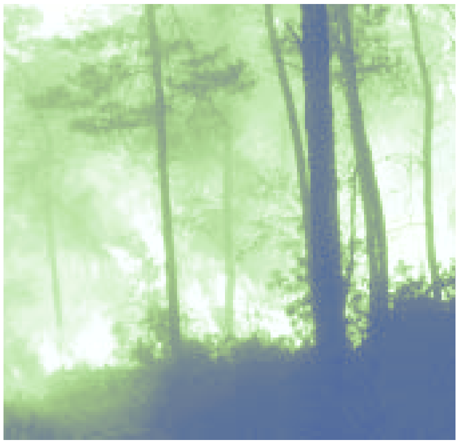

Chapter 25: Background Paper: Fire in Southern Forest Landscapes

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Fire as a Landscape Process

Other than land clearing for urban development (Wear and others 1998), no disturbance is more common in southern forests than fire. The pervasive role of fire predates human activity in the South (Komarek 1964, 1974), and humans magnified that role. Repeating patterns of fire behavior lead to recognizable fire regimes, with temporal and spatial dimensions. Understanding these fire regimes is essential to examining the importance of fire in southern landscapes and integrating fire into forest management. This chapter has six sections:

1. Fire regimes and fire types
2. Fire history in the South
3. Fire regimes of southern forests
4. Prescribed fire
5. Smoke management
6. Restoring fire into southern ecosystems

Fire Regimes and Fire Types

Fire Regimes

Fire regime refers to the long-term nature of fire in an ecosystem (Brown 2000), including both frequency and severity of effects. The interval between fires in southern forests may be as short as a year or as long as centuries. The intensity of fire and severity of effects can vary in scale from benign to catastrophic. Because of the spatial and temporal variability of fire and its effects, descriptions of fire regimes are broad (Whelan 1995). The fire regimes used in this chapter follow the descriptions used in Brown and Smith (2000). They include the understory, mixed, and stand replacement fire regimes.

Fires in the understory fire regime generally do not kill the dominant vegetation or substantially change its structure. Approximately 80 percent or more of the aboveground dominant vegetation survives fire (Brown 2000). The understory fire regime occurs primarily in southern pine and oak-hickory forests, which support pine and pine-oak associations such as Kuchler's southern mixed forest, oak-hickory-pine, and oak-hickory associations.

The severity of fire in the mixed fire regime either causes selective mortality in dominant vegetation, depending on tree species' susceptibility to fire, or varies between understory and stand replacement (Brown 2000). The mixed fire regime best represents the resettlement fire history for several hardwood- and conifer-dominated ecosystems. The conifers include pitch pine and Virginia pine of Kuchler's oak-pine association (Kuchler 1964) and pond pine, a dominant tree of the pocosin association. The conifer types fit the mixed fire regime because fire intensities are generally greater than in the understory fire regime and cause mortality ranging from 20 to 80 percent of the overstory. The hardwood ecosystems include mesophytic hardwood, northern hardwood, and elm-ash-cottonwood forest types. Although the hardwoods are prone to fire injury, many survive numerous fires before eventually being girdled. These fires tend to have low intensity because fuels are less flammable than in ecosystems with a substantial conifer component. The low-intensity presettlement fires that wounded or killed many trees did not cause enough mortality (greater than 80 percent) to be considered stand replacement regimes (Wade and others 2000).

In the stand replacement fire regime, fires kill aboveground parts of the dominant vegetation, changing the aboveground structure substantially. Approximately 80 percent or more of the aboveground dominant vegetation is either consumed or dies as a result of fires (Brown 2000). Several vegetation types in the Eastern United States are represented by stand replacement fire regimes, including oak-gum-cypress (bay forests), sand pine, Atlantic white-cedar, and spruce-fir. Table Mountain pine usually is regarded as having a stand replacement fire regime, but a mixed regime may be more accurate as it produces the seedbed conditions needed for survival of seedlings.

Fire Types

Three kinds of fires burn in forests when weather and fuel conditions permit ignition and sustained combustion: surface fire, ground fire, and crown fire. Surface fires burn the upper litter layer and small branches that lie on or near the ground. Surface fires usually move quickly through an area, and do not consume the entire organic layer. Moisture in the organic horizons often prevents ignition of the humus layer, and protects the soil and soil-inhabiting organisms from heat. The heat pulse generated at the burning front of these fast-moving fires does not normally persist long enough to damage tissue beneath the thick bark of large trees. However, it will girdle the root collar of small trees and shrubs, and reduce small-diameter branches and other fine surface fuels.

Ground fires smolder or creep slowly through the litter and humus layers, consuming all or most of the organic cover, and exposing mineral soil or underlying rock. These fires usually occur during periods of protracted drought when the entire soil organic layer may dry sufficiently. They may burn for weeks or months until precipitation extinguishes them or fuel is exhausted.

Crown fires occur when stand structure, weather, and ladder fuels (heavy accumulations of understory material such as slash piles, shrubs, and lower branches of standing trees, often draped with fallen needles) allow surface or ground fires to ignite tree crowns and spread to other crowns. Crown fires occur in forests during periods of drought and low relative humidity, particularly in areas with a dense, volatile understory. Crown fires generate tremendous heat that rises in a strong convection column, drawing in surface winds that fan the flames even more. Heated air blowing across the flames warms and dries the fuel ahead of the fire, and releases volatile gases from vegetation in the path of the flaming front. Crown fires kill all trees and shrubs in their path and consume most of the surface organic layers.

The shorter the interval between fires, the more likely that fires kill only small trees or particularly susceptible species, such as thin-barked hardwoods, resulting in an understory fire regime. This regime usually perpetuates fire-adapted species (Mutch 1970). As fire frequency decreases, fuel accumulates, increasing the probability of a fire intense enough to kill nearly all trees. Fires in forests regenerated by a stand replacement fire regime come at frequencies of 25 to 100 years and probably maintain high levels of diversity in the landscape (Waring and Schlesinger 1985). In the mixed fire regime, either some susceptible overstory species are killed but the stand is not replaced, or fire severity varies between understory and stand-replacing fire.

Fire History of the South

To appreciate the pervasive role of fire in shaping southern forests requires an understanding of the dynamic response of southern ecosystems to climate change since the retreat of the Laurentide Ice Sheet, which began around 18,000 years ago, and the extent of human influence, which likely began about 14,000 years ago. Humans exert an influence by igniting or suppressing fires. Native Americans used fire extensively for thousands of years. The early European settlers continued and to a degree expanded the use of fire. In the last century, however, human influence over fire in the South changed markedly.

We have divided the long history of fire since humans arrived in the South into five periods:

- From the earliest appearance of humans in North America around 14,000 years ago (Fagan 2000) until European contact 500 years ago, the first period was one of increasing human population level and more extensive use of fire.
- For the first 400 years after their arrival, the early European settlers continued to use fire in much the same way as Native Americans, often reoccupying and farming land cleared by Native Americans and expanding burning of woodlands to provide forage for livestock (Williams 1992).
- At the end of the 19th century and extending into the 20th century, the remaining southern forests were extensively logged to support economic expansion; wildfires were common in the slash left behind.
- In reaction to these widespread and destructive wildfires, the fourth period of fire suppression started in the early 1900s.
- The current period is one of fire management, in which the natural role of fire is increasingly recognized and incorporated into forest management.

Use of Fire by Native Americans

The role of fire was dramatically increased with the arrival of aboriginals in America about 14,000 BP (before present). Hunting and gathering characterized their progressively more sophisticated cultures until the advent of settled societies after 3,000 BP in the eastern woodlands (Fagan 2000). Beginning about 6,000 BP (Middle Holocene), warmer climates and final wastage of the Laurentide Ice Sheet (Delcourt and Delcourt 1981, 1983) translated into increased food resources and rapid population growth. By 5,000 BP, sea level had stabilized, and vegetation patterns were essentially as we find them today.

After this rapid population growth, more or less permanent settlements appeared, primarily in river valleys and rich bottomland soils from the Coastal Plain to the mountains (Fagan 2000). After 3,000 BP, population pressures led to cultivation of native plants typical of disturbed habitats. After 1,000 BP, corn cultivation was widespread (Hudson 1982) and bean cultivation by 800 BP (Smith 1994), but hunting and gathering were still prominent activities. Population density was probably greater in the southern than in the northern part of the eastern woodlands and greater on the coast than inland, but higher densities extended inland along major rivers (Driver 1961).

Judging the extent to which forests and other vegetation were influenced by Native American use of fire requires knowledge of the typical pattern of land use and the population levels before European contact (Kemmerer and Lake 2001). Williams (1992, p. 40, fig. 2.8) presented a concept of a typical southern woodland village. Located on a stream or river, the clearing for the village and surrounding fields of mostly corn, beans, and squash extended for 4 miles. Girdling larger trees and burning the undergrowth cleared this area originally, and burning kept it open, in much the way that swidden agriculture occurs in the tropics today. The field zone was buffered by a further 1.25-mile-wide zone that was burned annually for defense (visibility), where fuel wood and berry gathering took place. Another 1- to 2.5-mile-wide zone was burned frequently for small game and foraging. This entire disturbance complex was surrounded by closed forest. Nearby was a large zone kept in open grassland by burning for large game animals. Except in river floodplains, this village complex had to be moved periodically as soil fertility was reduced in the continuously cropped fields and as nearby fuel wood was exhausted. To maintain proximity to open grassland for hunting, successive village sites were probably within 6 to 25 miles of each other.

