegetation without the possibility of replacement by more salt tolerant species. Once the existing vegetation dies, the root structure that binds the soil system together and provides a buffer from incoming tides would also be lost, and coastal erosion is likely to accelerate. Although coastal erosion is a naturally occurring process in barrier islands and many other areas, an increase in the rate and severity of erosion, flooding, and loss of vegetative cover that is likely with rising sea levels could greatly accelerate the loss of valuable coastal property. How rapidly saltwater-tolerant flora and fauna could move across the landscape as sites shift from freshwater to saltwater is uncertain.

ECONOMIC WELLBEING AND QUALITY OF LIFE

Forecast of Timber Products Markets in the Mid-South

Wear and others (2013b) described expected southwide timber-market trends, most of which apply to the heavily forested areas that are east of the Mid-South. Even the timber markets in the forested Ozark and Ouachita Highlands have always differed from those of Coastal Plain and Piedmont—the Ozarks because they support hardwood-dominated forests in an environment that is extraordinarily difficult for harvesting operations, and the Ouachita because of its high concentration of national forests that are not primarily managed for commercial wood production. Much of the forest and woodland acreage of the Mid-South is >100 miles from the nearest pulpmill or chipmill (fig. 17), an indication of an imbalance in the supply-demand equation. Counties have somewhat more access to sawmills, which on average are less costly industrial investments than pulpmills (fig. 18). But by and large, the economy of the Mid-South will not be made or lost through changes in long-term trends from traditional forest products markets.

Forecast of Forest Biobased Energy in the Mid-South

Alavalapati and others (2013) described alternative outlooks for wood-based energy production across the Southern United States. Much of their analysis was built on inventory data, market trends, and modeling tied to the existing forest products industry and forest land ownership in the South, an environment that does not translate well into the Mid-South, and especially into the Cross Timbers, High Plains, and West Texas Basin and Range sections. A few of their

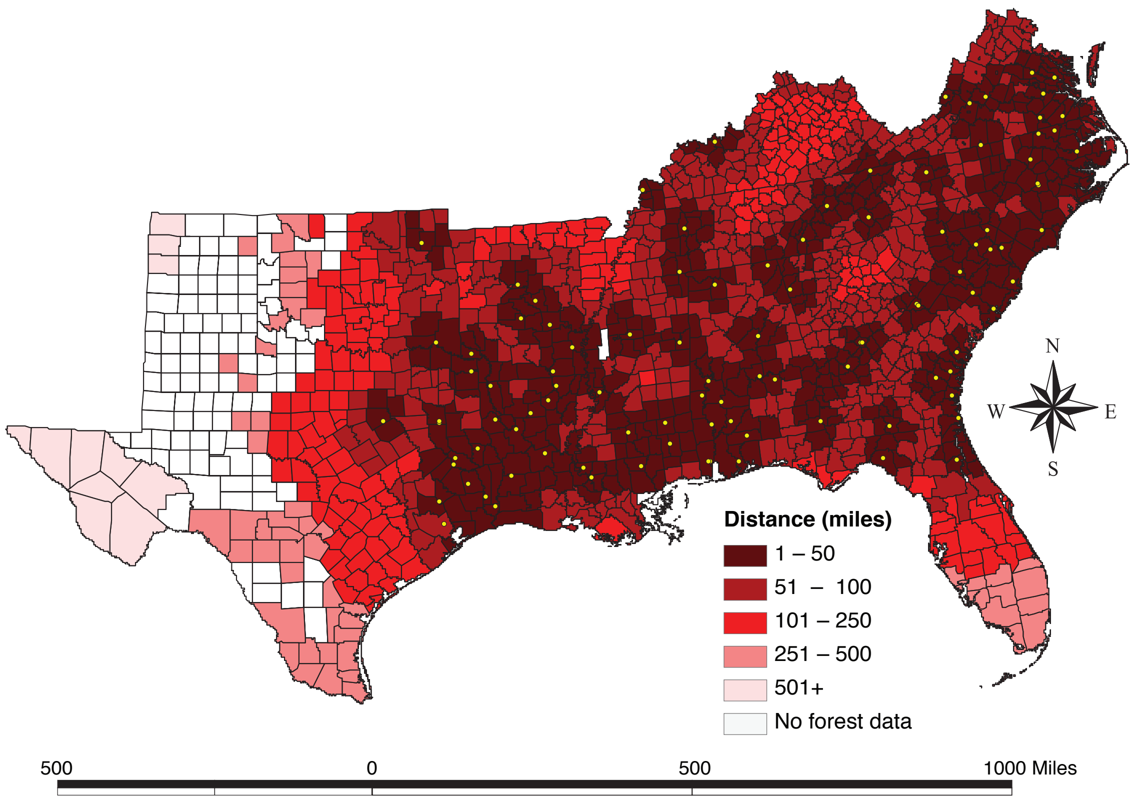

Figure 17—Distance in miles from the forested centers of southern counties to the closest pulpmill or chipmill (Source: Wear and others 2013b).

