Fuels management in the Subtropical Division—Mountains

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ABSTRACT

The Ouachita Mountains in western Arkansas and eastern Oklahoma are one of the most interesting ecosystems of the South. Paleozoic folding and faulting and subsequent erosion built the ridges and valleys of the Ouachitas into a unique east to west orientation, with forests predominantly on north- and south-facing slopes growing in rocky Hapludult soils. Forest ownership in the region is subdivided more or less equally among three groups—government, industrial, and non-industrial private forestlands. The native forest types in the Ouachita Mountains vary from stands heavily dominated by shortleaf pine and pine-hardwood mixtures to stands that are hardwood-dominated oak-hickory stands, with loblolly pine plantations extensively planted on industry land in the region. Both the shortleaf and loblolly pine types tend to be managed for timber and other resource products, and with greater attention to proper silvicultural practices, than the oak-hickory forest types. Prior to European colonization, fires were common in the Ouachitas, but effective fire control since the 1930s has altered the historic fire regime. Today, with the notable exception of the Ouachita National Forest, prescribed fires are minimally used and wildfires are quickly suppressed in the region. Across all ownerships, fuels treatments are not generally conducted separately per se except in certain situations where mulching and chipping are conducted to reduce disturbance-induced fuel loads. Otherwise, fuel reduction treatments occur within the context of ongoing silvicultural systems on public and industrial forest lands, less so on private forest lands. The cumulative effects of fire and fuels

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treatments are best characterized as an integral element of forest management activities generally. These effects can be mitigated through compliance with best management practices, which are voluntary on private lands, typically followed closely on industry lands, and specified in detail in Forest Plan standards and guides on the Ouachita NF.

THE OUACHITA REGION

Description

The heterogeneity of the forests west of the Mississippi River in the southern United States is strongly influenced by physiography and topography. The West Gulf Coastal Plain of south Arkansas, northwest Louisiana, and east Texas features highly productive pine-dominated forests on gentle terrain interspersed by major and minor alluvial bottomland hardwood forests. The Ozark Mountains are an uplifted eroded dolomitic plateau in north Arkansas, eastern Oklahoma, and southern Missouri, and feature primarily oak-hickory forests with a minor and varying pine component that was far more widely distributed 150 years ago than it is today. Both of these regions support forests similar in species composition and fire dependency as types farther to the east, and are discussed in greater detail in other chapters of this volume.

But between these two regions lie the Ouachita Mountains of western Arkansas and eastern Oklahoma, among the most ecologically unique and interesting ecoregions of the South. Three elements contribute to that uniqueness. First, the orientation of Ouachita ridges runs from east to west, a general orientation perpendicular to that of most other mountains and hills in the continental United States. This points to the second unique element—forest types are closely associated with aspect, with xerophytic pine-dominated forests on the south-facing slopes, and mesophytic oak-dominated forests on the north-facing slopes. The third unique element is the

dominance of shortleaf pine (*Pinus echinata* Mill.) in the Ouachitas. East of the 100th meridian, shortleaf is the most widely distributed of the southern pines (Guldin 2007), and is generally found in mixture with other pines or in pure stands of limited extent. But in the Ouachitas, shortleaf reaches its ecological maximum, where it is the only naturally-occurring pine and the dominant tree species in extensive stands in the region.

As a result of this unusual and unique ecological association between tree species, forest types and physiographic conditions, the region is classified as the Ouachita Mountains Mixed Forest-Meadow Province within the Subtropical Division (Division 230) of the southern United States. It is somewhat warmer, less wintry, and receives more precipitation than the Ozark Broadleaf Forest of the Hot Continental Division (Division 220) to the north. However, it is more prominently mountainous than the Southeastern Mixed Forest Province to the South or the Mississippi Alluvial Bottomland Forests to the east, which both lie within the Subtropical Division. And, it is more densely vegetated with trees than the prairie Parkland Province that lies to the west—although prairie elements exist in the Ouachita forests. Finally, the Ouachitas only cover roughly 29,000 km^2, making this ecoregion one of the smallest in the South.

Geologic origin and soils

Through most of the Paleozoic era up to about 320 million years before present (BP), the area of the current Ouachita Mountains was under ocean water, and deposition of organic and inorganic materials occurred through marine sedimentary processes. But from 320 million to 286 million years BP during the Pennsylvanian, a major tectonic event called the Ouachita Orogen resulted in the collision of what is now North America with a southern landmass. Essentially, the lateral compression from south to north compressed the marine sediments in ways that resulted in considerable folding, faulting, and subduction activity from west Texas to central Alabama

(Viele and Thomas 1989). Geologic evidence of metamorphic rocks in the region suggests the orogeny featured some volcanic activity especially in the Hot Springs area (Loomis and others 1994), which is not all that surprising to a lay reader in the context of prevailing theories of plate tectonics that continue to shape the Earth.

Over the past 280 million years, the major geological event in the Ouachita region has been weathering and erosion, which have reduced the sandstones and shales that were exposed during the orogeny to their current condition. The linear ridges of the Ouachita hills still show their folded and faulted history, with long ridges oriented from east to west. The terrain reaches maximum elevation of about 790m (2,600 ft), about 460 m (1,500 ft) above the adjoining valleys. The side slopes of the ridges are often steep and rugged in the upper slopes, but gradually flatten in the lower slopes. As a result, the hillsides grade into broad U-shaped valleys whose breath and gentle gradient is attributed to millennia of creek meanderings, especially along the larger creeks and rivers that flow between the ridges.

Soils in the region are highly weathered Ultisols (Buckman and Brady 1969). Pedogenesis is affected by the extremely rocky terrain, the resistance of the rocks to erosion, and the high degree of soil stoniness across the region. Phillips and Marion (2004) described the soils on the hillsides and ridges of the eastern Ouachitas as primarily medium textured, well-drained, stony Hapludults; on steeper slopes or higher elevation, soils were shallow, whereas on more gentle slopes and benches, soils were moderately deep to deep. Liechty and others (2005) reported that soils in the western Ouachitas are typic Hapludults with loamy surface textures, and having unusually high rock content in surface and subsurface soils.

Site productivity closely follows slope position, with poor sites on ridgetops and upper slopes, grading to better sites on lower slopes and floodplains. This common pattern occurs

because colluvial activity over the years carries soils from ridgetops to floodplains, resulting in thin soil depth on upper slopes but consequently greater soil depth on lower slopes. Soil depth correlates with both soil moisture and soil fertility. In addition, south-facing slopes receive considerably more solar radiation than north slopes. As a result, the south-facing ridgetops are the most xeric and least productive parts of the region, whereas the lower north-facing slopes are the most mesic and feature highly-productive sites.

Climate

Climatic conditions in North America have varied tremendously over the millennia, most recently seen in Holocene climatic variations associated with glaciation and interglacial ecosystem processes. However, over the past 4,000 years, pollen records show that the Ouachitas have supported relatively continuous vegetation under a relatively stable climate, but no doubt with annual variations in temperature and precipitation that can occasionally be ecologically important locally (Delcourt and Delcourt 1991, Smith 1984).

Current climatic conditions can be approximated by summaries of weather data over the past several decades. Using National Weather Service data and assuming that Little Rock is representative of statewide conditions, the Ouachita region is slightly cooler and slightly wetter than elsewhere in the state. Mean monthly average temperatures in the Ouachitas (fig. 1) vary from 3 degrees C in December and January to 25 degrees C in July and August; mean monthly highs and lows are about 6 to 7 degrees higher and lower, respectively, than the mean average. Compared to the statewide average, the Ouachitas are about a degree cooler in winter and about 2 degrees cooler in summer. Freezes are common in the state, but continuous freezing temperatures where daytime highs remain below 0 degrees C rarely last as long as a week.

Similarly, ice storms and snowstorms occur once or twice annually, but amounts of precipitation as snow are relatively low; 25 cm of snowfall in one storm is an exceptional event, and snowpack rarely lasts more than 2 weeks in the Ouachitas except on north-facing slopes. On the other hand, summer daily high temperatures frequently exceed 40 degrees C, and the Ouachitas annually experience hot weather in July or August where the daily high exceeds 38 degrees C for a week or longer.

Again, based on National Weather Service data, precipitation in the Ouachita region is about 15% greater than the statewide average, with annual averages of nearly 150 cm in the Ouachitas versus 130 cm statewide (fig. 2). This shows the orographic effect of the Ouachitas; moisture-laden clouds that approach the mountains from the west must rise upward to clear the ridges, which condenses water vapor and increases rainfall. May is the only month during the year when average monthly precipitation in the Ouachitas exceeds 15 cm, whereas January, February, and August have average monthly precipitation less than 10 cm. The largest differences between precipitation in the Ouachitas versus statewide are in the months of May, June, July, September, and October, each of which average 3-4 cm more precipitation than statewide.

The lack of rainfall in August interacts with high temperatures to create conditions favorable for drought. This summer drought is important ecologically from the perspective of whether tree seedlings and other vegetation can obtain adequate moisture from the soil to survive. Lightning is also common in the summer months, and the combination of dry vegetation and lightning strikes renders forests at risk from wildfire. Moreover, strong evidence suggests that Native Americans burned the landscape for human benefits (Guyette and others 2006). This

all suggests an ecological condition in which forest fires were an important agent of ecological disturbance prior to European colonization of the region.