Pyne (1997) described the careful use of fire by Native Americans. Cereal grasses were fired annually, basket grasses and nut trees every 3 years, and the grassy savanna hunting areas annually. Brush and undergrowth in forests were burned for visibility and game every 7 to 10 years. Fire also was used to drive and surround game (Hudson 1982) and reduce the threat of wildfires, especially along the coast, where pines dominated and lightning provided an ignition source. Even in areas of the Southern Appalachian Mountains that were sparsely settled and not prime hunting ground, major trails that followed rivers were kept open by burning, and escaped campfires probably caused large areas to burn.

The preponderance of anecdotal (Stewart 1963, Williams 1992), archeological (Dobyns 1966, 1983; Jacobs 1974), ecological (Delcourt and Delcourt 1997, 1998; Hamel and Buckner 1998), and meteorological evidence supports the conclusion that fire was a widespread occurrence in the pre-European landscape. The full extent of Native American impact, however, hinges on estimates of population levels. Until recently, it was thought that the earliest estimates, made after European settlement, represented precontact levels, and Native American populations declined only after sustained exposure to European diseases. A contrasting view, first presented by Dobyns (1983) but built on earlier work, assumed diseases were spread even without direct physical contact between Europeans and Native Americans. Thus, even the earliest census estimates reflected populations already decimated by disease, by as much as 95 percent. Dobyns (1983) estimated North American populations as high as 18 million at the beginning of the 16th century, in contrast to previously accepted estimates of less than 1 million (Fagan 2000). Archeological evidence in the Lower Mississippi River Valley was used by Ramenovsky (1987) to test contrasting hypotheses of how diseases spread and their effect on Native American populations. She found evidence of widespread declines during the 16th century, after the DeSoto expedition (1538–41) and before French settlement began in the late 17th century. Generally accepted estimates of population levels are more conservatively placed at between 9.8 million and 12.25 million for North America (Fagan 2000, Ramenovsky 1987, Williams 1992).

Estimates of the cleared land needed to support a person range from 0.33 acres (2.3 acres when fallowing is taken into account) to 30 to 40 acres for all cleared and burned land (Williams 1992). For argument's sake, we can assume that half the population of 12 million was part of the eastern woodland culture involved in the sedentary lifestyle described above, and that each person represented 10 to 20 burned acres. The 60 million to 120 million acres thus estimated to be affected by clearing and burning would constitute 22 to 44 percent of the cropland acreage presently farmed in the 31 Eastern States (Williams 1992). The point is not to accept the size of the number but to appreciate the magnitude of Native American impact on the landscape through the use of fire.

Use of Fire by Early European Settlers

Initial European agriculture differed little from that of Native Americans, but it rapidly became more extensive (Williams 1992). Spreading from the coast inland along rivers, the early settlers sought out Native American clearings for their farms or used similar techniques of girdling and burning to clear land. Instead of using the Native American system of rotational clearing (swidden agriculture), however, Europeans maintained extensive permanent fields. Burning was extended to the bottomlands and hilltops to support open grazing, particularly of hogs (Williams 1992). Prior to the Civil War, over 75 percent of the white population of the South was comprised of pastoral herders of Celtic origin (McWhiney 1988, Owsley 1945) who came from the British Isles, Spain, and France where fire had been an integral part of their livelihood.

In time, agricultural practices differed between the coast and the uplands. Small farmers and herders, who originated in the mid-Atlantic colonies, settled the mountains, Interior Highlands, and plateaus. They moved down the Appalachian valleys to settle western Virginia, eastern North Carolina, Tennessee, and Kentucky (Williams 1992). These small farmers adapted Native American cropping practices. Along the coast, large-scale plantations grew market crops, particularly tobacco, rice, and cotton. Before the American Revolution, rice cultivation was limited to inland swamps with minimal impact on coastal forests. Later, a new cultivation technique was introduced, probably by African slaves, which used tidal action to flood rice fields along rivers. This tidal irrigation affected forest lands as far as 35 miles inland (Edgar 1998).

After Coastal Plain soils were exhausted, plantation culture was extended into the Piedmont of Virginia, the Carolinas, Georgia, and the rich bottomlands of the Lower Mississippi Alluvial Valley. On the Coastal Plain, the extensive pine forests away from the rivers were exploited for naval stores. These woodlands were burned periodically, and grasslands were kept open by annual burning. These vast areas between major river valleys hosted large herds of feral and semidomesticated hogs and cattle, tended by prototypical cowboys (McWhiney 1988, Williams 1992).

Early settlers used fire in several ways. They sought out old fields and openings cleared by Native Americans and kept them open by plowing or periodic burning. Woodlands were burned for pasture. Burning small trees and shrubs and girdling large trees cleared new fields. Even though the practice was ineffective, woods in the Piedmont were burned to control the boll weevil, a pest of cotton (Dorn and Derks 1988). As settlers began moving into the mountains, they first settled the better land along the major streams. A description of the settlement of Mulky Creek in the north Georgia mountains tells of harvesting a first hay crop beneath the open timber on a south slope (Brender and Merrick 1950), where broom sedge grew shoulder high on drier sites and wild legumes were abundant. Fire must have played a major role in maintaining such an open ecosystem, even before grazing of livestock became a supporting factor (Van Lear and

Waldrop 1989). Annual burning became a standard practice wherever grazing animals were kept, even in the more remote mountain regions.

Fire Following Exploitive Logging

Lumbering was always a component of rural life in the South, but until the late 19th century it was a secondary activity to farming (Williams 1992). Lumbering activity increased after the Civil War to satisfy the needs of rapid industrialization. Between 1880 and 1920, annual lumber production rose in the South from 1.6 billion board feet to 15.4 billion board feet (Williams 1992). Much of the production was from the southern pinery on the Coastal Plain, but virgin stands of baldcypress and bottomland hardwoods were also cleared. The remainder of the "original" southern pine (longleaf) forest was heavily cutover, and then indiscriminately burned every spring to promote forage for free-ranging cattle (Stoddard 1962). These fires eliminated all pine regeneration except for grass-stage longleaf. Regeneration of even longleaf pine was effectively prohibited by the widespread clearing that eliminated sources of seed and by feral pigs that uprooted any seedlings that did get established (Frost 1993). By 1920, there was an estimated 90 million acres of cutover, unproductive land in the South (Williams 1992).

During the late 1800s, timber companies began buying large tracts of land in the more remote sections of the Southern Appalachians (Van Lear and Waldrop 1989). Slash often was burned after logging and then the land was grazed. In much of the Southern Appalachians, the combined effects of grazing and burning effectively prevented the reestablishment of woody vegetation (Brender and Merrick 1950). Even the pines could not reproduce under a regime of annual fire.

An Era of Fire Suppression

Suppressing all fire was seen as the only way to reforest the cutover land (Pyne 1997, Williams 1992). Rangeland users, however, were opposed to fire prevention, and arson was commonplace (U.S. Department of Agriculture 1988). The turning point was passage of the Clarke-McNary Act of 1924, which provided Federal funding for State fire-control efforts. Federal funding rapidly grew from $5 million in 1930, to a high of $18 million in the 1960s. State funding grew from nearly $10 million in 1930 to over $90 million in the 1980s (U.S. Department of Agriculture, Forest Service 1988). In 1930, 70 million acres were protected from fire; by 1980, over 233 million acres were protected (U.S. Department of Agriculture, Forest Service 1988). In 1930, about 2 million acres of timberland burned. By 1983, the area burned by wildfire dropped to 279,000 acres. During World War II, fire control became more difficult because personnel were diverted to the war effort. Nevertheless, prevention of smoke around airfields and fires near the coast, where they would make ships visible to submarines, became military necessities. The first approval for prescribed fire in southern national forests was on the Osceola National Forest in Florida. A prescribed fire was approved in 1943 because the forest could not muster fire suppression crews.

The rising value of pine pulpwood also helped fire control efforts. Pulp and paper companies invested heavily in manufacturing plants and wanted to protect their investments. They provided political support for increasing public expenditures for fire suppression on private as well as public land. A rise in public land ownership brought the Forest Service and National Park Service into suppression efforts. In the 1920s, the Forest Service was opposed to the use of fire in forests, and even light burning was prohibited on the recently established national forests (Demmon 1929, Schiff 1962). Earlier leaders of the Agency, however, recognized that fire exclusion led to another set of problems and advocated the use of prescribed burning under southern pines to reduce hazards (Eldredge 1911, Graves 1910, Pinchot 1899).

The Era of Fire Management

Native Americans and early European settlers practiced prescribed burning, where fire is set intentionally to manage vegetation and reduce the risk of wildfire. It became commonplace in southern forest management after World War II. The unrealistic goal of excluding fire from southern forests was abandoned, in the face of experience and research by Forest Service and university scientists (U.S. Department of Agriculture, Forest Service 1988). Prescribed fire was advocated in the management of longleaf pine and bobwhite quail (for a synopsis, see Wade and others 2000). The role of prescribed fire in reducing the hazards of disastrous wildfires was realized after major fires in the South during the droughts in the 1930s and 1950s. With the advent of fencing laws and the end of open range, the incentive for general burning to stimulate forage was reduced (U.S. Department of Agriculture, Forest Service 1988).