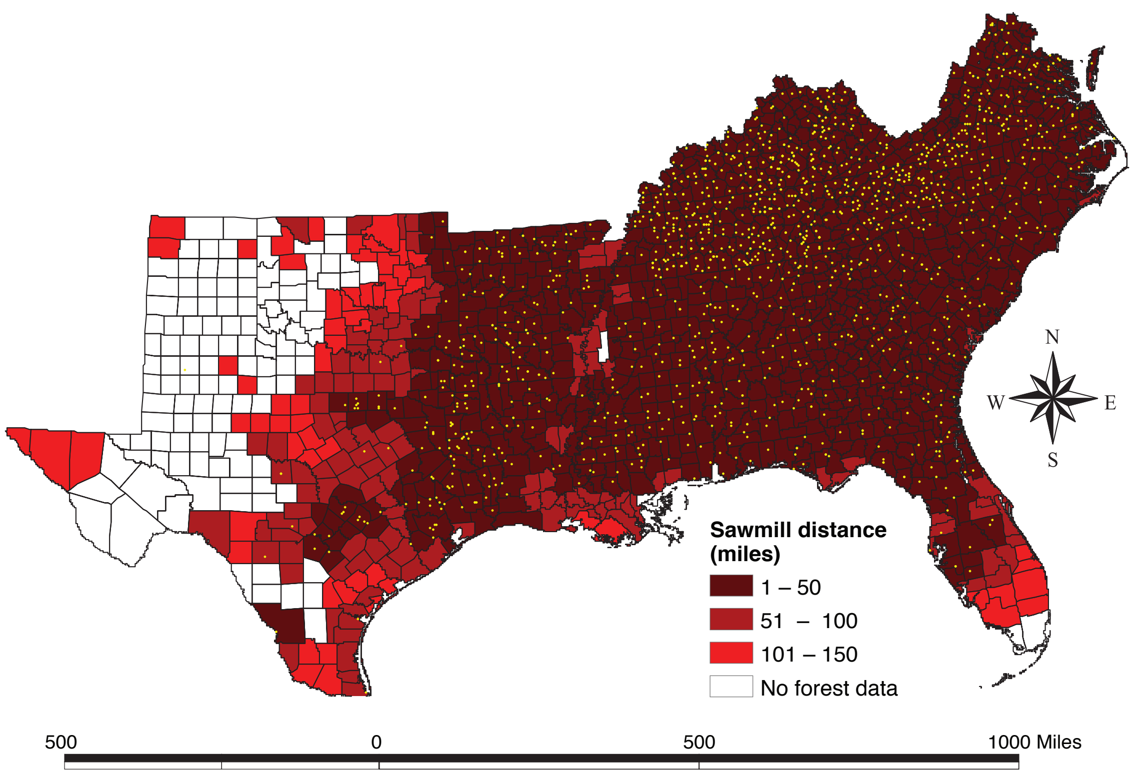

Figure 18—Average distance in miles from the forested center of each southern county to the closest five sawmills within 150 miles (Source: Wear and others 2013b).

key findings, however, could probably translate fairly well if applied generally to the potential for developing biomass and bioenergy markets in the Mid-South.

For example, Alavalapati and others (2013) reported that their forecasts of raw material consumption have a high level of uncertainty, given the interplay between public policies and the decisions that forest owners make about supply and investments. They concluded that the biomass requirements for energy are not likely to be met through harvest residues and urban wood waste alone, and that the preferred feedstock would likely be timber harvested specifically for energy production. The result could be the emergence of a new woody biobased energy market, leading to price increases for merchantable timber and increasing returns for forest owners. However, in the absence of government support, the necessary research, pilot projects, and incentives for production and commercialization of woody bioenergy markets would be unlikely to develop.

The required technologies exist, but with varied levels of feasibility. Combined heat and power, co-firing or direct combustion of biomass for electricity, and pellet technologies are commercially viable with facilities operating at various southern locations; but biochemical and thermochemical technologies for converting woody biomass to liquid fuels are not yet commercially operational. Fundamentally, the challenge is cost. Alavalapati and others (2013) reported that the national average price of delivered coal-based electricity in 2005 was $5.32 per megawatt hour, whereas the cost of electricity from logging residues is roughly 10 times higher; conversely, biomass from forest fuel treatment thinnings ranged from $6 to $10 per megawatt hour.

One challenge in establishing cost-effective biobased energy production is, quite simply, to yard up the raw materials in an effective manner and in a way that does not compete with existing pulpmill demand. Pulpmills that convert roundwood into paper are often significant local and regional economic drivers in and of themselves, and redirecting either the pulpwood resource or the logging crews that deliver it to the mills would be counterproductive to the local or regional economy.

Conversely, biobased energy resources must be lucrative enough to harvest and deliver the raw material to the energy facility. Harvesting solely for energy would likely require chipping, bundling, or other densification before transporting the material. Otherwise, the raw material would have to ride to the mill with wood intended for pulping and sawing, and be gathered essentially as a byproduct that is currently an integral part of co-firing for most sawmills and pulpmills. In short, the challenge is to find the raw material, purchase it from a willing landowner at a fair price, find people who will harvest and transport it at a living wage, and deliver it to a facility that can use it—all within the context of a price that can support what is in essence a new sector of the forest operations community.