Ecoregional descriptions

The USDA Forest Service developed an ecoregional framework for the eastern United States (Keys and others 1995) based on a national map of ecoregions of the United States (Bailey and others 1994, Bailey 1995). A new map based on slight movement of borders using local knowledge and experience was created as part of the Ozark-Ouachita Highlands Assessment (Foti and Bukenhofer 1999), and contains the best detail available with respect to coverage.

The Ouachitas lie to the south of the Arkansas River Valley in west-central Arkansas and eastern Oklahoma (fig. 3). The ecoregion is classified in the Subtropical Division, Humid Temperate Domain (200), as the Ouachita Mixed Forest--Meadow Province (M231), also referred to as the Ouachita Mountains Section (M231A). Within the Section are four prominent subsections—the Fourche Mountains (M231Aa) to the north, the Western Ouachita Mountains (M231Ab) to the west, the Central Ouachita Mountains (M231Ac) in the east-central part of the region, and the Athens Piedmont Plateau (M231Ad) lying in the southeasternmost part of the region (Foti and Bukenhofer 1999). Overall, these four sections encompass roughly 2.9 million ha.

The Fourche Mountains subsection occupies 1,180,414 ha across the northern part of the region. Ridges are moderate to high, containing some of the highest ridgetops in the region, and with broad valleys; elevation in this subsection varies from 250-790 m. Ridges are underlain by Pennsylvanian and Mississippian sandstone and shale, and valleys consist of sandy residuum (Foti and Bukenhofer 1999). The subsection is 78 percent forested, the lowest percentage in the

region; stands are dominated by shortleaf pine (47 percent of forested area), oak-pine (29 percent), and oak-hickory (22 percent) (Guldin and others 1999).

The Western Ouachita Mountains subsection covers 679,100 ha primarily in Oklahoma, where the ridges are high and relatively steep, again with broad valleys and variations in elevation from 250-760 m. The area is composed of Mississippian sandstone and shale with clayey colluvium in the valleys (Foti and Bukenhofer 1999). Nearly 88 percent of this subsection is forested; of that, 55 percent is in pine-dominated stands, 29 percent is in oak-pine stands, and 15 percent is in oak-hickory stands (Guldin and others 1999).

The Central Ouachita Mountains subsection encompasses 663,000 ha in two separate areas, a smaller part in Oklahoma and a larger area in Arkansas. Elevation varies from 250-760 m in open wide hills, low mountains, and wide valleys; the underlying geology consists of Mississippian sandstone and shale with clayey colluvium in the broad valleys (Foti and Bukenhofer 1999). About 82 percent of this subsection is forested. This subsection has the highest proportion of oak-hickory stands (48 percent) of any of the four subsections; pine stands account for 39 percent of the forested area, and oak-pine stands only 10 percent (Guldin and others 1999).

The Athens Piedmont Plateau is the smallest of the four subsections, covering 367,500 ha in the southeastern part of the region. Geologically, this area is the first uplift from the upper West Gulf Coastal Plain immediately to the south. Elevation varies from 250-750 m, and includes open high hills underlain by Mississippian and Pennsylvanian sandstone, with valleys built upon sand and clay-loam colluvium (Foti and Bukenhofer 1999). This subsection has the greatest percentage of forest area—91 percent—of any of the four subsections in the region, which is partly due to the concentration of forest industry ownership here. That is also reflected

in the forest type data for this subsection, where pine-dominated stands comprise 73 percent of the forested area, oak-pine stands only 6 percent, and oak-hickory stands 19 percent of the area (Guldin and others 1999). In this subsection more than the others, the influence of forest industry is converting oak-pine stands to plantations of loblolly pine (*P. taeda* L.).

Ownership of timberland in the ecoregion is roughly divided equally among three major ownership groups. Governments own 29 percent of the timberland, with 85 percent of that managed by the Ouachita National Forest. Forest industry manages 37 percent of the timberland in the area, with nearly 2/3rds of their ownership in the Western Ouachita Mountains and Athens Piedmont Plateau subsections. Private non-industrial forest landowners own the remaining 34 percent of the commercial timberland of the region (Guldin and others 1999). To date, the recent wholesale movement of forest industry land to non-industrial private landowners represented by timberland investment management organizations (TIMO's) or real estate investment trusts (REIT's) common elsewhere in the South has largely been avoided in the Ouachitas.

FOREST STANDS IN THE ECOREGION

The native forest types in the Ouachita Mountains vary from stands heavily dominated by shortleaf pine and pine-hardwood mixtures to stands that are hardwood-dominated oak-hickory stands, with only a minor pine component if any. Closed-canopy forests are typical today. However, open woodlands were probably more common 200 years ago than today, because of the changing midstory and understory forest conditions that resulted from effective fire control over the past eighty years. In addition, under forest industry ownership, large areas of native shortleaf pine-dominated stands in the region have been converted from to plantations of loblolly pine.

Pine-dominated stands

Pine-dominated stands take three forms in the region.

(1) The first are native shortleaf pine-dominated stands, where naturally-regenerated shortleaf pine is the dominant tree. Where fire has been excluded, a prominent hardwood midstory and understory is associated with these stands (fig. 4), which has the potential to complicate silvicultural practices intended to maintain that pine component especially at the point when old pine stands are harvested with the intent of obtaining new pine stands. As an alternative to fire exclusion, specialized silvicultural systems for ecological restoration have been developed on National Forest lands that reduce the overstory density of shortleaf pines, remove midstory hardwoods, and reintroduce a cyclical prescribed burning program (fig. 5). This work is done toward the goal of maintaining the production of high-quality pine sawtimber while concurrently restoring understory grasses, sensitive plant species such as coneflowers, and endangered animal and insect species such as the red-cockaded woodpecker (*Picoides borealis*) and the Diana fritillary butterfly (*Speyeria diana*). The value of good local markets for timber has been a critical factor in the success of this restoration (Guldin and others 2004a).

Average stand conditions were quantified for a 'typical' stand in a study of mature unrestored second-growth shortleaf pine and pine-hardwood stands on south-facing slopes on National Forest lands across the ecoregion (Guldin and others 1994). This stand has a stem density of approximately 800 trees ha-1, of which about half are pine and half are hardwood. This typical stand also has a basal area of roughly 30 m2 ha-1 in trees > 10 cm dbh, of which about 75 percent is pine and 25 percent hardwood; half of that hardwood basal area is in midstory trees 10-24 cm dbh. It follows that the average conifer is larger than the average hardwood; the quadratic mean diameter (the diameter of the tree of average basal area) for

conifers is 26 cm, whereas that for hardwoods is 16 cm. Pines are bimodally distributed with peaks in the 10-15 cm class (suppressed trees that still persist) and the 25-30 cm class, and with 30 trees ha-1 in the 40 cm class and larger. The dominant conifer is shortleaf pine, and the only two common overstory hardwoods in the typical stand are post oak (*Quercus stellata* Wagenh.), and white oak (*Q. alba* L.). Shortleaf pine also dominates the midstory with post oak, white oak, mockernut hickory (*Carya tomentosa* (Poir.) Nutt.), and black or Texas hickory (*C. texana* Buckley) the most common associates. However, 13 tree species are prominent in the understory of the typical stand, including post oak, white oak, mockernut and black hickory winged elm (*Ulmus alata* Michx.), black oak (*Q. velutina* Lam.), and blackjack oak (*Q. marilandica* Muenchh.).

(2) The second pine-dominated forest stand in the Ouachitas is a local exotic--the loblolly pine plantation. Forest industry and some private landowners use intensive silvicultural prescriptions to harvest shortleaf pine and oak-pine stands, and to replace that native vegetation with artificially-regenerated plantations established using seedlings of genetically-improved loblolly pine of Arkansas, Oklahoma, or North Carolina origin. These loblolly pine plantations are managed primarily for timber products over rotation lengths of 27-35 years. The silvicultural systems used to manage these stands typically include practices such as ripping to promote seedling establishment and development, broadcast herbicide applications and fertilization to enhance the growth of the pines and decrease the growth of vegetation that competes with the pines, thinning to maintain adequate growth, and pruning to ensure development of clear wood in the butt log of the crop trees. These practices are extremely effective in meeting the goal of growing wood fiber much more rapidly than that typically found in native naturally-regenerated

shortleaf pine stands in the region, with conservative estimates of 20 to 30 percent gain in volume production over local native species (Lambeth and others 1984).

The ecological concern in this practice is that loblolly pine is native only to the southeasternmost part of the Ouachita Mountains. Throughout most of their natural range across the South, and notably immediately to the south of the Ouachita ecoregion in the Upper West Gulf Coastal Plain, loblolly and shortleaf pines can be found in mixture, with loblolly as the dominant pine in most cases. But research papers and photo captions from 70 years ago refer to second-growth "shortleaf-loblolly" pine-hardwood type stands (e.g., Reynolds 1947), which may refer to a plurality of shortleaf pine in mixture with loblolly pine and hardwoods. Conversely, loblolly pine dominates these stands today. The difference may be due to the different regeneration dynamics of these two pines. Shortleaf, a less prolific seed producer than loblolly, resprouts if topkilled by fire as discussed above. But loblolly pines topkilled by fire will not recover. The tactic for loblolly seems to lie in that prolific annual seed crop, which drops adequate or better seedfall 4 years in 5 (Cain and Shelton 2001).