Southern resource managers burn an estimated 8 million acres annually of forest, range, and cropland for many objectives but mostly for hazard reduction, wildlife habitat improvement, and range management (Wade and others 2000). An increasing number of acres are burned each year for ecosystem restoration and maintenance. In spite of this level of prescribed burning, wildfires are common in the South. Most fires are human-caused in all Southern States, with arson playing a variable role, depending upon the State and region within a State. Wildfires are relatively common in the Southern Appalachian Mountains. The majority of wildfires on Federal land (88 percent) are human-caused, due either to carelessness or arson. The small proportion (12 percent) caused by lightning is restricted to ridgetops (Southern Appalachian Man and the Biosphere 1996).

Fire Regimes of Southern Forests

The climate of the South is characterized by long, hot growing seasons; abundant rain punctuated by occasional multiyear droughts; and the most frequent wind (Cry 1965) and lightning (Komarek 1964) storms in North America (Muller and Grimes 1998). Lightning becomes increasingly common as one moves from north to south. Natural disturbances such as microbursts, tornadoes, and hurricanes can have major impacts on forest structure (Peterson 2000) and the distribution of fuels, and set the stage for intense fires (Myers and Van Lear 1997).

Before Native Americans arrived, fire occurred mainly in the spring and summer thunderstorm season, ignited by lightning (Robbins and Meyers 1992). Most fires were probably limited in extent, as normally humid and still nighttime conditions in the summer tend to extinguish fires in light fuels. Some fires, however, were undoubtedly far ranging because they were associated with dry weather fronts (Wade and others 2000). Native Americans burned many sites frequently, limiting fuel buildup. They also extended the burning season, setting fires throughout the year, and often several times each year (Martin and Sapsis 1992). Periodic high-intensity wind-driven fires or severe-drought fires together with chronic lightning and Native American fires created the open woodlands, numerous smoke columns, and extensive smoke and haze referred to by early European explorers (Barden 1997, Landers and others 1990, Olson 1996).

In explaining the climate and vegetation interactions that influence fire regimes in southern forests, we refer to four broad physiographic regions (Martin and Boyce 1993): (1) the Coastal Plain (Atlantic and Gulf coasts, including peninsular Florida and the Lower Mississippi Alluvial Valley); (2) the Piedmont; the Southern Appalachians (including Appalachian plateaus and mountain ranges); (3) and the Interior Highlands (including the Interior Low Plateaus of Kentucky and Tennessee and the Ozark-Ouachita Highlands). Occurrences and frequencies of fire regimes for specific plant communities before European settlement are shown in table 25.1.

Table 25.1—Occurrence and frequency of presettlement fire regime types by SAF cover types

Fire regime types	Understory fire regime	Mixed fire regime	Stand replacement fire regime
	Frequency (years)		
Vegetation community			
Longleaf pine	1 to 4		
Slash pine	1 to 4		
Loblolly pine	1 to 4		
Shortleaf pine	2 to 15		
Oak-hickory	<35		
Pond pine		6 to 25	
Pitch and Virginia pines		10 to 35	
Table Mountain pine		<200	
Mixed mesophytic		10 to 35 or >200	
Bottomland hardwoods		<200	
Sand pine			25 to 60
Bay forests			20 to 100
Atlantic white cedar			35 to 200
Northern hardwoods			300 to 500

SAF = Society of American Foresters.
Source: Modified from table 4-1 in Wade and others (2000).

Fire-adapted plant communities span the full elevational gradient from saltwater marshes to mountain balds (Wade and others 2000). The extent of these communities at the time of European colonization is difficult to reconstruct because much of this region was cleared and plowed at least once, or logged to support the industrial revolution. An estimated 80 percent of the Coastal Plain was cleared, with some counties reaching near 100 percent (Brender 1974, Nelson 1957). Hamel and Buckner (1998) described the "original southern forest" at three time periods: (1) late glacial times, following retreat of the Laurentide Ice Sheet, but after aboriginal immigration; (2) prior to European contact in 1492; and (3) after the first permanent English settlement in 1607. They concluded that no specific time period represents the "true" original condition of the southern forest because it has been responding to climate change and has been shaped by humans for millennia. Even communities that escaped logging or clearing in the last 200 years have undergone dramatic changes because of decades of fire exclusion.

Coastal Plain Region

Coastal Plain forests in the South are predominantly pine in the uplands and hardwoods in the floodplains of major and minor rivers. Before European settlement, fire in virtually all forest types in the Coastal Plain had a return interval of less than 13 years (Frost 1998). Frequent light ground fires characterized most Coastal Plain ecosystems dominated by longleaf, slash, and loblolly pines (Wade and others 2000). Blowdowns and drought led to occasional severe fires (Myers and Van Lear 1997). Explosive increases in southern pine beetle (*Ips* spp. and *Dendroctonus frontalis*) populations and subsequent pine mortality often either preceded or followed these fires. Occasional severe fires in depressional wetlands typically cause stand replacement (Wade and others 2000).

The dominant species of Coastal Plain pine forests—longleaf, loblolly, slash, pond, sand, and shortleaf pines—differ in their tolerance of fire, requirements for soil aeration, and ability to withstand drought. In the following sections, we describe the fire regimes of forests dominated by these pine species, in addition to other forest types.

Longleaf pine—Open pine forests, woodlands, and savannas distinguish the longleaf pine ecosystem. Longleaf pine tolerates a wide range of sites from wet, boggy flatwoods underlain with tight clays across xeric, deep sands to thin stony soils on south-facing mountain slopes (Ware and others 1993). On infertile sites, surface soils are typically acidic, tend to dry quickly after precipitation, and are characterized by a lack of organic matter and low fertility (Landers and Wade 1994). Longleaf pine also occupied a significant area of fertile soils where frequent fires gave it the advantage over loblolly pine and hardwoods. These fertile sites were cleared for agriculture. Examples of longleaf on fertile soils persist in the red hills region of Georgia and at Fort Bragg, NC. Many soils in the Gulf Coastal Plain also tend to be more fertile than the infertile sands often associated with longleaf pine. Longleaf pine ecosystems persist and maintain their diversity because of constant disturbance (Christensen 1993, Landers and Wade 1994, Landers and others 1995, Wells and Shunk 1931), and recurrent fire is crucial to perpetuation of these ecosystems (Andrews 1917).

Typical longleaf pine sites burned every 1 to 4 years prior to the arrival of Europeans, and then every 1 to 3 years until aggressive fire suppression activities began in the 1920s and 1930s (Landers 1991, Landers and others 1990). Fire frequency decreases as typical upland sites grade toward very wet sites where ignition is inhibited or very dry sites with low rates of fuel accumulation.

Longleaf pine has numerous traits adapted to recurrent understory fires. It goes through a grass stage of limited aboveground growth while an extensive root system is developed. Coming out of the grass stage, a growth spurt (called bolting) quickly gets the terminal buds above the height of the flames. The large buds of longleaf pine are protected from high temperatures by an encompassing sheaf of long needles. Stem bark rapidly thickens, protecting the seedling from light surface fires during the first year of height growth.

If the fire regime is disrupted, such as by suppression activity, longleaf stands are invaded by hardwoods such as sweetgum, oaks, hickories, common persimmon, and southern magnolia (Daubenmire 1990, Gilliam and Platt 1999). These hardwoods form a midstory that prevents the shade-intolerant longleaf pine from regenerating. Many of these hardwoods are somewhat resistant to low-intensity fires when mature (Blaisdell and others 1974), and rootstocks of even understory trees are able to withstand all but annual growing-season fires (Glitzenstein and others 1995, Waldrop and others 1987). Invasive exotics such as cogongrass (Lippincott 1997), Japanese climbing fern, and melaleuca (Wade 1981, Wade and others 1980) are promoted by fire. They create serious problems for those who are trying to restore longleaf ecosystems.

Remnant populations of longleaf pine are also found in the Piedmont and Appalachian Highland (both Blue Ridge and Ridge and Valley) physiographic Provinces of Alabama and Georgia (Boyer 1990, Wahlenberg 1946).

Slash pine—Slash pine is the chief conifer associate of longleaf pine on wet Coastal Plain sites throughout its natural range, from South Carolina to Louisiana (Lohrey and Kossuth 1990). Slash pine seedlings are susceptible to fire, thus confining it historically to wet sites (Monk 1968). Slash pine has successfully invaded many drier sites after exploitive logging and fire suppression removed longleaf pine and disrupted fire regimes. The most hydric slash pine sites are depressions such as bays, bayheads, titi swamps, and cypress pond margins embedded within the flatwoods matrix. On such sites, slash pine generally develops a pronounced buttress (comprised mostly of bark) that protects the tree from heat girdling during drought fires.

Loblolly pine—Loblolly pine historically occurred on wet sites similar to those occupied by slash pine, and for the same reason—its susceptibility to fire when young. With increased fire suppression, loblolly pine dominance dramatically increased as it seeded into former longleaf pine sites and abandoned agricultural fields. Loblolly pine was planted even more extensively than slash pine. It is currently the leading commercial tree in the Southern United States, comprising more than half of the standing pine volume in the region (Baker and Langdon 1990).

Loblolly pine is also common along stream bottoms in the Piedmont where fire-free intervals historically exceeded 5 to 6 years (Wade and others 2000).