Overcoming this significant challenge requires easy access to the wood supply and to distribution markets; such access does not yet exist in the Mid-South, especially in the Cross Timbers and High Plains.

The Ozark-Ouachita Highlands is on the periphery of the western Coastal Plain, which suggests that biomass activity may have a place in these forests especially as a byproduct of existing management activities. But even in the Ozark-Ouachita Highlands, the real challenge is access and economical transportation of harvested material. The issue was last addressed in the late 1990s, when a Pacific Rim export market for dense hardwood chips became established in the Ozarks. The practice resulted in degraded forests, because contractors preferred to high-grade stands rather than to apply silviculturally sound thinning operations. But the larger issue was the high cost of transporting harvested sawlogs and pulpwood through the rugged Boston Mountains to the chipmills along the Arkansas River (Gray and Guldin 2001).

Outdoor Recreation

Cordell and others (2013) described demographic trends that are expected across the Southern United States. Several of these trends have implications for the Mid-South. Populations are growing at a faster rate than in the rest of the Nation, especially in the Cross Timbers section. Growth is reflected in the change in population density, which is highest around the major cities of Texas; those high population densities are expected to increase recreation pressures on public resources—especially in metropolitan areas of Texas, and to a lesser extent Oklahoma and Arkansas.

Cordell and others (2013) reported that the activities that people choose for outdoor recreation today are different from choices that were made by previous generations. Shifting from a rural to an urban or suburban lifestyle influences the choice of recreation activities, as does ease of access to public land, especially lands managed by Federal and State agencies. Hunting and fishing remain popular, but bird watching, wildlife observation, and photography have begun to gain participants. Although recreation forecasts were not calculated at the section level, the trend is for continued popularity of traditional hunting and fishing activities in rural areas and small towns, and increased popularity for other activities as populations become more suburban and urban.

Opportunities for recreation on Federal land are concentrated in the Ozark and Ouachita Highlands, which contain the only national forests in the Mid-South. But

other opportunities are available on public lands scattered across the other sections. In the Cross Timbers, Federal lands include the Caddo National Grasslands north of Dallas, properties managed by the U.S. Army Corps of Engineers for flood control, and wildlife refuges that are usually associated with rivers, lakes, and the Gulf of Mexico. In the High Plains, Federal lands include the Black Kettle National Grasslands in western Oklahoma, the McClellan Creek National Grasslands in the Texas Panhandle, and the Padre Islands National Seashore and several wildlife refuges along the Gulf of Mexico. In the West Texas Basin and Range section, National Park Service properties include Big Bend National Park, Guadalupe Mountains National Park, and the Amistad National Recreation Area near Del Rio. State parks are usually smaller than these Federal holdings but are more numerous and more uniformly distributed across the Mid-South; they also offer significant opportunities for outdoor activities.

Bowker and others (2013) identified some issues that could affect demand for outdoor recreation in the South from 2010 to 2060. For example, people of different ethnicities, genders, income levels, and ages may pursue different kinds of activities. Some activities become more popular because of new or changing technologies (such as windsurfing or jet-skiing), or because equipment becomes more readily available (such as kayaking and orienteering). Other factors are not likely to change; for example, in 2010 the vast majority of recreation occurred within a few hours' drive of the participant's residence—an attribute likely to be true in 2060 as well.

Bowker and others (2013) reported a number of key recreation forecasts for the period ending in 2060. Land-based activities (developed site use, hiking, horseback riding, off-road vehicle use, and visiting primitive sites and wilderness areas) are all expected to increase more or less constantly with population. Water-based activities are also expected to increase more or less constantly with population. Nonmotorized boating (canoeing, kayaking, and rafting) is likely to increase more rapidly and proportionally to population increase than motorized boating because the equipment required for participation is less expensive. Wildlife-based activities (birding, hunting, and fishing) are all expected to increase, but at different rates. Birding is expected to increase faster than population growth, in part because it can include everything from watching backyard feeders to engaging in ecotourism to see unique specimens in the wild, a common activity along the Gulf of Mexico. Fishing is projected to increase at a rate slightly lower than population growth. People in the Mid-South have strong affinities for hunting and fishing; however, in a generation or two (and certainly by 2060), the number of people participating in hunting and fishing as a percentage of the population is expected to be lower, leading some to speculate that the actual number of hunters will be lower in 2060 than today. This trend reflects increasing population of ethnic groups that usually eschew hunting, increasing numbers of urban residents, higher educational levels that result in higher income levels and less need for subsistence hunting for food, and declining forest and rangeland area per capita. Bowker and others (2013) did not stratify their data below the regional level; therefore, one can only speculate whether the general trends reported southwide would apply in the Mid-South, which has had—and still has—a long and strong tradition of hunting and fishing.