But as one crosses the ecotone northward from the Coastal Plain into the Ouachitas, loblolly drops out of the native forest completely and rapidly, within a span of 20 to 30 miles. That is an unusually rapid change in species composition, and suggests some sort of major ecological influence at work. But the nature of that influence is not clear, and is further clouded by the generally successful development of loblolly pine plantations in the Ouachitas. These plantations grow rapidly, reach reproductive maturity, and observation shows successful loblolly pine regeneration beneath their planted parents. This is not the developmental dynamic one would expect from a species that essentially disappeared in the mountains under pre-Columbian influences.

Moreover, the industry experience with loblolly pine plantations began in the early 1970s, and in the past 40 years there have been only two ecological events that adversely affected these plantations to any important degree. The first was a prolonged drought in 1980, which resulted in some mortality especially of seed sources from North Carolina planted on some of the driest Ouachita hillsides (Lambeth and others 1984) The second was the ice storm of December 2000, which caused mortality only in the window of stands in their late teens that had been recently thinned (Bragg and others 2003). So while there have been some isolated instances of planted loblolly pine stands being adversely affected by natural events, there has been no regional disturbance event to date of sufficient magnitude or duration that would explain loblolly pine's absence from the Ouachitas.

(3) The final and least widespread pine-dominated forest stands in the Ouachitas are shortleaf pine plantations, which are typically been established on National Forest lands but also on some private lands after clearcutting or in response to rehabilitation of cutover or understocked stands. The use of shortleaf pine rather than loblolly on National Forest land relates to the general Agency mission to manage native ecosystems for native flora and fauna. The oldest shortleaf pine plantations on the Ouachita NF approach 70 years of age or older, dating to the 1930s when Civilian Conservation Corps workers were assigned to reforestation work. Today, one would not recognize the older stands as plantations, because the easily-detected rows in which seedlings were planted generally become less obvious as stands mature (Rosson 1995).

Shortleaf plantations are established using similar intensive silvicultural prescriptions as loblolly plantations on private land, but usually involve individual-stem applications of herbicide rather than broadcast treatment, and also usually do not involve pruning. The genetically-improved seed source for shortleaf pine used in these plantations comes from Ouachita families

maintained in a National Forest seed orchard in Montgomery County, Arkansas, in the eastern portion of the Central Ouachita Mountains subsection. However, because clearcutting is required when using artificial regeneration such as planting, the establishment of new plantations on National Forest lands has declined dramatically from the mid-1980s to the mid-1990s (Guldin and Loewenstein 1999). Since 2000, clearcutting followed by planting shortleaf pine has been used on slightly more than 500 ha annually on the Ouachita NF, and each of those instances has been to reforest understocked stands or to convert cutover loblolly pine plantations acquired from forest industry back to shortleaf pine.

Oak-hickory stands

Oak-hickory stands lie at the opposite end of the silvicultural spectrum from pine-dominated stands in the Ouachita Mountains with respect to species composition of course, and also to topography and intensity of management. These stands are most commonly found at two topographic extremes in the Ouachitas. In the highest elevations, stands dominated by post oak, blackjack oak, some white oak and black oak, and black hickory occupy the steep south-facing and north-facing thin-soiled slopes and ridgetops too exposed or too xeric for pines. Some of the most interesting stands in the entire ecoregion are the stunted oak-hickory stands on the ridges on top of Rich Mountain and Black Fork Mountain, where dominant oaks can exceed 100 years in age and yet not exceed 3-10 m in height, and whose reduced stature can in part be attributed to wind and ice (Johnson 1986). Stands such as these support old-growth remnants, and are important sources of dendrochronological records for analyses of disturbance and changing climate (Stahle and Hehr 1984).

Conversely, stands that feature white oak, southern red oak (*Q. falcata* Michx. var. *falcata*), black oak, red maple (*Acer rubrum* L.), and sweetgum (*Liquidambar styraciflua* L.) can

be found in mesic conditions on flat or gentle terrain along ephemeral and perennial streams on low north-facing and south-facing slopes that that in many respects are the most productive sites anywhere within the ecoregion. White oak can become especially important especially on lower slopes on the more mesic sites where the species could probably be managed for timber purposes under reasonable rotation lengths if managers elected to do so. These mesic Ouachita oak-hickory stands will be dominated by white oaks, tending toward post oak on more xeric sites and white oak on more mesic sites. The red oaks such as southern red oak, black oak, and blackjack oak will also be found, though slightly less commonly than the white oaks. Other common species include winged elm, sweetgum, red maple, and flowering dogwood (*Cornus florida* L.).

Ouachita oak-hickory stands are rarely managed specifically for timber products. Foremost among the reasons is that the market for hardwood sawtimber and pulpwood is minimal. Most of the sawmills in the ecoregion are dedicated to pine, and the few hardwoods that loggers are willing to take for firewood or other merchandising opportunities can be filled from the hardwood component in harvested pine stands. Moreover, recent Forest Plans for the Ouachita NF have not placed an emphasis on hardwood management for timber production, although the standards and guides in the Plan do allow for silvicultural activities as needed to improve or restore ecosystems, manage or restore key species of flora and fauna, and to promote hard and soft mast production for use by wildlife species. In landscapes that are being aggressively restored with prescribed fire, the area burned in a single fire has in some cases exceeded 1000 ha at a time. No effort has been made to deliberately exclude hardwood stands from these large burn units, largely because periodic fires undoubtedly have a role in maintaining healthy and sustainable ecological conditions in hardwood stands. Allowing large-scale fires to

roam as they will also places an appropriate degree of natural variation within the burn unit, as the fires will burn with less intensity and even die out on the most mesic sites.

Oak-pine forest stands

The delineation between pine-dominated stands and oak-hickory stands in the Ouachita Mountains is rarely discrete. A transect northward over a Ouachita ridge shows a mesic oak-hickory stand next to a creek; a pine-dominated hillside midway up the south slope, a pine or oak-hickory stand on the ridgetop; a pine-oak or oak-pine stand on the upper north slope, and a white oak-dominated oak-hickory stand on the lower north slope. Almost all of these stands contain both hardwoods and pines; but hardwoods are more likely than pines to occupy the midstory and understory unless surface fires have occurred in the area. The varying proportion of oaks and pines is as much a product of changing past of stand development and disturbance as it is a stable representation of the intermediate stand condition.

Historical accounts (e.g. Smith 1986) outline a systematic harvest of virgin shortleaf pine stands through the Ouachita ecoregion from 1880 to 1920. This harvest activity spread from south to north; railroads were constructed through the mountain passes in the rugged terrain, and then branched out from east to west through the valleys to the ridges. Merchantable pines were cut to a 12” diameter limit, and horse-logged downhill through the network of creek drainages to the railroads in the valleys between the ridges. Small pines below the diameter limit were not cut, and these responded to the suddenly open conditions with continued growth. Other larger pines that were rotten, hollow, and otherwise not useful for lumber were not cut either, but they were capable of producing seed to reforest the site. Harvested stands may also have had some shortleaf seedings and saplings as advance growth prior to harvest, and if they were present, many would resprout after the disturbance of logging. Thus, there was probably a varying degree of pine of

various size and vigor left uncut after the harvest of the virgin stands. Hardwoods, too, were left on the site, especially smaller diameter hardwoods that would not have been cut for local use as lumber, fuelwood, or railroad ties.

The next influence, though, would be an uncontrolled surface fire. One might speculate that with frequent or intense fire, seedbeds would be create for pine seed to germinate, advance growth seedlings and saplings would resprout, hardwoods would be killed, and the developmental direction would be for the subsequent stand to be colonized by pines. With infrequent surface fires, or if fires were controlled, the hardwood residual trees and sprouts would gain the upper hand, and the pines that successfully competed in the stand would also persist, but at lower densities than if more intense or more frequent fires were involved. The influence of the Civilian Conservation Corps in fire suppression during the 1930s may thus have been important in development of oak-pine stands.

Across the South, there is a decrease in naturally-regenerated pine and oak-pine stands, and a concomitant increase in pine plantations (Conner and Hartsell 2002), a trend that is prominent in the Ouachita region as well. Certainly some of the loblolly pine plantations being established by forest industry were planted on sites that had previously supported oak-pine stands. The logic behind this from the company's point of view is that the volume of pine timber growing in either a naturally-regenerated mixed oak-pine stand or a pine-dominated naturally-regenerated stand is much less than that produced in an intensively-managed plantation of genetically-improved pines.

Throughout this discussion, the key is deciding what to manage and with what tools. The Ouachitas have such a variety of conditions, soils, and species that foresters working within different ownership sectors can easily develop whatever spectrum of pine, oak-pine, or oak-

hickory stands that they think is appropriate to meet the prevailing ownership objectives of the landowner.