Pond pine—Some pocosins (depressional wetlands) with a mixed fire regime are dominated by pond pine (Wade and others 2000). Most pocosins burn on a 20- to 50-year cycle (Christensen and others 1988), but on better sites fire-return intervals of 3 to 10 years can result in pine savanna with a grass understory. These wet sites have a rank shrub layer comprised of many ericaceous evergreen shrubs that tend to burn intensely, resulting in the topkill or death of all vegetation except pond pine. Pond pine has the ability to resprout from its base as well as along its stem and branches (Wenger 1958); thus, its aboveground stem survives higher intensity fires than stems of other pine species. This trait allows the species to dominate wet areas such as pocosins, which support intense fires. Summer fires during severe droughts usually eliminate the pond pine as well, because the underlying organic soil burns, destroying root systems.

Sand pine—Sand pine has a stand replacement fire regime, but its two varieties, Choctawhatchee and Ocala, require different fire management because one (Ocala) has serotinous cones and the other does not (Wade and others 2000). The historic fire frequency for the Choctawhatchee variety is unknown, but lightning fires were rare where it occurs. This variety grows in pure stands, directly inland from the beach, separated from more fire-prone vegetation types by wet intradune swales and sparse dune vegetation. Hurricanes were likely a frequent disturbance and probably more responsible than fire for stand replacement. Both varieties are thin-barked and easily killed by fire. The fire cycle for Ocala sand pine corresponds roughly to stand longevity, which is 30 to 60 years (Christensen 1981). Sand pine needles are short and tend to form a flat mat on the forest floor that does not burn well, but it will support creeping fires. The Ocala variety recaptures the site after fire from seed from the freshly opened serotinous cones. Although Ocala sand pine can be regenerated using prescribed fire, this must be a stand replacement fire. Such fires are useful only for management of wilderness or natural areas where timber production is not an objective.

Bay forests—This general type is characterized by a stand replacement fire regime (Wade and others 2000). Carolina bays and pocosins without a pine or Atlantic white-cedar overstory are the major vegetation types. Many stands contained a merchantable overstory that has been harvested, thereby altering the fire cycle. They are all characterized by a dense tangle of evergreen and deciduous shrubs and vines (Richardson and Gibbons 1993). Numerous species of special concern, including several Federal- and State-listed species, occur in this vegetation type. This type now burns on about a 20- to 100-year cycle, but uncertainty exists about the historic fire frequency (McKevlin 1996, Wharton 1977). Shrub bogs are bay forests that burn every 2 to 5 decades (Christensen 1977). More frequent burning, at least once a decade, removes the shrub layer, resulting in an herb bog. If the underlying organic soils are completely consumed, both pocosins and bays will revert to marsh (Richardson and Gibbons 1993).

Atlantic white-cedar—Before European settlers harvested this prized species, it was generally perpetuated by major disturbances, probably stand-replacing crown fires (Wade and others 2000). It is a prolific seeder, beginning at an early age (as young as 3 years). The seed, released in the fall, is stored in the forest floor. Under normal (wet) conditions, crown fires destroy the aboveground vegetation. Fires during droughts consume the forest floor and stored seed. Two fires in close succession (before the seed bank is replenished) will create an herb bog, shrub bog, or bay forest, depending upon the future fire return interval.

Bottomland hardwoods—The historical role of fire in the bottomland hardwood ecosystem is unclear (Wade and others 2000). Drought probably played a role, and low- to moderate-intensity wildfires may have been frequent (Lentz 1931, Toole and McKnight 1956). Low-intensity fires are the norm in these forests because fuel loads are generally light (except after damaging wind and ice storms) due to rapid decomposition on these moist, humid sites. In canebrakes, fire intensity is much higher, but fire severity is low except during drought. Large fires can only occur after extended drought, usually when a dry fall is followed by a dry spring.

Other community types—Embedded within pine and floodplain ecosystems were numerous other ecosystems such as depressional wetlands, including Carolina bays, lime sinks, cypress ponds and savannas, gum ponds, bay swamps, pitcher plant bogs, shrub bogs, and spring seeps (Stanturf and Schoenholtz 1998). During prolonged dry periods, fire can enter these wetlands from adjacent upland communities (Kirkman and others 1998, Wharton 1977). When rainfall is more normal, periodic fire keeps hardwoods from invading and capturing upland sites (Barrett and Downs 1943, Chaiken 1949, Harcombe and others 1993, Heyward 1939, Oosting 1942, Platt and Schwartz 1990, Wahlenberg 1949, Wells 1928). As the interval between fires increases, the hardwood midstory also increases in height and leaf area, shading out herbaceous groundcover. When the continuity of the herbaceous understory is broken up and its ability to spread fire is reduced, the hardwoods expand until they eventually dominate the site.

Piedmont Region

The Piedmont region is a transition topographically and ecologically between the Coastal Plain and the Appalachian Mountains. Pine and hardwood species from these adjacent regions overlap in the Piedmont, often occurring together in mixed pine-hardwood stands. Fire behavior may differ considerably between these regions, however, even in plantations, because of very different understory species assemblages. Nevertheless, fire regimes are similar, depending upon site and stand conditions, particularly the amount of pine versus hardwood in a stand. The following discussion focuses on shortleaf pine, which is more widespread in the Piedmont and mountains than in the Coastal Plain.

Shortleaf pine—Shortleaf pine has the widest range of any of the eastern pines and is found throughout the Piedmont, mountains, and Interior Highlands, as well as the Coastal Plain. Shortleaf pine has an understory fire regime (Wade and others 2000). It occupies a wide variety of soils under many environmental conditions but will not tolerate poor drainage. Shortleaf pine is a prolific seeder but requires a mineral soil seedbed. Loblolly pine is the chief associate of shortleaf pine at lower elevations throughout the Midsouth and Southeast. Loblolly pine dominates the heavier, moist soils while shortleaf pine dominates the lighter, drier soils. Loblolly drops out at about 400 feet elevation in the Ozarks and Ouachitas, resulting in pure stands of shortleaf pine up to about 2,000 feet on south-facing slopes. Above 2,000 feet, hardwoods begin to dominate with shortleaf pine disappearing at about 3,000 feet. In the Appalachians and upper Piedmont, Virginia pine replaces shortleaf pine on drier, nutrient-poor sites east of the Appalachian divide.

The historic shortleaf pine fire return interval is thought to have ranged from about 2 to 6 years on fertile, lower elevation sites. It extended to 6 to 15 years on drier, nutrient-poor sites where fuels take longer to accumulate. Annual burning was common throughout the shortleaf pine region after European settlement (Matoon 1915).

Ability to resprout, abundant seed crops, rapid juvenile growth (especially of sprouts), and a low resin content of the wood make this species markedly tolerant of fire (Mattoon 1915). Shortleaf pine forms dense sapling stands that are favored over competing hardwoods by frequent fire. Shortleaf pine can repeatedly sprout from the base if the tree is topkilled, at least until trees are 15 to 30 years old (Matoon 1915, Wakeley 1954). Trees larger in diameter at breast height than 0.5 inches are somewhat resistant to fire, and mortality is negligible once trees reach 4 inches in diameter at breast height (Walker and Wiant 1966). Like other southern pines, trees over 5 feet tall rarely die when crown scorch is less than 70 percent and buds are not killed when foliage is consumed.

Mountains and Interior Highlands Regions

Fire played a major role in shaping vegetation communities in the Appalachian Mountains. Overstories of southern yellow pines (Virginia, shortleaf, pitch, and Table Mountain) typically dominate south- and west-facing slopes (Whittaker 1956), but in the absence of hot fires at rather frequent intervals, hardwoods will succeed pines. Table Mountain pine is well adapted to fire because of its serotinous cones. Although these can open without fire, many remain closed and ensure a supply of seed regardless of the time of year when a fire occurs (Barden 1977). This adaptation allows Table Mountain pine to cast seeds when seeds of other pine species would be destroyed. Serotinous cones have also been observed in pitch pine and rarely in Virginia pine, but this character is not well documented. Shortleaf and pitch pines can sprout from the root collar after topkill by fire. Fires of human origin probably perpetuated pine in the Appalachians since lightning fires did not occur frequently enough or were not intense enough to maintain pines on these xeric sites (Whittaker 1956). Fire protection in recent decades has allowed hardwoods to dominate on sites where pines once thrived.

Oak-hickory forests—The oak-hickory forest type (Barrett 1994, Braun 1950) occurs primarily on average to dry upland sites, but it also can be found on moist upland sites, depending upon past disturbance history. The oak-hickory type historically had an understory fire regime (Brose and others 2001, Van Lear and Waldrop 1989, Wade and others 2000), but presettlement fire frequencies are not known. Conservative estimates from dendrochronological studies suggest fire return intervals of 2.8 years (Cutter and Guyette 1994) to 14 years (Buell and others 1954, Guyette and Dey 1997). The frequency and extent of Native American burning decreased substantially after European contact. As a result, forest canopies closed over previously open grasslands, savannas, and woodlands (Buckner 1983; Denevan 1992; Dobyns 1983; MacCleery 1993, 1995; Pyne 1997). European settlers of oak-hickory forests increased the frequency and extent of burning and shortened fire-return intervals to 2 to 10 years; they burned many sites annually (Cutter and Guyette 1994, Guyette and Dey 1997, Holmes 1911, Sutherland 1997, Sutherland and others 1995).