CHAPTER 6. Management Implications

The biggest concern arising from the analysis of the Mid-South for the Southern Forest Futures Project is not changing climate, drought, warmer temperatures, invasive native vegetation, threats to forest and woodland health, biomass, land use, or water. All of these are important, but they pale in comparison to the tremendous implications of one primary threat—human population. The 2010 U.S. Census showed a 10-year population increase of 20.3 to 24.2 million. That rate of population growth over five decades would result in a 79 percent population increase, 20 percent more than the Forest Futures Project assumption of 59 percent (Wear and Greis 2013). The largest impacts clearly would be in Texas, whose population of 25.15 million in 2010 was 20.6 percent higher than in 2000 and more than three times the combined rate of growth in Arkansas and Oklahoma.

The interpretation of the data from the Forest Futures technical reports must be made with this in mind. Their findings are probably conservative with respect to the increase in human populations if growth continues at the rate reported by the U.S. Census from 2000 to 2010. That will have the most profound effects on the demands that society places on natural resources in the Mid-South.

DROUGHT

The 2011 drought in the Mid-South, especially damaging for Texas, was certainly a rude awakening. The State has experienced droughts of this duration before, but never in combination with expanding urbanization and a booming population. Texas lost an estimated 2 to 10 percent (or 100 to 500 million trees) of its forests and woodlands as result of that drought.

The experience raised fundamental questions not just for Texas but for Oklahoma and Arkansas as well, such as how a resource manager can know exactly when a tree is dead and why; how mortality might affect canopy cover, wood volume, and biomass on a statewide level; and what the implications of drought-related tree mortality might be for wildlife and wildlife habitat. In addition, there is the practical question of large-scale cleanup, which can only be accomplished after completion of a hazard estimation that quantifies damage to life or property, estimates the cost of tree removal in urban settings, and identifies what, if anything, needs to be done about standing dead trees in forests, woodlands, popular outdoor recreation areas, and the wildland-urban interface.

Anecdotal evidence and analysis of data collected in Texas suggest management activities that could have enhanced resistance and resilience of forests and woodlands to drought. Older mature hardwood and pine stands experienced more damage than plantations (whether thinned or unthinned), reinforcing the value of shorter rotations, or plantations, or both, in managed stands. A larger role for prescribed burning would be useful as a conditioning factor in the event of wildfires that follow drought episodes. Keeping stocking levels at the lower end of fully stocked, and perhaps allowing stands to become slightly understocked, would conserve water. Ensuring that forest understories are relatively open and free of encroaching brush such as redcedar, juniper, and live oak would also conserve the water that is available in an ecosystem. For example, redcedar studies are underway in Oklahoma to quantify that relationship.

Research on the relationship between forest cover and water quality and quantity in forests needs to be expanded so that it applies to woodland settings as well. Opportunities exist for researchers to increase cooperation with municipal watersheds and the U.S. Army Corps of Engineers on understanding how urban and suburban development, thinning of stands, and removal of encroaching woody vegetation affect the flow of water from woodlands into reservoirs. In short, research is needed to better understand the implications of these and other suggested management activities within the context of drought.

FOREST AND WOODLAND OPERATIONS

By necessity, the emphasis of the Southern Forest Futures Project was on southwide changes expected in a number of important contexts and issues. However, one issue that is important in the Mid-South was not specifically addressed—how would the forecasted changes dictate alterations in the management of forests, woodlands, and pasturelands?

As an example, consider forestry in the Ouachita Mountains, where short-rotation intensive plantation management

is practiced on investment lands and where Federal agencies manage stands of native species using natural regeneration over long rotations. Planting pine seedlings is not inexpensive; in the 2012 winter planting season, land managers wondered whether seedlings planted in 2012 would survive on sites affected by the 2011 drought. The degree to which other costly treatments—such as fertilization and herbicide application—are confounded by drought or excessive episodic rainfall is not well understood and therefore difficult to predict. Models of fuel moisture and fire behavior may need to be modified for extreme drought conditions; this is especially important because the models often underestimate fire behavior in extremely dry conditions. New tools might be needed, both to help land managers adapt and to help policymakers develop appropriate policies and response capabilities.

Downscaling forest management for application to small properties is another opportunity to help landowners, not only with tools to manage their own lands but also to promote responsible forest and woodland management in general for an increasingly urban and suburban society that is increasingly distant from the rural landscape. These tools would likely be welcome, as forest health and wildlife are both high on the list of desired attributes for forest and woodland owners and for society in general. The expanding second-home market in rural areas would benefit from downscaled management recommendations and activities—for example a backyard prescribed burning program that involves burn cooperatives with trained members instead of untrained homeowners. Adaptation of forest certification programs beyond the forest products industry to smaller sized tracts would open those holdings to viable markets for sawlogs and pulpwood.

If the level of education of landowners increases, their interest in management and receptiveness to management advice could also increase, creating an appetite for communication with professional foresters and especially for management advice that they can use on smaller forests or woodlands. Foresters need to learn how to deliver effective management not only for a particular stand, but also across a landscape, especially if advising owners of highly parcelized properties.