Fire as an element of Ouachita ecosystems

Fire has been important in these ecosystems for thousands of years. The evidence for this is found in the analysis of fire scars from old pines in the area, from historic observations of explorers and surveyors, and from an understanding of the silvics of the plants that are found in these forests. Fire scar analysis reveals changing patterns in the occurrence of fires over time. Before European settlement, fires generally occurred on the order of every seven to twenty years (Foti and Glenn 1991). However, in the two centuries since European colonization, the fire return interval in the region has become much longer--with some estimates as low as once every 1200 years (Johnson and Schnell 1985). Thus, for some indeterminate period of time before European colonization, fires occurred frequently; since colonization, fires have occurred much less frequently. This has important implications for the dynamics and development of the forest ecosystems of the region, and for their management.

Before European colonization, fire occurrence was a combination of natural ignition and deliberate ignition by Native Americans. Guyette and others (2006) related the occurrence of fire to historic populations of Native Americans, and showed a close correlation between population and fire scars. This creates a strong implication that Native Americans used fire as part of their daily lives. The benefit that Native Americans obtained from the use of fire was probably related to the open understory conditions that burning creates. One might speculate that those benefits would include controlling ticks and chiggers, promoting grasses and browse for wildlife, and clearing openings for agricultural use. In addition, projectiles such as arrows will fly longer and

more accurately in the open rather than through brush, which would have value both in hunting and perhaps also in community defense from marauding wildlife or aggressive neighbors.

The need for fire control was real in the 1930s, because wildfire in cutover stands was a problem for resource management and conservation. The first field survey of Arkansas forest conditions was made in 1929, and reported that of the 22 million total acres of land remaining in forest at that time (about two-thirds of the area of the State), 20 million had been cut over; moreover, 70 percent of this had been severely damaged by wildfires, with millions of acres burned annually (Roberts and others 1942, Beltz and others 1992). The need for fire suppression and control was an important element in the expansion of the forestry profession especially in state forestry agencies such as the Oklahoma Forestry Commission (now Oklahoma Forestry Services), established in 1925, and the Arkansas Forestry Commission, established in 1931. Firefighting was a primary reason for their establishment. But it took the end of World War II and the educational investment of the GI Bill for returning soldiers and sailors to educate professional foresters for Federal and State agencies in numbers sufficient to effectively control wildfires.

Harvesting the virgin forest, rampant wildfires, and effective fire suppression combined over a seventy-year period from 1930 to 2000 profoundly altered forest ecosystems in the Ouachita Mountains. The change was especially pronounced with respect to reproduction dynamics and stand development. Ecologically, a vigorous midstory woody vegetation component thrived in the absence of fire. Excluding fire over these seven decades led to a change in habitat conditions from open forests and woodlands to closed canopy forests with a prominent midstory. With the loss of that open habitat came the decline in populations of species that thrived in open forest and woodland conditions such as woodland bison (*Bison bison athabascae*

Rhoads) and eastern elk (*Cervus elaphus canadensis* Erxleben), both extirpated in the nineteenth century. Also greatly reduced in extent were prairie flora such as purple coneflower (*Echinacea purpurea*), bluestem grasses (*Andropogon spp.*), flowering plants such as birds-foot violet (*Viola pedata*), pollinators such as the Diana fritillary butterfly, and birds such as the cavity-nesting red-cockaded woodpecker (*Picoides borealis*) which is currently on the endangered species list.

The regeneration ecology of shortleaf pine and the oaks closely follow this natural dynamic. Fires benefit the establishment and development of shortleaf pine for a number of reasons. Most pines germinate best on exposed mineral soil; fires promote a patchy distribution of mineral soil for optimum seed germination and seedling establishment. Shortleaf pines up to about 8 years in age also have a unique silvical trait not shared by the other southern pines—the ability to re-sprout if topkilled. The significance of this was appreciated by foresters early on when Mattoon (1915) discussed the trait as an adaptive advantage in response to frequent fires. The importance of this trait is that if fire burns a cutover or understocked stand, regeneration of the pines can occur either through seedfall after the fire or through resprouting of the existing advance-growth seedling and sapling pines that existed on the site before the fire.

Similarly, the oaks are adapted to advance-growth regeneration dynamics (Johnson and others 2002) in which resprouting and dieback of the shoot of the seedling and sapling continue over time. Over time a robust root stock develops, and eventually a sapling will become permanently established and grow into the midstory and overstory. In the absence of fire, the shoot of the oak will persist in the understory until overstory shading causes it to die back to the root collar, and recruitment of the sapling into the midstory and overstory will be slow. But if frequent surface fires occur, the process of growth and dieback of the shoot occurs more rapidly,

the rootstock grows more rapidly, and the development of the sapling into the midstory and overstory occurs more expeditiously.

With fragmentation of the Ouachita by different ownership and varying degrees of agricultural development, it is unlikely that forest managers will see widespread fires restored across the entire into region. The best example of restoring fire in these ecosystems is found in the western Ouachita Mountains on national forest land in the Shortleaf Pine-Bluestem Management Area. Here, managers have developed a prescriptions for ecosystem restoration that use commercial timber sales to reduce overstory density, mechanical treatments to remove the midstory hardwoods that have developed under seven decades of fire exclusion, followed by the re-establishment of a program of cyclic prescribed burning (Hedrick and others 2007; Guldin and others 2004a). When that management area has been fully restored, about 100,000 hectares of the Ouachita forest land will have structure and function similar to that of pre settlement conditions.

However, management activities on the remaining 97% of the Ouachita landscape will have to be managed in ways that do not utilize sustained cyclic prescribed burning, but that nevertheless reduce the levels of fuels so as to minimize risk of loss of forest stands to wildfire, an increasingly important consideration in society's growing wildland urban interface.

FUELS AND FUEL MANAGEMENT IN THE CONTEXT OF SILVICULTURE

From a forest management perspective, the vegetation that has developed as overstocked overstory trees, excessive numbers of midstory trees, and standing or downed dead trees and branches all represent biomass that has built up as a result of the exclusion of fire in the Ouachita ecosystems. That biomass is also flammable material that can maintain, support, increase the

intensity, and otherwise exacerbate conditions associated with wildfires in the State. Fuels treatments represent a subset of intermediate silvicultural treatments specifically designed to reduce that material in the short term, so as to alter the behavior of wildfires should they occur. But a more profound impact on forest management is made not through short-term stopgap solutions to fuels, but in long-term programmatic management practices that integrate fuels treatments with the larger long-term ownership objectives of the landowner. Fuels treatments are therefore more robust if they are examined as part of a larger and integrated program of silvicultural treatments called a silvicultural system (Smith and others 1997). (See Chapter 2 for a larger description of silvicultural treatments and systems.)

The individual treatments in the practices of silviculture can fit in several categories—treatment of the forest site, the forest floor, the woody vegetation in the main canopy, the woody and non-woody vegetation in subordinate canopy positions, and the residues of vegetation. While these treatments are designed to achieve specific goals in forest stand dynamics and development, all have ancillary effects with respect to the accumulation or reduction of biomass residues when viewed from the perspective of wildfire hazard and risk.

Identification of fuels in a silvicultural context

The silvicultural system is little more than a long-term plan for the stand being managed. It is implemented using a silvicultural prescription containing a planned set of treatments, each applied at a given point in time, and intended to guide the stand to its desired future condition. But in some situations, events conspire to interrupt the long-term plan. For purposes of a discussion of fuels, that event is triggered when enough plant material exists in the forest stand to pose a threat to the continued life of the stand in the event of an uncontrolled fire.

Fuels are the living vegetation and detritus from dead vegetation that accumulates in the forest through natural or managed events. They are found as logging slash, pruned branches, and vegetation in the various canopy strata of the forest. The term can include living trees and non-woody vegetation, and also dead material that is still attached to live standing trees or dead snags, and also dead material that has fallen to the forest floor but has not yet decomposed.

The biomass of material that can be called fuels changes during the course of a rotation. It follows that some periods of stand development produce more or different kinds of fuels than others. It also follows that the main canopy of the stand is more susceptible to loss from fire at some periods of time than others, despite the fact that the biomass of material may not be as great as during other points of time in the rotation.

The absolute level of biomass is not the concern of fuels treatments; rather, the key is the effective implementation of treatments placed in the right stands at the right time. The danger is that without timely or effective fuels treatments, fires can ignite a given level of biomass that is distributed in certain ways at highly sensitive times of year, resulting in the loss of the entire stand. In uncontrolled fire conditions, the resulting conflagration will jump from stand to stand, and the losses will accumulate unacceptably across the landscape before the fire can be contained.

The question of what constitutes fuels, and of when and how to treat fuels, is complicated by the fact that wood and wood fiber have monetary value. In the ideal world, fuels can be treated as an element of broader silvicultural treatments that involve identifying a desired complement of trees to retain, by the partial harvest and commercial sale of trees surplus to that desired complement, and by then using some of the proceeds from the commercial sale to reduce any residual fuels to an acceptable level. The situation is made less than ideal if there are no local

markets for commercial sale, if harvesting is precluded in a stand for some reason, or if natural disturbance events adversely affect the commercial value that a stand might have.