Presently, infrequent low-intensity surface fires during the spring and fall characterize the fire regime of oak-hickory forests. These fires are caused almost exclusively by humans and burn small areas (Barden and Woods 1974, Pyne and others 1996, Ruffner and Abrams 1998). Fire exclusion created a fuel complex that is probably very difficult to ignite. On drier mountainous sites, fire exclusion allows ericaceous shrubs such as mountain laurel and rhododendron to move from riparian areas into upland forests (Elliott and others 1999). These shrubs are shade tolerant and evergreen, shading the forest floor throughout the year. Although the forest floor rarely dries enough to support surface fire, the ericaceous shrub layer is flammable. When it burns, it typically supports intense crown fires.

Mixed mesophytic hardwoods—The hardwood forests of the Appalachian and Ozark Mountains and the upland hardwoods of the Coastal Plain and Piedmont have been grazed and burned regularly from the time of earliest settlement (Van Lear and Waldrop 1989). In the absence of fire, a mixed mesophytic forest develops. Although little is known about presettlement fire, it appears that fire was much more common in the mesophytic forests west of the Appalachian divide than in those to the east (Harmon 1984).

Table Mountain pine—Prehistoric fire regimes are unknown, but the presence of serotinous cones suggests that Table Mountain pine is adapted to stand replacement fires (Wade and others 2000). However, some stands are known to regenerate successfully without fire (Barden 1977, Williams and Johnson 1992), and crown fires can create seedbed conditions too xeric for optimum survival (Waldrop and Brose 1999). The historic fire regime for Table Mountain pine stands is probably best described as mixed. Native Americans exposed both Table Mountain pine and pitch pine to frequent understory burns, keeping these stands fairly open. Stand replacement fires probably occurred only when Native Americans were not living in a particular location and fuel loads became heavy. Fires in Table Mountain pine were more frequent, more intense, and probably larger earlier this century (Barden and Woods 1974). Evidence from existing stands supports this mixed fire regime. Table Mountain and pitch pines occur as uneven-aged stands throughout the Southern Appalachians, with most trees ranging from 50 years to over 200 years old (Brose and others 2002, Sutherland and others 1995). Abundant mountain laurel in the same stands is younger than 50 years old, suggesting that frequent low-intensity fires created and maintained these uneven-aged stands until the 1950s. Fire exclusion since the 1950s allowed mountain laurel to establish and create understory conditions that prevented the pines from regenerating.

Pitch and Virginia pines—Mixed severity fires were probably prevalent over much of the range of pitch and Virginia pines. Native American burning maintained pitch pine as an understory fire regime type, with a 2- to 10-year fire interval (Wade and others 2000). This frequency maintained stands with relatively large pines, scattered smaller pines and oaks, and sparse understory besides low ericaceous shrubs and herbs (Little 1946, 1973). The historical fire regime in Virginia pine is unknown but was probably less frequent and resulted in higher mortality. Today, there is a mixed fire regime with long fire-return intervals. The majority of wildfires occur during the growing season when damage is greater.

Southern forest types with long fire-return intervals—Only three vegetation types in southern forests typically have long fire-return intervals: mangroves, high elevation spruce-fir, and northern hardwoods. Surface and ground fires are precluded from mangroves because of their location in tidal zones, but lightning may influence stand dynamics and crown fires can enter after severe freezes that occur every few decades (Wade and others 1980). Spruce-fir forests, which occur from the Southern Appalachians northward, burn only after periodic spruce budworm epidemics, probably on the order of centuries (Wade and others 2000). Northern hardwoods occur only on north-facing slopes and deep coves in the South; return intervals there are on the order of millennia (Lorimer 1977).

Prescribed Fire

It is paradoxical that while so much effort is devoted to suppressing wildfires, controlled fire is used extensively in the South to manage forests. By reducing fuel loads with prescribed burning, the risk of catastrophic wildfire is reduced. The history of fire in the South during the last century, as distinct from other regions of the country, reflects the process of coming to terms with this paradox (Pyne 1997).

Prescribed burning is used to attain several objectives: (1) reducing fuel loads and the risk of wildfire (hazard reduction); (2) preparing sites for seeding or planting; (3) controlling understory vegetation in order to regenerate desirable species; (4) benefiting wildlife; (5) controlling insects and diseases; (6) enhancing appearances; (7) improving access; (8) protecting threatened and endangered species; (9) perpetuating (or restoring) fire-dependent species; and (10) improving forage for grazing (Wade and Lunsford 1989). Prescribed burning is most common in Coastal Plain pine forests and in the Piedmont. It is used to a lesser extent in mountain forests, but use will increase as historic fire regimes are reintroduced into natural stands.

Prescribed burning is used less in the Southern Appalachian Mountains than in other areas of the South. Fire behavior is less predictable due to highly variable topography, and the benefits of burning in hardwoods are not well documented (Van Lear and Waldrop 1989). Interest in prescribed fire in hardwoods is increasing, however, as the need to control accumulations of explosive fuels such as mountain laurel and rhododendron becomes recognized (Van Lear and Waldrop 1989). Fire plays a role in community dynamics of several forest types in the Southern Appalachians, indicating a potential role for prescribed burning in their restoration (Brose and others 2001, Southern Appalachian Man and the Biosphere 1996). These community types include mixed mesophytic hardwoods on lower slopes, northern hardwood-hemlock types on north and east slopes, pine-oak mixtures on south to west slopes, and yellow pine dominated communities on ridges and upper slopes with south and west aspects.

Types of Prescribed Fires

Prescribed fires are generally one of three types: head fires, backing fires, or flanking fires. Head fires burn with the wind or upslope. They are of relatively high intensity and move through fuels at a relatively high rate of speed. Head fires are often ignited in strips (called strip head fires) to speed the burning process and to provide the desired intensity. Fire intensity increases as the rear of a previously ignited strip merges with the advancing front of a subsequent strip (Brown and Davis 1973). Backing fires back into the wind or burn downslope. They burn with lower flame heights and lower intensity, and move through the stand at slower speed than head fires. Because of their lower intensity and slower speeds, backing fires are more easily controlled. Flanking fires are set moving parallel to and into the wind. They are generally used to supplement other burning techniques. For example, flanking fires can be used to speed the process of burning with backing fires. Flanking fires are set perpendicular to backfires. Where flanking fires merge, fire intensity increases, but not as much as it does with strip head fires.

The choice of which fire to use depends upon objectives, fuel and moisture conditions, and need to manage smoke. To understand fire behavior and fire effects, the difference between fire intensity and severity should be appreciated. Fire severity describes the condition of the ground surface after burning (Wells and others 1979), whereas fire intensity is the rate at which an ongoing fire produces thermal energy. Although an intense fire usually has severe effects, such congruence is not always the case. For example, any fire that consumes the entire organic layer and alters mineral soil structure and color would be classified as a "severe burn." A high-intensity fire in heavy fuels when the soil and forest floor are moist, however, would leave a large amount of residual forest floor and would not alter soil structure and color. Thus, the severity of such a high-intensity fire would be classified as "light."

Fire effects are related to intensity and duration of exposure. Fire line intensity is the heat output of a unit length of fire front per unit of time (Deeming and others 1977). Fire line intensity is directly related to flame height, which influences fire effects. As trees grow taller and their bark thickens, resistance to fire increases because crowns are higher above the heat of the flames and thicker bark insulates their cambium. The duration of exposure (residence time) also is an important consideration in prescribed fire. Living tissue can be instantly killed at a temperature of 147 °F; it also can be killed by prolonged exposure to lower temperatures (Hare 1965, Nelson 1952). Backing fires of low intensity can be lethal to small stems because the slow speed of the burning front enables lethal cambium temperatures to be reached just aboveground.

Leaf litter is the primary fuel that sustains fire. Loading and thickness of the litter layer vary depending on site, stand age, and season (Albrecht and Mattson 1977, Blow 1955, Crosby and Loomis 1974, Kucera 1952, Loomis 1975, Metz 1954). Fuel weights in like stands on comparable sites vary little longitudinally, but increase northward because decreasing mean temperatures slow decomposition. Most hardwood stands have a litter loading from 1 to 4 tons per acre and a depth of 1 to 5 inches, depending on season. Litter loading and depth are greatest immediately after leaf fall in the autumn and decline until the following autumn. Hardwood leaves in general tend to cup and hold water after a rain, but the leaves of some species of oak tend to curl and dry quickly in comparison to other hardwoods, allowing fire to run through oak litter when other hardwood fuel types are too wet to burn.

Under mature southern pine stands on the Atlantic Coastal Plain, forest floor fuel loads range from about 1.5 tons per acre under an annual dormant-season fire regime to 13 tons per acre after 40 years without a fire. Live groundcover and understory fuels with a ground line diameter less than 1 inch range from about 0.75 tons per acre with annual burns to over 11 tons per acre after 25 years. On Piedmont sites, roughly the same trends hold. Fuel weights are highest in loblolly and longleaf pine stands and appreciably lighter under shortleaf and Virginia pine stands. Shortleaf and mixed shortleaf pine-hardwood stands in the mountains may have substantially heavier fuel loads than similar stands in the Piedmont, at least in part because of a heavier understory component (Albrecht and Mattson 1977). Small woody fuels can be abundant in young stands originating after a major disturbance. Woody fuels are less abundant in midsuccessional and mature stands, but increase in old-growth stands due to accumulation of large downed or standing dead woody material. When present, ericaceous shrubs such as mountain laurel and rhododendron can burn with extreme fire behavior resulting in a mixed severity or stand replacement fire (Waldrop and Brose 1999). Many of the firefighter fatalities in hardwood forests have occurred because of the explosive nature of these fuels.