Each of the three States in the Mid-South has a set of voluntary BMPs in place for forested conditions, and compliance levels are generally quite high. However, whether BMPs for forests conditions apply equally well in woodlands and grasslands is unknown. If not, they would need to be modified to reflect the challenges that woodland and grassland owners face. An example is the practice of retaining trees within streamside management zones, which is considered to be an effective way of ameliorating water temperature along permanent streams and moderating sediment delivery in forests. In woodlands and grasslands, a different approach may be necessary if those trees have the potential to encroach on native vegetation or increase ecosystem water stress.

RECREATION

Overall, the interaction of increasing populations with finite recreation areas foretells several important likely developments—more people will be participating in outdoor recreation activities, the number of participation days in these activities will continue to increase, and the land base (especially the Federal land base) available for recreational activities will remain static. Over the next 50 years, recreational use in all kinds of activities will likely increase, some more than others, potentially leading to more conflicts among participants.

With increasing population and increased demand for outdoor recreation forecasted, conservation-based management activities that have traditionally been promoted by State game and fish agencies would need to continue. However, the number of participants who purchase fishing and especially hunting licenses is not projected to grow rapidly, and absolute numbers might even be lower than today because of changing demographics from rural to suburban and urban areas. Because many conservation activities such as wildlife habitat improvements have traditionally been funded by the sale of hunting and fishing licenses, resources might be reduced over time, and new revenue streams would be needed to support that demand.

FOREST BIOBASED ENERGY

The market for wood, fiber, and biomass that existed in the 20^{th} century, with its emphasis on milled lumber and waste byproducts, has changed its emphasis to pulpwood, fiber, and scraps with decreasing regard for milled lumber. Markets are changing, as is the relationship between the forest products industry and its suppliers on private forest ownerships, whether they are "commercial" private owners such as real estate investment trusts and timber investment management organizations, or more traditional family forest owners. The forest products industry, which once owned vast acreages in addition to mills, now has a primary focus on mills; increasingly, companies rely on the free market to supply their mills. Sales of large high-quality sawtimber that once commanded $80 per ton in the 1990s now can be purchased for $30 per ton in western counties along the Gulf of Mexico. Crews with the equipment needed to handle large products are disappearing, and mills with headrigs big enough to cut large products are on the decline. Although all of these changes are understandable from an economic perspective, they do not bode well for sustainable forestry that can create future options for landowners.

Part of the driving force behind these trends is a change in industrial capability, both in the woods and at the mills. Mechanized equipment is now available to log, haul, and delimb trees in the woods, transport them to mills, and effectively process them. Silviculture has been simplified in the woods—especially on lands held by timber investment groups—into short-rotation fiber farming to fulfill mill contract requirements; the result is a very efficient process for harvesting trees in the woods, provided that they are all of similar size. In essence, the relationship between the timber investment groups that have contracts to provide raw materials for mills and the mills themselves, which have been modified for a product stream that is predominantly all of one size, drives a homogenization of product size, market conditions, and mill demand that extends beyond the timber-investment group to all private forest ownerships.

All of these developments do not bode well for the establishment of biomass opportunities from heretofore-unmerchantable standing trees and residuals. These products are not valued highly, partly because they contain marginal amounts of volume for biomass, but also because their structures are very heterogeneous. Redcedar and post oak are classic examples. Open-grown redcedar trees can retain limbs to the ground, they are difficult to harvest even with mechanized equipment, and their bushy limbs do not compact very easily for hauling to a mill. Post oaks in woodlands seemingly are as wide as they are tall—they cannot simply be thrown in a chipper without intensive delimbing. The cost of labor required to process these materials exceeds their value; under a traditional paradigm of forest economics, the harvest would not be justified because it cannot turn a profit.

Perhaps the time has come for a new paradigm that minimizes cost. Many landowners in the Cross Timbers and High Plains are working to restore woodlands that have become overgrown with native species such as redcedar, mesquite, and oak. They are willing to spend ≥$100 per acre in out-of-pocket costs to remove 6 to 10 tons of encroaching woody biomass. Even if a biomass market would not allow them to break even, any positive cash flow from the sale of the biomass they are already removing could help partially defray the cost of the treatment. That is an attractive alternative for landowners committed to the restoration of their grasslands and woodlands. An added benefit would accrue from enhanced water conservation, as described previously. What would be needed is a way to downscale energy production so that facilities are located 50 to 100 miles from the sources of the biomass. The challenge would be to develop that capability in a site that could be operational for a given length of time, and then moved to a new location.

Also missing from this scenario is the availability of tools and equipment designed to harvest small tracts and tracts with difficult biomass, as well as opportunities such as landowner cooperatives that would consolidate the acreage needed to attract producers. The Cross Timbers and High Plains have already developed an infrastructural extension network based on their long history of agricultural and rangeland activity. That could be useful in developing biomass as a marketable commodity. They would need better estimates of volume and yield especially for nontraditional woody biomass at the stand and landscape scales, equipment that is specifically designed for efficient harvesting and transportation of unwieldy biomass, management guidelines that are tailored for small landowners, and silvicultural practices and prescriptions that would restore desired woodland and grassland vegetation while removing unwanted biomass. New partnerships between traditional forest management agencies and the Natural Resources Conservation Service could introduce landowners to the resources available through existing plant materials centers and the opportunities these centers provide for restoration of native vegetation.