In the Federal ownership sector, there are two sources of funds for treatment of fuels—funds generated through timber sale proceeds that can be reinvested to manage fuels in the harvested area, or funds appropriated to the Forest Service through Congress to manage fuels. A program of fuels treatment that relies on sale proceeds will be more effective in the long term, because it will allow larger areas to be treated more rapidly, making a faster and more durable ecological change on the landscape—essentially, a sustainable stand structure in a fuels context. That then allows the more scarce appropriated funds of the agency to be applied strategically in stands that are not in a condition, or a location, in which the agency timber sale process can be effectively applied. In the private sector, there is far less opportunity to tap Congressional funds for fuels treatment, except through Federally-supported landowner assistance funds which are both scare and competitively distributed. Thus, fuels treatments are unlikely to occur on private lands unless proceeds from harvest activity in the stand in which the fuels exist can support the treatment.

This also explains the interest in biomass in both the public and private sector. Wood fiber that has previously been too small for commercial use might become commercially operable if markets for biomass and biofuels can be developed. That potential could lower the size threshold for commercial value, allowing smaller material (perhaps including branches and twigs) to be sold. This might have ecological implications if carried to extremes, but it would be useful if smaller standards for merchantability could allow more stands to be self-sustaining in fuel treatment costs.

Regeneration treatments

Both natural and artificial regeneration is used to regenerate shortleaf pine-dominated forests in the Ouachitas, whereas loblolly pine plantations in the region are by definition established with artificial methods. Planting either loblolly or shortleaf pine after clearcutting in the Ouachitas is not a trivial matter, because of the high stoniness of the soils and the late summer droughts common in the region. Two elements have enhanced plantation survival. The first is to plant a seedling with a big root collar (Brissette and Carlson 1992), which promotes root development during the growing season and enhances the chances of the seedling to survive. The second is to prepare a suitable planting spot through the intensive site preparation technique called ripping or subsoiling, by using a bulldozer to plow a furrow into which the seedling is subsequently planted. In combination, these practices improved plantation survival in the Ouachitas by 10-30 percent (Walker 1990).

Natural regeneration of shortleaf pine and hardwoods in the Ouachitas can be accomplished using either even-aged or uneven-aged methods, but some methods work better than others (Guldin and others 2004b). Studies show that shortleaf pine produces only 3 to 5 adequate or better seed crops per decade (Shelton and Wittwer 1996, Wittwer and others 2003); moreover, there is considerable geographic variation in seedfall with higher amounts in the eastern Ouachitas and lower amounts in the western Ouachitas.

Practicing silviculturists see advantages in using prescribed fire as a site preparation tool, which is easier to implement in even-aged than uneven-aged stands. There is also a practical preference for using group selection rather than single-tree selection when using uneven-aged reproduction cutting methods, because logging is less damaging (groups serve as logging decks), the groups can be drawn on a map to assist contractors site preparation and release treatments, and the matrix between groups can retain hardwoods for wildlife and aesthetic reasons. These

elements suggest that research scientists have more work to do to better quantify regeneration dynamics and development in shortleaf pine stands, because there are some yet-to-be-answered questions about stocking and distribution of regeneration resulting from their application.

The sprouting habit of shortleaf pine might be useful in silvicultural applications in the context of pine regeneration accumulation, where foresters might rely upon both new seedlings and sprouts from established sapling rootstocks to regenerate a stand (Guldin 2007). A properly-timed surface fire in a stand with some existing shortleaf pine saplings will result in topkilled seedlings that subsequently resprout, and will also create exposed seedbed conditions favorable to germination of new seedlings. Repeated fires of proper intensity thus serve the dual advantage of both controlling fuels and developing a cohort of pine saplings and sprouts to naturally regenerate the site after disturbance or reproduction cutting.

There have been no dedicated studies on oak regeneration in the Ouachitas. But many studies of oak regeneration in upland forests, including studies in the Ozark Highlands of Arkansas and Missouri, suggest that the principles of oak regeneration established elsewhere would most likely be successful. Those principles suggest 1) that successful oak regeneration depends on the presence of competitive regeneration sources at the time substantial overstory removal is made, and 2) that when the regeneration sources are absent, treatments to develop competitive oak regeneration sources must be applied and might require a decade or two prior to harvest to be effective (Johnson and others 2002, Loftis 2004). As with the pines, the objective is to accumulate enough sources of oak regeneration—seedlings, saplings, and stump sprouts—so that the probability of successful regeneration is high.

The first step is to evaluate the existing oak regeneration potential in the stand using established guidelines (Sander and others 1984), and decide if supplemental regeneration sources

are needed. If these are adequate, reproduction cutting can be imposed directly. If not, one should either wait for a good acorn crop, underplant oak seedlings, or both. Controlling competing vegetation in the understory and midstory is important to promote the development of the oak seedlings and seedling-sprouts.

The role of prescribed fire as part of a regeneration prescription has not been fully explored, but one might expect fire to contribute to maintaining or increasing the vigor of oak seedlings and saplings, as well as discriminating against fire-intolerant competing species in the understory. Numerous studies are underway to investigate fire effects on oak regeneration and to better define how it might be used.

Intermediate treatments

Three basic practices comprise the bulk of intermediate silvicultural treatments for the Ouachita ecoregion—release, thinning, and pruning. All have effects to be considered for fuels management, because the byproducts of intermediate treatments are often of marginal commercial use.

In the Ouachita ecoregion, release treatments typically consist of removing small hardwoods or herbaceous plants competing with small pines that are less than ten years old. Release can be done using chemical, mechanical, or ecological methods. Herbicides offer the most permanent solution to the elimination of competing vegetation because both shoots and roots of the hardwoods are killed and there is no resulting resprouting. But topkilling the hardwoods may be sufficient to allow the pines to prosper. If so, mechanical treatments and prescribed burning treatments both can be applied. However, prescribed burning in young stands requires an experienced crew and a cool fire; backing fires ignited using hand tools in the coldest

months of the dormant season are a good combination of intensity and timing to apply in these stands.

Thinning is used in immature and mature stands to reduce stem density of trees primarily by removing trees of poor quality, form, vigor in order to promote the health and vigor of the trees that remain (Helms 1998). In the Ouachita Mountains, thinning is used in both pine and hardwood stands, but treatment acreage in pines far exceeds treatment acreage in hardwoods given that both Federal land managers and forest industry foresters in the region concentrate on management of pine-dominated forest stands.

Almost by definition, thinning is a major tool foresters have to reduce the volume of fuels in a forest stand. At the stand level, thinning reduces biomass in rough proportion to basal area; retaining 75 percent of basal area after thinning will result in about the same proportion of biomass being retained. The pattern of thinning might affect the size class and distribution of the biomass being removed, which may result in some treatments being more effective than others for purposes of reducing fuels. A key consideration is whether the thinning can be conducted using a commercial timber sale. Payments made to the landowner from timber sales can then be reinvested in treatments to further reduce fuels, especially fine fuels such as branches and tops that might not have been hauled from the stand during logging.

Thinning done in stands too small to sell commercially is called precommercial thinning, and is the biggest single challenge in fuels treatment of forest stands. Stands that are candidates for precommercial thinning in the Ouachita Mountains are usually overstocked with small trees of marginal to no commercial value, with a high number of stems dead trees standing or down, and dead needles draped over the lower branches of the trees. Stands such as this are at a high hazard of loss from fire, and the two treatment options are both costly. The first is to conduct the

precommercial thinning using either appropriated dollars on public lands or out-of-pocket dollars on private non-industrial lands. The second is more risky--wait until the stand grows to commercial size, hope that the stand does not burn in the meantime, and then prescribe a commercial thinning.

Pruning is a relatively unusual intermediate treatment in other forest types, but it is commonly applied in the Ouachitas in loblolly pine plantations managed by forest industry for wood production. This treatment removes living and dead branches from the stems of trees up to a certain height from between 10 to 20 feet, so that the wood that is produced on the bole after the pruning is free of knots. The byproduct of the treatment is a mat of dead branches and needles around the base of the tree. Because all these branches and needles are close to the ground, natural decomposition reduces this threat in a year or two. However, for that short period of time, there is a high hazard and risk of widespread mortality should wildfire occur.

Reproduction cutting methods

The first indicator of forest sustainability is found at the stand level--whether, when a reproduction cutting is made, a new cohort of the desired species is successfully established in conditions that will allow it to grow and develop in an acceptable manner. Even-aged and uneven-aged methods are both used in the Ouachitas to sustainably manage the forest types in the region.

Clearcutting is common in the Ouachita Mountains, especially in pine-dominated stands on private lands managed by forest industry. The typical silvicultural prescription is to clearcut the stand, utilizing as much biomass as can be removed, to conduct supplemental site preparation treatments to dispose of logging slash and competing vegetation as needed, to use ripping to prepare the site for planting, and then to plant with genetically-improved loblolly pine planting

stock selected for rapid growth as well as some degree of drought tolerance. When used on public lands, improved shortleaf pine planting stock is used. Clearcutting has been a controversial practice in the Ouachitas because of the unsightly aesthetic appearance of recently-harvested stands. But there is no question that, silviculturally, clearcutting is an effective reproduction method that quickly results in the establishment of a new fast-growing stand of species that are sought by land managers and landowners.