Resource managers generally prescribe burning conditions that limit fuel consumption to 1 to 3 tons per acre during passage of the flame front. Residual smoldering combustion can more than double these values, especially under drought conditions, or 5 to 6 years after a major disturbance when large downed woody fuels become partially decomposed. More detailed descriptions of fuels and fire behavior can be found elsewhere (Cheney and Gould 1997, Hough and Albini 1978, Johansen 1987, Wade 1995, Wade and Lunsford 1989, Wade and others 1993).

Hazard-reduction burning— Prescribed fire is often used to reduce fuel loads from dangerous levels to protect forests from wildfire. Most wildfires are accidental; campfires, debris burning, or sparks from machinery are common ignition sources. Burning embers carried aloft by the convection column (rising hot air and gases) may ignite numerous spot fires far away from the main fire. Nevertheless, arson remains a serious problem in southern forests. Fires set by arsonists are difficult to control because they often occur during times of extreme fire danger. Wildfires in recently harvested stands can be intense because of heavy fuel loadings (Sanders and Van Lear 1987).

Pine stands usually develop an understory of hardwoods, shrubs, and vines. When draped with pine needles, this understory becomes highly flammable. If the condition extends over a large area, the whole forest is at risk of destruction by wildfire. In hardwood stands, rhododendron and mountain laurel often form thickets of highly flammable fuels, which allow fire to climb into the canopy. Prescribed fire is an economical way to reduce dangerous fuel accumulations. Wildfires that burn into areas previously subjected to prescribed fires cause less damage and are controlled more easily. The appropriate interval between prescribed burns for fuel reduction varies with several factors, including the rate of fuel accumulation, which is high in pine stands in the Coastal Plain because of the rank understory. Past wildfire occurrence and the values at risk are other factors to consider. The interval between fires in pine stands can be annual, but a 3- to 4-year cycle between fires usually is adequate after an initial fuel reduction burn (Wade and Lunsford 1989).

Fire for regeneration—Judicious use of fire reduces the large amount of highly flammable fine woody material present after clearcutting by more than 90 percent (Sanders and Van Lear 1987). Site-preparation burns in pine plantations are normally conducted in the summer and are of moderate to high intensity. They are used to reduce logging debris, control hardwood sprouts, and improve the plantability of the site. Because of their intensity, these burns must be conducted under the proper fuel- and soil-moisture conditions to prevent damage to the soil, especially in the steep terrain of the Southern Appalachians (Swift and others 1993, Van Lear and Waldrop 1989). Broadcast burning late in the summer following long periods without rain can completely remove organic layers from the soil. Such burns reduce logging debris, ensuring that the site will be plantable, but they can cause site damage from accelerated erosion and loss of nutrients and organic matter. In addition, severe burns may contribute to poor initial survival of planted seedlings because of the loss of mulching effects of a residual forest floor. Both onsite and offsite damage from broadcast burning can be minimized by burning earlier in the summer, soon after soaking rains.

Prescribed fire prior to harvest is used to prepare seedbeds for natural regeneration of pine. Low-intensity burns are used to protect the stand that is being regenerated when seed trees are retained as future cavity trees for red-cockaded woodpeckers. One or more winter burns may be required to reduce fuel loadings. A final summer burn is used to prepare the seedbed and reduce the vigor of understory hardwoods. Dormant season logging further enhances seedbed preparation and allows seeds to germinate the following spring.

Mixed pine-hardwood stands can be regenerated after clearcutting in the Southern Appalachians with minimal adverse site effects using the fell-and-burn technique (Abercrombie and Sims 1986, Danielovich and others 1987, Phillips and Abercrombie 1987). As the name suggests, fell-and-burn requires two steps after clearcutting of hardwood or pine-hardwood stands. First, residual stems over 6 feet tall are felled with chainsaws during early spring after full leaf development when carbohydrate reserves in the roots are low. Allowing full leaf development is important for two reasons: (1) leaves on the felled trees speed the drying of small twigs and branches, which serve as fuel for the broadcast burn; and (2) leafing out reduces root reserves and therefore reduces the vigor of hardwood sprouts. The harvested stand is burned in midsummer, within 24 to 48 hours after a soaking rain. The damp forest floor reduces fuel consumption, minimizing heat penetration into the soil and protecting against erosion. Pine seedlings, planted at a wide spacing the following winter, generally compete well with hardwood coppice.

Using fire to regenerate hardwoods generally has not been recommended because of the fear of damaging stem quality and because of the danger of erosion, particularly on steep slopes (Van Lear and Waldrop 1989). Nevertheless, many oak stands that currently occupy better sites in the Appalachians no doubt became established 60 to 100 years ago when burning was a common practice. Observations of conditions after wildfires are the basis for avoiding burning in hardwoods. Wildfires, however, burn with higher intensity and severity than prescribed fires (Abell 1932, Nelson and others 1933, Wendel and Smith 1986). A low-intensity winter backing fire in mature hardwood stands probably has little adverse effect on crop trees (Sanders and others 1987).

Excluding fire or other disturbances like grazing from mature oak stands may have altered the ecology of mixed-oak, cove hardwood, and pine-hardwood cover types to the detriment of advanced oak regeneration (Little 1974, Van Lear and Johnson 1983). Fires every few years may be the key to enabling oaks to become dominant over their associates in the advance regeneration pool. Oak seedlings are less susceptible to root kill by fire than other species, providing oaks a competitive advantage (Langdon 1981, Niering and others 1970, Swann 1970). The combination of season, frequency, and number of burns to foster oak regeneration in the Appalachians has not been determined, but multiple prescribed burns are probably necessary to promote development of advance oak regeneration prior to harvest (Brose and others 2001, Carvell and Tryon 1961, Keetch 1944, Thor and Nichols 1974). Oak seedlings initially may be more readily established on burned areas in part because the openings encourage activity by blue jays. Jays hoard and scatter acorns, and they seek out areas of thin litter, low vegetation, and full sunlight to bury nuts (Healy 1988). Germination can be enhanced by fire as weevil and beetle species that prey on germinating acorns are reduced on burned seedbeds (Galford and others 1988). Once established, subsequent fires favor oak seedlings over other hardwoods, and single prescribed fires have little effect on species composition in the understory (Augspurger and others 1987, Johnson 1974, Teuke and Van Lear 1982, Waldrop and others 1985, Wendel and Smith 1986).

The task of regenerating oaks, particularly northern red oak, is especially challenging on moist, fertile cove sites. Fire exclusion allows other understory species to compete vigorously with oak seedlings and usually overtop them (McGee 1979). In addition, control of the subcanopy and midstory is necessary to allow enough light to reach the forest floor and favor advance oak regeneration (Van Lear and Waldrop 1988). Fire has been successful for regenerating yellow-poplar on cove sites. This shade-intolerant species is well adapted to fire disturbance. Its light seeds are disseminated by wind and gravity, and they germinate rapidly on fire-prepared seedbeds. Yellow-poplar seeds also remain viable in the forest floor for 8 to 10 years (Little 1967) and will germinate after a fire creates the needed site conditions (McCarthy 1933, Shearin and others 1972, Sims 1932).

Management of competing vegetation—Prescribed burning is used in pine stands to control competing hardwoods that develop from root or stump sprouts after harvesting, or that encroach from adjacent areas such as depressional wetlands. Control is desirable to decrease competition for water, nutrients, and growing space; to reduce risk of wildfire damage in stands with palmetto, gallberry, or wax myrtle understories; and to aid in stand management and regeneration. In most situations, total eradication of the understory and midstory is neither practical nor desirable. Dormant-season burning can reduce the size, but not the number of hardwood stems in understories. Effects depend on the frequency and timing of prescribed fires (Thor and Nichols 1974, Waldrop and others 1987). Low-intensity fires generally kill most hardwood stems up to 3 inches in diameter. Summer fires are more effective than winter fires in killing hardwood rootstocks, but numerous summer fires in successive years are necessary (Waldrop and others 1987).

Periodic prescribed burns can control the size of hardwoods, reduce wildfire hazard, and facilitate stand regeneration. Burning at about 5-year intervals controls the size of sprouts developing from topkilled rootstocks. By controlling the size of understory hardwoods, pines can be maintained more easily on sites where they are the species of choice. If not controlled, hardwoods will form a midstory and capture the site once the pine is harvested (Wade and Lunsford 1989). If a large pine component is desired in the next rotation, these unmerchantable stems must be removed during site preparation at additional expense and risk of compaction.

Prescribed fire shows promise for the control of laurel and rhododendron in the Southern Appalachian Mountains. Fire suppression in this region has resulted in dense stands of these evergreen shrubs. These thickets compete with and substantially limit reproduction and growth of both woody and herbaceous vegetation (Swift and others 1993, Van Lear and Johnson 1983) and therefore are thought to have a major negative impact on hardwood species. Hence, the objective of many prescribed burns in the Southern Appalachians is the control of these evergreen species. Fire initially decreases mountain laurel density, but, in time, laurel regains dominance in the understory because it sprouts quickly after fire or fell-and-burn treatment (Elliott and others 1999). Mountain laurel sprouts grow slowly, however, allowing planted pine and other species to get established in the midstory and overstory before this shrub dominates the understory (Williams and Waldrop 1995).