In summary, the future development of a biomass and bioenergy industry in the Mid-South is unlikely unless a targeted market can take advantage of the tremendous amount of dispersed woody plant resource occurring in woodland ecosystems that are encroaching in pasturelands and grasslands. If efficient industrial processes could be developed that would be somewhat portable, partially reimburse a landowner for the cost of conducting the vegetation removal treatment, and minimize the hauling distance for the resource, the next challenge would be to determine whether such an operation could be sustainable in the political and environmental context. Of these two challenges, the first is probably the more daunting.

WILDLIFE

The Mid-South is a wonderfully diverse area, with more species in more distinct ecosystems than anywhere else in the South. However, a growing human population has led to increased urban development, expansion into the wildland-urban interface, and changing patterns of land use. When coupled with the prospects for increasingly warmer temperatures, increasingly dry conditions, and less water on landscapes, these societal changes would manifest themselves as changing habitat conditions, and those changing habitats will likely have an effect on the absolute number and geographic distribution of plant and animal species.

The Mid-South species at risk are in specialized and restricted habitats that are likely to change, and from which no pathway for migration is available. When the habitat for a given species becomes inhabitable, animals will seek a suitable habitat by migrating, unless the migration is constrained by barriers. Migration of plant species across a landscape in response to a forcing factor such as changing climate is more difficult to predict or to enable, given the varying ways that plants reproduce and disperse from one generation to the next. In all likelihood, a species near the boundary of its natural geographic distribution may be more at risk of local extirpation than species in the heart of their natural range. However, considerably more research is needed to understand the ways that plant and animal species would relocate to suitable habitat within short periods of time under changing climatic conditions. Some species would be likely to flourish in place, or to migrate quickly and vigorously. Others would struggle to persist in their current location. Yet others would be unable to survive in their current location and would be unable to relocate; for them, extirpation or even extinction would be the inevitable result.

Assisted migration has been suggested as a possible tool to help species adapt in a changing climate. Some very narrowly defined methods—such as afforestation or reforestation by planting—may be available for moving common and dominant tree species from one location to another. Although clearcutting a mature stand of pines and replanting a new age cohort of pines is a common forestry practice in the South, "assisted migration" of all the interrelated subdominant species-midstory woody plant species, understory annual and perennial species, soil fauna and flora, and the vertebrate and invertebrate organisms that have evolved with the dominant tree species is simply untenable. The protocols and nursery infrastructure needed to propagate and disperse many of these subdominant species simply do not exist. Establishing a 40-acre stand of longleaf pine with a suitable complement of annual and perennial plants into the Ouachitas, for example, would be an extraordinary ecological challenge; but it would also be cost-prohibitive in any rational practical context at the stand level, and even more so at a landscape scale.

By law, State and Federal agencies are required to protect endangered and threatened species and to manage habitat for population recovery, but agency budgets are not increasing fast enough to support the increasing monitoring and habitat-restoration needs for an increasing number of species. For example, in the summer of 2013, white-nose syndrome was reported in the caves of the Arkansas Ozarks, raising concerns about survival of many local bat species. This was an inevitable outcome, but nonetheless disappointing.

If concerns are realized and species become threatened or endangered, the importance of research that quantifies the forest and woodland habitat requirements for forest bats will become extremely important—not so much to understand requirements in the vicinity of cave entrances, but rather to understand how forest bats use general habitat features (such as standing dead snags in Ozark-Ouachita Highlands pine stands), and whether bat species can adapt to new and different habitats for roosting and hibernacula in forested terrain. It will be difficult for Federal and State agencies to balance the increasing need for state-of-the-art science and management advice about threatened and endangered species in an era of decreasing budgets and human resources.

INVASIVE SPECIES

Ironically, invasive plants provide a model for success in changing conditions. Some have unique attributes that allow successful establishment and growth to the point where they outcompete native species and disrupt stand dynamics and development. Others have developed unique adaptations for widespread dispersal—either through natural patterns such as bird dissemination of seed from Chinese tallow or Brazilian peppertree, or through unintended human assistance such as cogongrass dispersal from one stand to another in the mud on logging equipment. Some species have been introduced from other countries, but others, such as mesquite and juniper, are natives that are taking advantage of altered land-use patterns by expanding their occupancy of ecosystems. Control or removal of invasive plants will largely depend on the actions of individual landowners and their ability to afford effective control treatments.

Unlike invasive plants, which generally cause only localized difficulty on a small scale, insect and disease pests threaten species across large landscapes. The three major catastrophic losses of the 20^{th} century were from Dutch elm disease, chestnut blight, and the recent hemlock woolly adelgid outbreak in the Eastern United States. Each of these pests has resulted not only in widespread mortality but also in range-wide losses of natural regeneration and even in scattered instances of utter failure for the affected tree species to become reestablished in nature.