The seed tree and shelterwood methods are more commonly applied on National Forest lands in the region. Current management plans on national forest land under both methods calls for some of the residual seed trees to retained through the life of the new age cohort so as to provide structural diversity in the new stand. However, removing the seed trees in either method after the new age class is adequately established is feasible on private lands if the landowner so desires.

Uneven-aged silviculture has been used in the region since the 1950s by family lumber companies and forest industry landowners. The single-tree selection method is used occasionally on private lands to grow large high-quality shortleaf pine sawtimber. Uneven-aged structure can be sustained in these stands by cutting cycle harvests every 10 years that retain about 5000 board feet of volume in 60 square feet of basal area of the best trees across all size classes. These stands have annual growth rates of approximately 200 board feet per acre and 2 square feet of basal area, which give operable cutting cycle harvest volumes of about 2000 board feet every ten years. Control of competing hardwoods using herbicides roughly once every ten years is generally needed to maintain pine sapling development.

Since the early 1990s, changes in management on national forest lands have resulted in a commitment to broaden the use of uneven-aged silviculture in pine and pine-oak stands on public

lands. The single-tree and group selection prescriptions that are being applied are somewhat less intensive than the industry single-tree selection method because retaining some hardwood component within these managed stands is desired. Most of the applications to date are still in the early stages in the transition from mature second-growth even-aged pine and pine-oak stands to uneven-aged structure.

As is the case throughout the U.S., there has been virtually no long-term experience in the Ouachita Mountains with multiple entries using the group selection method. Questions remain as to whether the group identity can be retained in the long run, and whether doing so is even important in the long term. In all likelihood, the group selection methods will probably gravitate more toward a single-tree selection method as multiple age cohorts are established, and stand structure becomes more balanced.

By definition, uneven-aged reproduction cutting methods in southern pine stands create discontinuous stand conditions. They provide a temporally and spatially transient distribution of logging slash and debris within the stand, resulting in a heterogeneous distribution of volatile fine fuels. This reduces the need to treat fuels, since there is less of a chance that the entire stand will have fine fuels throughout, but it also makes it difficult to treat those fuels if one should decide to do so. The added complication is that pine regeneration is being recruited in a discontinuous spatial pattern as well, and recruitment is repeated following every ten-year cutting cycle. As a result, stand-wide treatments such as prescribed burning are difficult to implement in uneven-aged stands. On the one hand, fuels are sufficiently heterogeneous to confound uniform fire effects and fuels treatment. On the other, the logging debris is concentrated in the openings where the desired regeneration is found, and the saplings won't survive the fire. More research is needed to better understand the degree to which uneven-aged

stands can be managed with fewer age cohorts obtained every two decades rather than one, which might provide a window during the second decade when prescribed burning would not kill the youngest age cohort.

Not many hardwood stands in the region are actively managed for hardwood species, because management for pines is more productive in growth and yield, and there is a far less vigorous forest products market for hardwoods than for pines. But for landowners interested in white oak, the dominant commercially valuable hardwood species in the region, the clearcutting method and the shelterwood method both can be successfully applied. To do so, one must have sufficient oak regeneration potential in the stand (as discussed previously) prior to making the harvest, and this must be followed with site preparation treatments appropriate to encourage the development of the different sources of oak regeneration on the site.

The nearest successful example of uneven-aged silviculture being successfully in oak-hickory stands is found in the Missouri Ozarks on the Pioneer Forest (Iffrig and others 2008, Flader 2004, Loewenstein and Guldin 2004). However, to date there has been no effort to translate the reasonable silvicultural approach used on the Pioneer Forest to oak-hickory stands in the Ouachita Mountains. That is partly due to the absence of markets, to the generally higher site quality of oak sites (especially white oak-dominated lower north slope sites) in the Ouachitas, and perhaps also because the silvicultural systems used on the Pioneer Forest have not been effectively tested in other oak-hickory stands across the South.

Unique silvicultural systems

Two unique silvicultural systems merit some special consideration in the context of fuels treatments in the Ouachita Mountains. One is the excellent work done for shortleaf pine-bluestem grass restoration on national forest land in the region, which has a management goal of

roughly 100,000 ha over time (Guldin and others 2004a, Hedrick and others 2007). The other is the equally excellent intensive forest management practiced on roughly 800,000 ha by forest industry on their timberlands in the region. Both practices have been successful in achieving the goals of their respective ownerships, and the scale of application for both is large enough to have considerable ecological and silvicultural effects on the region's forestland.

COMMON FUELS TREATMENTS IN THE ECOREGION

The concept of fuels treatments is in large measure a popular name for a classically-established subset of silvicultural practices in the Ouachita Mountains that contribute to a reduction in standing and down woody biomass. In that context, a number of practices that have been discussed merit specific mention in the context of fuels treatments.

Timber Harvesting Treatments

Harvesting activity such as reproduction cutting and thinning removes large piece sizes from the stand being harvested, but adds a considerable amount of fine fuels within the stand. Although decomposition rates are rapid as would be expected in the Humid Subtropical Domain, the volume of material and the hazard it presents can be a threat between harvest and decomposition. Supplemental standards in harvesting such as lopping and scattering the slash will speed the rate of decomposition, but this comes at a cost because of the extra work involved. The current interest in biomass utilization may result in more complete utilization of biomass during harvest. Otherwise, supplemental site preparation treatments such as mechanical reduction of excess biomass or prescribed burning two or three years after harvest may be prescribed.

The greatest potential watershed impact in harvest activity is associated with logging activity in the woods and on skid roads which can adversely affect forest soils, and with log transport activity on permanent roads resulting in sediment delivery directly to creeks. The application of best management practices is voluntary in both Arkansas and Oklahoma, but attention to the rules set forth in the voluntary BMP guidelines for the respective States is a good place to start to minimize adverse effects from skidding and hauling. A more in-depth discussion of these effects is found in Chapters 12 and 13.

Prescribed Fire Treatments

Prescribed fire is generally applied as either a site preparation or an intermediate treatment with a goal of cleaning and release in even-aged naturally-regenerated shortleaf pine, pine-hardwood, and hardwood stands, and pine plantations, in the region. The prescription is usually applied on Federal lands, where burns in the dormant season through the early part of the growing season typically are conducted from January through April. Forest industry avoids using prescribed fire on their lands because of concerns about unwanted reductions in growth and yield in the loblolly pine plantations that they manage. Private non-industrial landowners typically do not have access to the personnel required to efficiently burn large areas, and liability issues are also limit a broader application of prescribed burning on private lands.

When prescribed fire is used, the ignition source depends on the condition of the landscape being burned, whether there are young stands within the landscape that need special attention to withstand prescribed fire, and the proximity to private land. Burn units near or interspersed with private land are usually burned with drip torch ignition earlier in the burning season, so as to better control the intensity or burning and the area covered by the fire. Young stands are often burned very early in the growing season, again using drip torches, so as to

consume fine flashy fuels that might create too hot a fire if burned later in the growing season. Otherwise, especially in large well-burned landscapes where sensitive stands have been pre-burned, aerial ignition is preferred because of the efficiencies gained in cost and labor that results from burning large areas.

The watershed effects of prescribed fire are usually minimal. Vegetation recovers quickly after prescribed burning in the Ouachita Mountains, and the risk of direct erosion through overland flow is minimal. Smaller fires ignited directly with drip torches are often imposed at a stand level, and in these cases permanent and intermittent stream channels usually provide an opportunity to establish one of the boundaries of the burn unit. The intensity of larger fires ignited by aerial ignition can be adjusted by the spacing of the incendiary spheres dropped from the helicopter, and stream channels are likely to burn with lower intensity if no spheres are dropped within them or if soil conditions in the stream zone are wet, as they usually are in the spring. The greatest likelihood of unwanted watershed effects is if firelines directly cross perennial or intermittent streams, and this can be avoided as conditions warrant.

Mechanical Treatments

Mechanical treatments associated with site preparation and intermediate prescriptions are widely applied in lieu of prescribed fire on all ownerships in the region regardless of species composition. The silvicultural objective generally depends on the ownership, the origin of regeneration (whether natural or planted), on the silvicultural system being applied, and the cost able to be supported by the landowner.

The goal of site preparation treatments is to reduce logging slash and competing vegetation, and to prepare the seedbed. Usually, the intensity of treatments prescribed depends on whether natural regeneration or planting is to be used, with more intensive site preparation

activities usually being conducted for plantation establishment. In even-aged reproduction cutting, harvest activity removes all of the commercial timber, and the non-commercial residual biomass is removed by mechanical felling (shearing, chopping, or chain-saw felling), sometimes concentrated by piling, and then either broadcast burning or burning of piles is conducted to eliminate slash from the site. Ripping usually follows again in late summer, with planting feasible in the following spring. Bedding is not typically used in the Ouachita Mountains because of the extreme rockiness of the soils.