Protection of threatened and endangered species and unique plant communities—Some threatened and endangered species require fire to become established and survive. Although the role of fire in the ecology of many threatened and endangered species is not well understood, fire has played an essential role in maintaining most ecosystems in the South (Spurr and Barnes 1980). The once extensive longleaf pine ecosystem was fire maintained (Stout and Marion 1993, Ware and others 1993). The forest mosaic of the Southern Appalachians was largely a product of fire disturbances interacting with complex topography. For example, the grassy balds on the summits of high Appalachian peaks may have been created and maintained by fire (Clements 1936), though other explanations are credible (Whittaker 1956).

Many plants have structural adaptations, specialized tissues, or reproductive features that favor them in a fire-dominated environment. Such traits suggest a close association with fire over a very long period of time. Many endemics are only found the first 1 to 2 years after a fire. Changes in the "natural" fire pattern as a result of attempted fire exclusion have led to dramatic decreases in many of these fire-tolerant or fire-dependent species. Many picturesque flowers, including several orchids, currently listed as threatened or endangered, are benefited by fire.

Prescribed burning, however, does not automatically help perpetuate plant and animal species. It may be necessary to burn during the same season in which the site historically burned. The interval between prescribed fires as well as fire intensity may be important. The individual habitat requirements of a species must therefore be understood before fire can be prescribed to benefit that species.

Fires affect vegetation by altering or maintaining successional stages. When fire was more frequent in the South, fire-dependent or fire-associated species dominated the overstory and understory of many forest stands. In the absence of fire and other similar disturbances, forests have gradually changed composition from predominantly longleaf pine and pine-hardwood to communities dominated by other pines in the Coastal Plain and hardwoods in the mountains and Piedmont. When fire is excluded or suppressed, fire-intolerant hardwoods compete with pine species. Many threatened, endangered, or sensitive plants are understory or midstory plants of fire-dominated communities. For example, mountain golden heather, turkey-beard, sand-myrtle, and twisted-head spike-moss grow in the Appalachians on ledge habitats created and kept open by natural fires and severe weather (Morse 1988). Burning also enhances habitat preferences of several endangered animal species, including the Florida panther, gopher tortoise, indigo snake, and red-cockaded woodpecker (Wade and Lunsford 1989).

Manipulation of wildlife habitat—Prescribed fire improves habitats of certain wildlife species, but it also degrades habitats for other species. Each of the hundreds of wildlife species in the South responds differently to fire, depending upon the frequency, intensity, severity, and season of burning. To effectively use prescribed fire to benefit wildlife requires an understanding of the habitat requirements of each species (Harlow and Van Lear 1981, 1987; Lyon and others 1978; Wood 1981). Some general guidelines for burning to enhance habitat for game species are shown in table 25.2.

Prescribed burns to improve wildlife habitat in existing pine stands historically have been conducted in the winter (Mobley and others 1978) to avoid the spring nesting season. Burns at about 3- to 5-year intervals favor deer and turkey. On the lower Coastal Plain, bobwhite quail are favored by burning at 1- to 2-year intervals, and some results indicate that growing season burns can be used where control of invasive hardwoods is needed (Brennan and others 1998). Appropriate burning frequencies for other species are not well known. Low-intensity burns in hardwood or mixed pine-hardwood stands improve wildlife habitat by increasing sprouting of advance regeneration and stimulating production of herbaceous forage. More intense site-preparation burns can also be beneficial where they increase the abundance of legumes and other herbaceous and perennial plants that are preferred by many wildlife species.

Effects of Prescribed Burning

Soil—Many factors, including fire intensity, ambient temperature, vegetation type, and soil moisture influence the effects of fire on the soil (Wells and others 1979). Low-intensity prescribed fires have few, if any, adverse effects on soil properties; in some cases such fires may improve soil properties (McKee 1982). Repeated burning over a long period may affect levels of available phosphorus, exchangeable calcium, and organic matter content of mineral soil. Fire volatilizes nitrogen from the forest floor, but the losses are often offset by increased activity of nitrogen-fixing soil microorganisms after the fire. Calcium and phosphorus may be lost from the forest floor but are partially retained in lower mineral soil horizons. Low-intensity burns have little, if any, adverse effect on soil erosion even on relatively steep slopes (Brender and Cooper 1968, Cushwa and others 1971, Goebel and others 1967).

Prescribed burns conducted when the soil and fuel are too dry can cause severe damage. Broadcast burns conducted under these conditions can remove the entire forest floor and accelerate erosion in steep terrain. High-intensity prescribed fires have a temporary negative effect on site nutrient status resulting from

Table 25.2—Prescribed burning regimes to improve wildlife habitat

Species to benefit	Time of burn	Size of burn	Type of fire	Frequency	Remarks
Deer	Winter preferred	Small or leave unburned areas	Backing fire or point-source fires	2 to 4 years	Want to promote sprouting and keep browse within reach. Repeat summer fires may kill some rootstocks.
Turkey	Winter preferred; summer burns in July-August	Small or leave unburned areas	Backing fire or point-source fires	2 to 4 years	Avoid April through June nesting season.
Quail	Late winter	25 or more acres	Not critical; do not ring fire	1 to 2 years	Avoid April through June nesting season, although summer burns may be used. Leave unburned patches and thickets.
Dove	Winter	Not critical	Not critical; do not ring fire	Not critical	Leave unburned patches and thickets.
Waterfowl	Late fall or winter	Not critical	Heading fire	2 or more years	Marshland only. Do not burn in hardwood swamps.

Source: From table, p. 46 in Wade and Lunsford 1989.

volatilization of nitrogen and sulfur, plus some cation loss due to ash convection. Such effects are short-lived after low-intensity fires, but recovery is not as rapid after severe fires.

Site-preparation burns of high intensity with high fuel loads and low soil moisture may damage soil by overheating. When burning is done with soil moisture near field capacity, however, little heating damage will occur (DeBano and others 1977). Fires that burn completely to mineral soil may accelerate soil erosion in steep terrain. Soil loss after severe burns can exceed 200 tons per acre per year in the Piedmont (Van Lear and Kapeluck 1989). Infiltration is decreased, and run-off and sediment yield increased after severe burns in the Southern Appalachians (Robichaud and Waldrop 1994). Such losses have not been documented in the South, but they appear to be negligible after prescribed burns (Van Lear and Danielovich 1988).

Vegetation—Plants in fire-prone ecosystems have adapted to fire in various ways, including thickening of bark, ability to resprout from below the soil surface, and dispersing seeds. Some trees have thick insulating bark, which protects them from the scorching heat of surface fires (Hare 1965). Mature longleaf pine is well known for its resistance to fire damage because of its thick bark. Slash, loblolly, and shortleaf pines also generally survive bole scorch when they reach sapling size or larger (Komarek 1974). Virginia pine and white pine tend to have thinner bark and are more susceptible to fire damage. However, when pine trees are young, crown scorch rather than damage to the bole is the principal cause of mortality (Cooper and Altobellis 1969, Storey and Merkel 1960). All southern pine species except longleaf are generally both crown-killed and stem-girdled when less than about 1- to 2-inch ground-line diameter, although most species can produce basal sprouts when very young. As the trees increase in size, bud kill rather than stem girdling is likely to be the culprit in periodically burned stands.

Southern pines have the ability to leaf out soon after defoliation from crown scorch (Komarek 1974). Trees are most susceptible to crown scorch during the growing season, when buds are elongating and not protected by needles. Diameter growth apparently is not significantly affected when crown scorch and root damage are minimal (Wade and Johansen 1986).

Aboveground portions of hardwood species are not as resistant to fire damage as conifers, primarily because of thinner bark. Bark thickness is not as critical to hardwood survival in Appalachian hardwoods, because most fires burn in light fuels and are of low intensity (Komarek 1974). There are some exceptions, however, such as when understories of mountain laurel produce high-intensity fires in hardwood stands. Some hardwoods develop exceptionally thick bark upon maturity. According to Nelson and others (1933), yellow-poplar is one of the most fire-resistant species in the East when its bark thickness exceeds 0.5 inch. On the Coastal Plain, many hardwood stems over 6 inches in diameter at breast height survived after 30 years of low-intensity annual and biennial burning (Waldrop and others 1992) with little or no damage to boles.

Hardwoods sprout, generally from the base of the stem or from root suckers, when tops are killed. Suppressed buds at or below ground level often survive the heat of a surface fire and sprout in response to the loss of apical dominance (Augspurger and others 1987, Waldrop and others 1985). Although many sprouts may develop from a stump, over time they thin down to one or a few per stump.

Many species have adapted to a high-frequency fire regime by developing light seeds, which can be disseminated over large areas by wind and gravity. These light-seeded species often pioneer on burned seedbeds. Some species, such as yellow-poplar, produce seeds that remain viable for years in the duff. Yellow-poplar seeds stored in the lower duff germinate rapidly after low-intensity prescribed fires (Shearin and others 1972).

Water quality—Effects of prescribed fire on water quality vary, depending on fire intensity, type and amount of vegetation present, ambient temperature, terrain, and other factors. The major problems associated with prescribed fire and water quality are potential increases in sedimentation and, to a lesser degree, increases in dissolved salts in streamflow (Tiedemann and others 1979). However, most studies in the South indicate that effects of prescribed fire on water quality are minor and of short duration when compared with effects of other forest practices (Brender and Cooper 1968). For example, when prescribed fires are conducted properly, nutrient loss and stream sedimentation are likely to be minor compared with those resulting from mechanical methods of site preparation (Douglass and Goodwin 1980, Douglass and Van Lear 1982, Ursic 1970). Even intense broadcast burns may disturb the root mat very little, leaving its soil-holding properties intact. Furthermore, slash tends to be randomly distributed over logged areas and is seldom completely removed by broadcast burning. Therefore, the root mat, residual forest floor materials, and incompletely consumed slash form debris dams that trap much of the sediment moving downslope (Dissmeyer and Foster 1980). Also rapid regrowth in the South quickly protects sites.