Whether discussing insect or disease pests of pines or hardwoods, the future is clouded with uncertainty. Scientists do not know how changing climate will affect insect and disease pests, or which pests will be seen as scourges of forests and woodlands in 50 years. The best advice resource managers can give is to maintain healthy forests. Unfortunately, even that may not stop insect and disease pests, known or unknown, in the future.

FIRE

The management and policy challenges associated with fire in the forest and woodland landscapes of the 21st century are perhaps the most difficult to address. On the one hand, prescribed burning across a large percentage of the landscape serves an important role in conservation. In addition to reducing fuels and promoting open woodland conditions that are currently underrepresented on the landscape, prescribed fire is critical for the restoration of the endangered red-cockaded woodpecker (*Picoides borealis*) in the Ouachita-Ozark Highlands, and for reducing incursions of redcedar, mesquite, and juniper into the woodlands and prairies of Oklahoma and Texas. The regular use of prescribed fire may reduce mortality of dominant overstory species in the event of wildfire. A host of native species that depend on open understory conditions in forests and woodlands would benefit from expansion of prescribed burning to Mid-South landscapes.

On the other hand, the predicted pattern of increasing population, increasing temperature, and increasing drought adds a perspective that is difficult to address. Climate changes that are forecasted would reduce the number of days that are suitable for prescribed burning, and increased populations and increased urban, suburban, and wildland-urban interface areas would exacerbate smoke management issues. The result would be reduced opportunities to initiate prescribed burning and reduced areas burned in any given day, which would increasingly limit the scale and scope of the resource management benefits that derive from prescribed fire.

Increased air temperature, drought frequency and severity, and human population growth would increase the threat from wildfire, at the same time that wildfires are expected to occur more frequently and cover larger areas. If weather conditions result in more frequent severe thunderstorms, the resulting increases in lightning strikes would expose more landscapes to the threat of wildfire. In such an environment, State agencies would need early warning protocols for wildfire detection and response and anytime operational information to help plan or position resources.

Questions still linger about existing fuels and fire behavior models that were developed based on past conditions; conditions that may be encountered in the future could easily exceed the range of variability that underlie current models. Validating existing models of fire behavior and controllability based on current experience and revising models that do not match predicted fire behavior will be essential, especially in light of suspicions that models may be too conservative for the hotter and drier conditions that are predicted.

SUMMARY

The four sections of the Mid-South Region offer vistas of unparalleled ecological variety, species diversity, and scenic beauty. The sheer physical size of the area is difficult to grasp; for example, the straight distance from Little Rock to El Paso is 840 miles, and 700 miles from Enid, OK to Harlingen, TX. From the highly dissected terrain in the Ozark-Ouachita Highlands section, to the rolling upland woodlands of the Cross Timbers section, to the windswept prairie features of the High Plains section and the desert ecosystems of the West Texas Basin and Range section, the Mid-South supports more, and more varied, ecosystems than anywhere else in the South.

The prevailing trends from east to west are reflected in one simple statistic—from Little Rock to El Paso, an inch of precipitation is lost for every 20 miles. With the Cornerstone Futures projecting that air temperature will increase, precipitation will decrease, and population will grow by ≥60 percent, continually rising water stress is expected, reflecting increased functional aridity. Issues for society to address include diminishing water supplies and the distribution of increasingly scarce fresh water for agricultural use and human consumption, coupled in coastal areas with rising salt water levels.

The Cornerstone Futures also predict that changing climate and water stress will combine to modify existing forest and woodland ecosystems, with implications for native vegetation dynamics, the distribution of tree and plant species, the sustainability of ecosystems, and the native terrestrial and aquatic wildlife species that depend on those ecosystems. Some species would respond favorably to these changes; the effects would be adverse for others, especially those with limited geographic ranges, specialized resource needs and habitat requirements, or an inability to easily reproduce and disperse.

These changes are compounded by the likely increased activity of unwanted native and nonnative invasive plants. The challenge in western areas of the Mid-South is not from invasive plant species, but rather from grasslands that are reverting to woodlands—the result of decades-long alterations both in range management and in burning practices that have allowed encroachment by juniper and mesquite. Reversal of this trend will be increasingly difficult given increasing drought, increasing risk from wildfire, and the absence of management guidelines.

Nonnative insect and disease pests also fall in the category of unwanted species. Today, the list of pests that threaten Mid-South forests and rangelands is longer than it was several decades ago. Several of these threaten substantial damage that could result in widespread demise of key species, such

as the loss of ash species to the emerald ash borer, the loss of soapberry to the soapberry borer, and the loss of oaks to sudden oak death. How these pests will interact with hosts across the Mid-South landscape under changing conditions is still a matter of some conjecture.