Soil displacement as a result of site preparation is a concern for cumulative watershed effects of silvicultural activity. Prescriptions that require logging debris to be raked, pushed, or dragged into rows or piles cannot be accomplished without some degree of soil movement; the less of this activity that is prescribed, the less of a problem there will be with soil movement. Ripping is designed to deliberately promote soil movement so that rainfall can wash soil particles from the sides of the rip into the furrow, thereby to create an ideal planting medium and increasing the survival of planted seedlings. Cumulative watershed effects can be minimized by ripping along the contour, by creating periodic discontinuities of the rip along the contour so that flow within the rip is interrupted, and by stopping the ripping before sensitive watershed areas such as stream zones are encountered. However, in essence, ripping along the contour at 10-foot spacing creates a hillside of small firelines, which impede prescribed fires such as site preparation burning. Site preparation burns on ripped sites are best made using drip torches, dropping fire between each rip. Once the rips are grassed over, though, prescribed fire can carry across the rips without a problem.

Intermediate mechanical treatments include activities to reduce fuels such as chipping or mulching. This activity is expensive, however, and thus is typically reserved for situations in

which the possibility exists that an uncontrolled fire might escape across property boundaries. There have been several recent disturbance events such as windstorm and ice storm in the Ouachitas over the past decade that have resulted in down woody debris across land lines, and these are a high priority to reduce with chipping and mulching. These treatments produce a rather thick layer of chips and residues that usually remain in place within the stand, and that do not burn easily. Cumulative watershed effects would be minimized by the simple expedient of not operating the mulchers or chippers within stream zones.

Of course, the problem with mechanical treatments is that only the tops of trees are removed; rootstocks remain. Hardwood rootstocks without hardwood tops quickly become hardwood sprouts, and sprouting hardwoods especially provide unwanted ecological influence on developing pine seedlings and saplings. This is not because of any inherent superiority or inferiority of hardwoods over pines ecologically, but rather because the competitive superiority in height growth between sprouts supported by a large pre-existing root system versus a seedling supported by its own small developing root system. This imbalance threatens the seedling with suppression by the sprout.

Chemical Treatments

When one seeks a more permanent approach to sprout control either through cleaning, weeding, or release treatments, the best treatment to use is an herbicide applied in a manner that kills both the tops and the roots of the sprouts. Aerial application of herbicides is effective when the goal is to control hardwoods competing with pines; a number of chemicals and application methods exist that allow for control of hardwoods with minimal effect on pines. For example, late-summer herbicide application targets the seasonal window when hardwoods are still photosynthetically active but pines are dormant; this concentrates the herbicidal effect on the

hardwoods rather than the pines in a way that allows stands to be treated with a single treatment that is easy to apply over large areas either by helicopter or skidder. Individual-stem treatment methods are more labor intensive, but have several advantages in specificity of target application and minimizing non-target effects. These treatments are usually done in one of two ways-through mechanical felling of a tree with hand tools followed by applying herbicide directly to the cut stump, or by using a backpack sprayer to apply herbicide directly on the foliage of the tree targeted for removal. Although these methods are labor-intensive, they minimize the volume of herbicide applied across a stand, and they are specific to a target tree rather than a target species—meaning that they can be used in pine-hardwood, hardwood-pine, or hardwood stands release desired hardwoods from competing hardwoods. These differences in application often reflect ownership differences as well; the broadcast methods are more typically conducted on private lands, and the individual-stem applications are more common on public lands.

The cumulative effects of herbicide applications are considerably lower than decades ago. Modern herbicides are developed to act specifically on plant metabolism such as through inhibition of photosynthesis or inhibiting the synthesis of amino acids that are limited to plants, and thus have much lower non-plant effects than herbicides used in the past, and a short half life in the environment is also a desirable attribute. Watershed effects are generally limited to the movement of soil solution containing the herbicide prior to its degradation in the environment, and also by the general chemical activity of the inactive ingredients of herbicide formulations such as carriers and surfactants. The common safety precautions used in applying herbicides should be applied to limit cumulative watershed effects, such as application setbacks from sensitive areas, avoiding direct application to streams, and attention to environmentally safe loading and cleanup procedures.

Across a region, cumulative watershed effects are a function of the proportion of forest land in ownership sectors that vary in their ability to rigorously address and monitor those effects. In many respects, the Ouachita Mountains are in a better place than many other regions of the eastern United States because of the percentage of area within the region that is under an effective program of sustainable forest management, and the infrastructure in place as part of that overall management program to comply with best management practices. As noted above, two-thirds of the forest land is managed by either forest industry or Federal agencies, more than elsewhere in the east. These landowners and managers have a highly capable infrastructure in place to control wildfire, to efficiently process unwanted forest residues (usually as part of commercial timber sale or harvesting activity), and otherwise to integrate specific attention to fuels, treatment of fuels, and minimization of cumulative effects from treating fuels as part of their larger forest management program.

Forest lands owned by forest industry in the Ouachitas are primarily under an intensive program of even-aged forest management emphasizing clearcutting and planting for commercial timber and fiber production. On these lands, management activities are carried out with keen attention to prompt reforestation, effective site preparation and release, timely thinning and pruning, and efficient reproduction cutting. Industry foresters are rightly proud of their efforts to execute this intensive program of silviculture with a minimum of adverse cumulative watershed effects, and in doing so have agreed to be bound by independently-verified Sustainable Forestry Initiative standards for compliance with best management practices.

Similarly, public ownership in the region is dominated by the Ouachita National Forest. Again, these lands are managed under a comprehensive Land and Resource Management Plan using a diversity of both even-aged and uneven-aged silvicultural systems, and include

comprehensive standards for ensuring that forest operations conducted under the timber, water, recreation, lands, and engineering programs are carried out in compliance with best management practices, all of which are detailed in public records.

The non-industrial private forestry sector is the more variable sector in this regard. Owners of these forest lands are less likely to be under a management plan, less likely to know what the hazard of fuels buildup is, somewhat less likely to be able to respond to risk of wildfire (as that is a state responsibility taken seriously by the respective state agencies in Arkansas and Oklahoma), and less likely to be proactive in integrating fuels treatments into an overall program of silvicultural activities specified by management plans for their forested property. Finally, cumulative watershed effects on non-industrial private lands are addressed by best management practices issued by State forestry agencies that are voluntary only. The greater the degree to which non-industrial private forest lands can be brought under management plans, advised by professional foresters when making harvest decisions, or involved in public or private management assistance programs, the better will be scientific basis of the silviculture that is applied on their lands, and the fewer will be the cumulative watershed effects from improper attention to fuels and fuels treatments.

CONCLUSIONS

Fuels are a subset of the living and dead vegetation found within every stand in the forest. They are important insofar as their size, biomass, and distribution contribute to the risk of loss of the forest in the event of uncontrolled wildfire. Similarly, tools such as prescribed fire, fire surrogate treatments, and fuels treatments are a subset of a broader array of general silvicultural practices typically applied within forest stands and landscapes as a result of forest management

activities generally. These tools for fuels are most effectively implemented if they fall within the context of the larger silvicultural systems being imposed within stands and landscapes, rather than as stand-alone treatments applied at a given point in time. In light of this perspective, the cumulative watershed effects of fire, fire surrogate, and fuels treatments are best characterized as similar to those that occur as a result of forest management activities generally. Unlike other regions in the South, two-thirds of the Ouachita Mountains forest landscape is under management, either by Federal or forest industry landowners. Active management under the guidance of professional foresters is the most effective way to integrate fuels treatments, and to minimize their cumulative watershed effects, as elements of a larger program of active forest management.

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Figure 1. Mean monthly high, average, and low temperatures (in degrees Celsius) for the Ouachita region, compared with the mean monthly average temperature at Little Rock. Source: National Weather Service, Little Rock (web access, active on 1/8/2008, http://www.srh.noaa.gov/lzk/html/climain.htm), Southern Regional Climate Center (web access, active on 1/8/2008, http://www.srcc.lsu.edu/southernClimate/arkclim/)

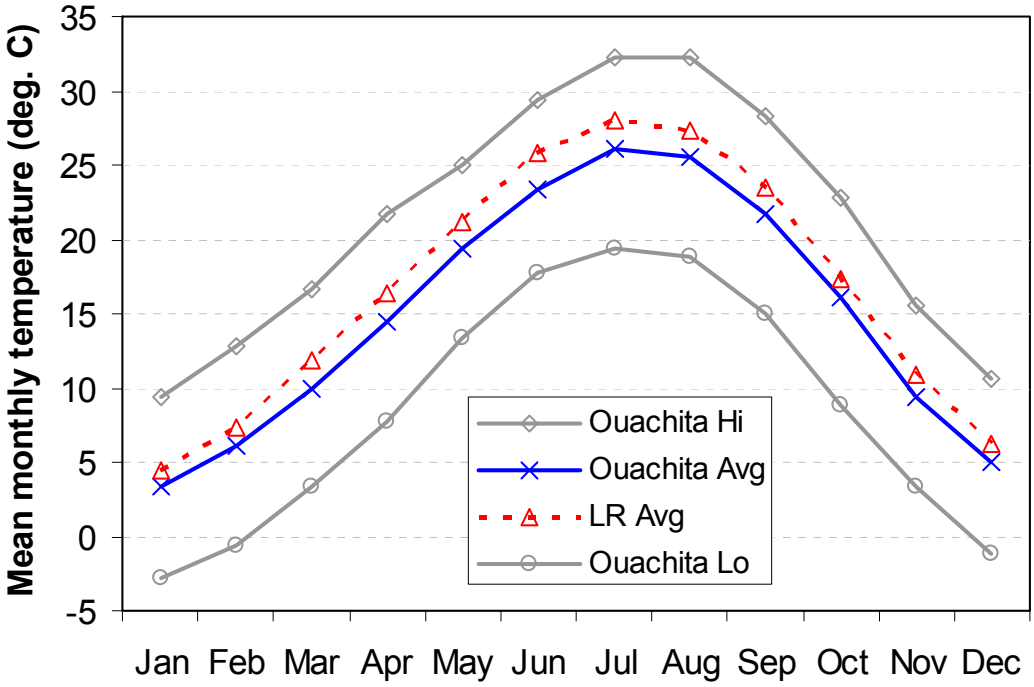

Figure 2. Mean monthly precipitation (cm) for the Ouachita region and for Little Rock. Source: National Weather Service, Little Rock (web access, active on 1/8/2008, http://www.srh.noaa.gov/lzk/html/climain.htm), Southern Regional Climate Center (web access, active on 1/8/2008, http://www.srcc.lsu.edu/southernClimate/arkclim/)

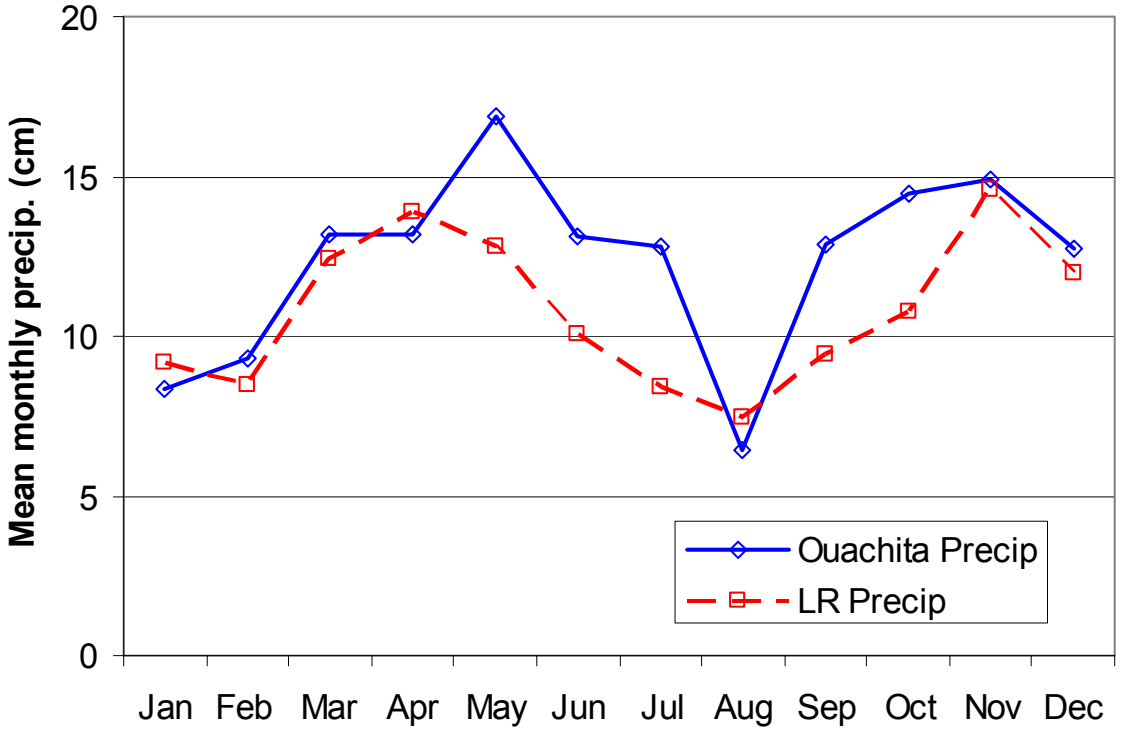

Figure 3. The ecological subsections in the Ouachita Mountains lie to the south of the Arkansas River Valley in western Arkansas and eastern Oklahoma. Cities are absent within the Ouachitas largely because of of the rugged terrain, which impedes transportation and commerce.

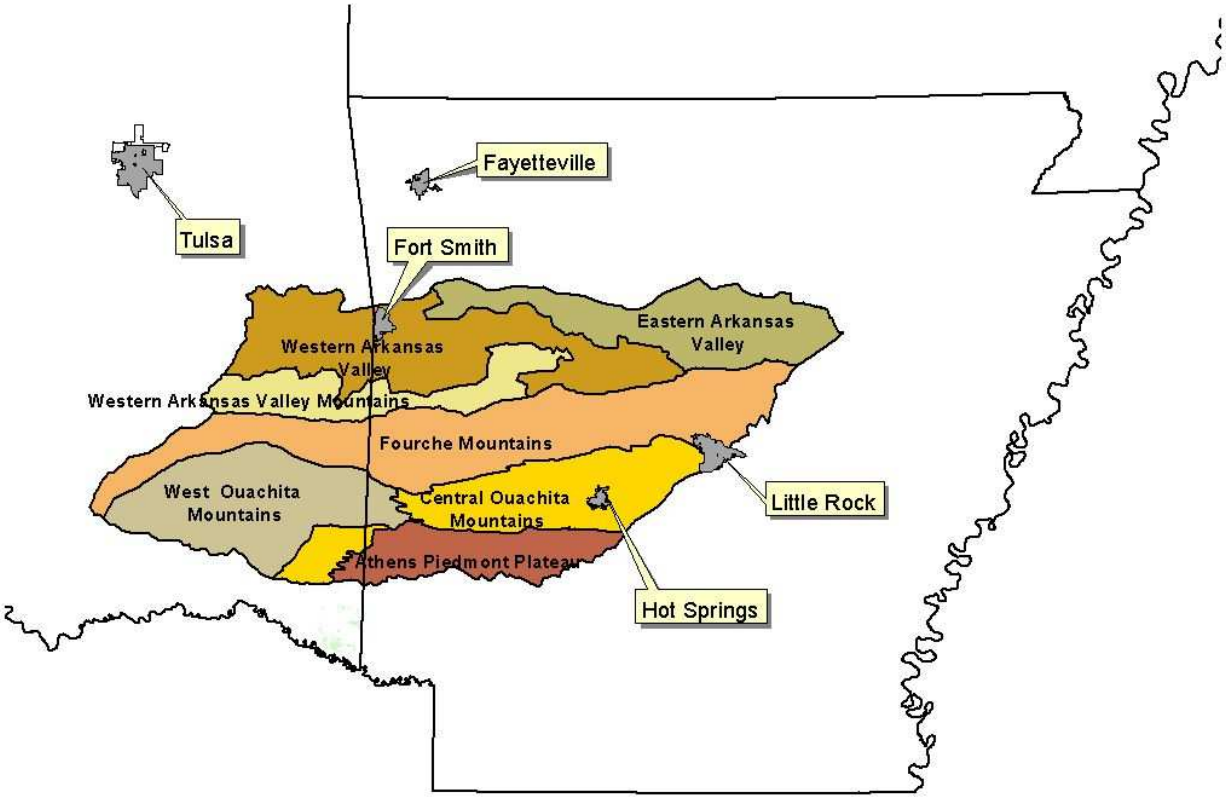

Figure 4. Mature second-growth shortleaf pine-dominated stand in the Ouachita Mountains, with typical development of midstory and understory in the absence of prescribed fire. (Photo by James M. Guldin)

Figure 5. Mature second-growth shortleaf pine-dominated stand in the Ouachita Mountains after overstory thinning, midstory reduction, and reintroduction of cyclic prescribed burning. (Photo by James M. Guldin)

Figure 6. Loblolly pine plantation after prescribed burning and first thinning near Waldron, Arkansas. (photo by James M. Guldin)

Figure 7. Shortleaf pine and hardwood regeneration 12 years after seed cutting under the seed tree method in a shortleaf pine stand near Mount Ida, Arkansas. (Photo by James M. Guldin)

Figure 8. Shortleaf pine and hardwood regeneration 12 years after seed cutting under the seed tree method in a shortleaf pine stand near Mount Ida, Arkansas. (Photo by James M. Guldin)

Figure 9. Shortleaf pine and hardwood regeneration 12 years after the first cutting cycle harvest under the group selection method in a shortleaf pine stand near Mount Ida, Arkansas. (Photo by James M. Guldin)

Figure 10. Shortleaf pine and hardwood regeneration 12 years after the first cutting cycle harvest under the single-tree selection method in a shortleaf pine stand near Pencil Bluff, Arkansas. Several cutting cycles will be required to develop the typical structure of an uneven-aged stand. (Photo by James M. Guldin)