Analysis suggests that the demand for outdoor recreation will likely expand proportionally with population. Motorized activities such as power-boating and all-terrain vehicle use and nonmotorized activities such as hiking, birdwatching, outdoor photography, canoeing, and kayaking are all expected to continue increasing. However, any increased activity would necessarily be concentrated on a fixed area of land, potentially resulting in use conflicts, especially on public lands and bodies of water. Land managers will need new skills to mediate and resolve those conflicts. Data also suggest that participation in hunting and fishing will likely decrease with increases in population, and that the number of hunters could decline —the result of societal shifts from rural to urban or suburban lifestyles. If States rely on fees from the sale of hunting and fishing licenses to support resource conservation, plans will need to be developed to address the resulting shortfall.

It is likely that changing climatic and economic conditions will trigger new issues across the Mid-South region that were not analyzed in the Forest Futures project. One important issue that has emerged in the past 5 years has been the expansion of oil and gas development in shale formations across the region. Production of oil and natural gas through hydraulic fracturing have commenced in the Fayetteville Shale in the Ozarks, the Woodford Shale in eastern Oklahoma, the Barnett Shale in north central Texas, the Eagle Ford Shale in southeast to south central Texas, and several west Texas Permian Basin shale deposits. The main feature of this economic development is the large amount of water required for its production (Nicot and Scanlon 2012), which will certainly add to the stress on water resources of the Mid-South.

Management of the existing forest, woodland, and rangeland resources may require modification within the context of rising temperatures, decreasing precipitation, increasing drought, and the many other changes forecasted for the Mid-South. Questions have already been asked by land managers—as yet, unanswered by research—about routine operational activities such as whether planting pine seedlings in the winter after a severe drought will affect survival the following year, and whether thinning during drought years will invite attacks by pine bark beetles. More research is needed to convert existing management prescriptions into prescriptions for management in a changing climate.

A major effort to revamp the entire forestry profession or to move ecosystems dozens of miles northward in response to a changing climate is unlikely; such ambitious landscape-level changes simply are not operationally practical or feasible. Instead, management of forests and woodlands in the face of changing conditions will likely mirror past efforts to redirect management within the context of forest health, such as the responses to outbreaks of southern pine beetles in the latter part of the 20th century. When atypical disturbance events such as drought-related mortality occur, resource managers typically work in affected stands to salvage losses, attempt to improve resistance to disturbance agents, develop management prescriptions that promote resilience in the face of new disturbance events, and reestablish stands that do not recover on their own in a timely manner. But a successful response to a drought, insect outbreak, or other event triggered by changing climate would be most likely if the landowner has an active management plan before the disturbance event occurs.

The availability of wood and fiber is increasing across the Mid-South, but so are markets, bringing changes to the relationship between the forest products industry and the suppliers of timber on public and private lands. Industry capacity to process sawlogs and pulpwood is also changing. Mechanization is increasing, and working in the woods in the 21st century is more likely to involve operating a machine than using a chainsaw to fell and buck a tree. In this new environment, both the logger and the mill benefit if all the trees are of similar size, with additional advantages accruing for those involved in hauling and processing. But trees and other woody vegetation that are outside the optimal size range are becoming increasingly inefficient to handle, which complicates the development of new markets such as cellulosic bioenergy.

Finally, some of the Southern Forest Futures Project forecasts for the Mid-South—specifically those that pertain to the Cross Timbers, High Plains, and West Texas Basin and Range sections—do not have the benefit of repeated survey measurements. Estimates of resource conditions from the initial survey implemented over the past decade in these sections have been calculated, but repeated measurements of permanent survey plots are essential for developing accurate trend information and for quantifying how resource attributes such as timber and fiber volume change over time. Repeated measures will greatly improve the accuracy of data on long-term changes in vegetation of forests, woodlands, and rangelands. Over the next two decades, the accumulation of forest survey data will support a much more dynamic analysis of resource status and trends across the Mid-South. Also, the forecasts must be interpreted with this caveat—that the underlying population assumptions are probably conservative with respect to the Mid-South, and that the demands society places on natural resources, especially water, in the Mid-South are likely to result in profound consequences.

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Guldin, J.M.; Hallgren, S.; and Crooks, J.S. 2015. Outlook for Mid-South forests: a subregional report from the Southern Forest Futures Project. Gen. Tech. Rep. SRS-206. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 70 p.

This report presents forecasts from the Southern Forest Futures Project that are specific to the Mid-South, which consists of four sections located within Arkansas, Oklahoma, and Texas: the Ozark-Ouachita Highlands, the Cross Timbers, the High Plains, and the West Texas Basin and Range. Ranging from Little Rock, AR to El Paso, TX, it is the most diverse subregion in the South. The Mid-South faces a number of important challenges to management of forests and woodlands over the next 50 years, including population increases, the likelihood for increased drought, increased demand for water and water supply stress, sea level rise along the Gulf of Mexico, and invasive native species. Understanding these challenges, and the implications they could have on management and policy in the region, is critical to maintaining the diversity, health, productivity, and sustainability of Mid-South forests, woodlands, and grasslands.

Keywords: Climate change, Cross Timbers, drought, forest management, High Plains, Mid-South, Ouachita, Ozark, Southern Forest Futures Project, water, West Texas Basin and Range, woodlands.

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