Only a few studies in the South have documented the effects of prescribed fire on nutrient concentrations in streams or ground water. Low-intensity prescribed fire had no major impact on stormflow or soil-solution nutrient levels (Douglass and Van Lear 1982, Richter and others 1982). Severe wildfire in heavy fuels in mountainous terrain had no adverse effects on water quality (Neary and Currier 1982). Research from Western States documented several cases where slash burning increased nitrate-N levels in streamflow. In no case, however, did burning cause nitrate-N levels to exceed the recommended U.S. Environmental Protection Agency standard of 10 parts per million for drinking water. Phosphorus and major cations often increased in streamflow and the soil solution, but the effects were of short duration and of a magnitude not considered damaging to surface water or site productivity (Tiedemann and others 1979).

Smoke Management

All woods fires produce smoke. Smoke from prescribed burning is a problem when it creates an annoyance or nuisance, and when it negatively affects human health and safety. Prescribed burners, therefore, must be able to predict smoke production and movement before they ignite a fire.

Problem Smoke

Smoke can contribute to regional haze and may be considered an annoyance by recreationists and residents in scenic areas. Smoke is a nuisance when it irritates the eyes and mucous membranes of the nose and throat, or when it deposits soot on homes. Smoke exacerbates health problems for those with respiratory difficulty or other illnesses. Smoke is a safety hazard when it impedes visibility of drivers of motor vehicles. Problem smoke is chronic in the South because of three factors:

1. A lot of smoke is produced by wildfires and prescribed fires.
2. A lot of people live in interfaces between forests and urban areas.
3. Southern meteorology produces air masses that entrap smoke close to the ground at night.

Of the South's 200 million acres of forest, 4 to 6 million acres burn annually. The area burned is the most in any region of the country. Prescribed burning is used to manage fuel loads and reduce the risk of catastrophic wildfire. The long growing season and warm, humid climate create conditions for rapid buildup of live and dead fuels, which contribute to greater smoke production when burned.

The southern forests are crisscrossed by a dense road network, even in predominantly rural areas. Population density is increasing in many areas of the South with an expanding interface between forests and dwellings. The population living within or near southern forests is greater than in other parts of the country where prescribed fire is widely used. In addition, many people travel through the South who are unaware of smoke and fog hazards.

Climate and weather contribute to problem smoke in several ways. First, prescribed burning is conducted when soil and litter are moist in order to avoid damaging tree roots. Fires in moist fuels burn less efficiently and smolder longer than fires in dry fuels, increasing smoke production. In addition, inefficient combustion produces less heat to carry smoke aloft, so smoke stays close to the ground. Second, shallow valley inversions can develop in the winter, trapping smoke near the ground. Weak drainage winds can carry smoke more than 10 miles, far enough to reach roadways in most areas.

Constituents of Smoke

Particulate matter is the major pollutant in the smoke from prescribed burning (Dieterich 1971, Hall 1972, Sandberg and others 1979). It is a complex mixture of soot, tars, and volatile organic substances, either solid or liquid. Sizes average about 0.1 micron in diameter (McMahon 1977). With low windspeed and high humidity, moisture condenses around particulates and forms dense smoke or combinations of smoke and fog. Reductions in visibility during and after prescribed fires, therefore, have caused numerous highway accidents.

Particulates are not the only emissions from fire. Besides carbon dioxide and water vapor, gaseous hydrocarbons, carbon monoxide, and nitrous oxides are also released (Chi and others 1979). However, only a small proportion (less than 3 percent) of the total national emissions of particulates, carbon monoxide, and hydrocarbons can be attributed to prescribed burning.

Carbon monoxide is a poisonous gas, which may reach toxic levels above and adjacent to prescribed fires, but these concentrations decline rapidly with increasing distance from the flame (McMahon and Ryan 1976). By burning under atmospheric conditions that encourage rapid mixing, the problem of high carbon monoxide levels can be eliminated.

Hydrocarbons are a diverse group of compounds that contain hydrogen, carbon, and their oxygenated derivatives (Hall 1972). Unsaturated hydrocarbons result from the incomplete combustion of organic fuels. Because of their high affinity for oxygen, these compounds may form photochemical smog in the presence of sunlight and oxygen-donating compounds. Methane, ethylene, and hundreds of other gases are released in prescribed burning. Most of the hydrocarbons released during prescribed fires are quite different from those released in internal combustion engines.

Nitrogen oxides are not likely to be released in significant quantities during prescribed burning. The threshold temperature for the release of nitrogen oxides is 1,500 °C, which is hotter than the temperatures normally occurring in prescribed fires (McMahon and Ryan 1976). Nitrogen is volatilized, with the amount released varying with the temperature. At temperatures of 500 °C, 100 percent of the nitrogen is volatilized; at temperatures of 200 to 300 °C, only about 50 percent of the nitrogen is lost (Dunn and DeBano 1977). Sulfur dioxide emissions from prescribed fires are of minor importance since the sulfur concentration of most forest fuels is less than 0.2 percent.

Smoke Management

An extensive wildland-urban interface, a dense road network, and up to 6 million acres of prescribed burning make smoke the foremost forestry-related air quality problem. The risk of smoke movement into sensitive areas such as airports, highways, and communities is probably the major threat to the continued use of prescribed burning. Public concern is likely to occur before levels of smoke exposure violate National Ambient Air Quality Standards. Because of the potentially serious effects of prescribed fire on air quality and its value in forest management, guidelines for smoke management have been developed by the Forest Service to reduce the atmospheric impacts of prescribed fire (U.S. Department of Agriculture, Forest Service 1976). The guidelines recommend five steps: (1) plot the trajectory of the smoke; (2) identify smoke-sensitive areas such as highways, airports, hospitals, etc.; (3) identify critical targets close to the burn or those that already have an air pollution problem; (4) determine the fuel type to be burned; and (5) minimize risk by burning under atmospheric conditions that hasten smoke dispersion, or by using appropriate ignition patterns to reduce smoke pollution.

Burning under proper weather conditions can reduce the impact of smoke. The fire manager should have current weather forecasts with enough information to predict smoke behavior. Both surface weather and upper atmospheric conditions are important. Burning should be conducted when wind is moving away from sensitive areas such as highways and homes. The atmosphere should be slightly unstable for optimum smoke dispersal without loss of fire control.

The ability to predict smoke movement is critical to meeting these guidelines and protecting the public. Efforts to avoid smoke moving to sensitive areas are often complicated by highly variable weather during the burning season in the South.

Weather fronts pass frequently in the South in the winter, producing variable but predictable wind directions. Coastal forests are subject to wind shifts brought on by sea breezes during the day and land breezes at night. These circulations are inconsistent from one day to the next. Regional weather systems also interact with the Appalachian Mountains, producing sudden wind shifts, large changes in wind direction, and a lowering of mixing heights.

Several approaches are being taken to improve the ability to predict smoke movement. Computer models are in operation or being developed to predict smoke movement over the southern landscape. Daytime movement and concentration of particulate matter in smoke, assuming level terrain and unchanging winds, is modeled by VSMOKE (Lavdas 1996). Managers use VSMOKE to assess where smoke from prescribed burns might impact sensitive targets. Movement of smoke trapped near the ground at night can be simulated in the complex terrain of the Piedmont by the PB-Piedmont model (Achtemeier 2001). PB-Piedmont does not predict smoke concentrations, because we do not have good information on emissions from smoldering combustion. Two sister models are planned, one for the Appalachian Mountains and one for coastal areas influenced by sea/land circulations.

High-resolution weather prediction models promise to increase accuracy in prediction of windspeed and direction, as well as mixing height, at time and spatial scales needed by land managers. Accurate predictions of sea/land breezes and associated changes in temperature, wind direction, atmospheric stability, and mixing height are critical. The Florida Division of Forestry is a leader in the use of high-resolution modeling for forestry in the South. Recently the USDA Forest Service, The University of Georgia, and other partners have initiated a Southern High Resolution Modeling Consortium to develop new models and deliver them to clients.

Restoring Fire into Southern Ecosystems

The adverse effects of 70 years of fire suppression are evident in many ecosystems in the South, and the risk of catastrophic wildfires has increased. Many of these ecosystems can be restored with the judicious reintroduction of fire, sometimes in combination with chemical or mechanical methods. Reintroduction of fire is driven by two objectives: (1) fuel management to reduce the risk of wildfire; and (2) restoration of unique, fire-prone ecosystems that support many threatened, endangered, and sensitive plant and animal species.

The long association of southern vegetation with fire has resulted in key species developing traits that favor them in fire-prone ecosystems (Christensen 1977, Landers 1991). If a certain threshold has not been reached, the natural resiliency of these systems allows them to recover if fire is reintroduced (Vogl 1976). Once this threshold has been exceeded, however, natural processes can no longer rectify the situation in a reasonable amount of time. Thus, many components of the original ecosystem cannot survive long-term without fire (Garren 1943). Restoration of longleaf pine grasslands is the goal of many organizations, but longleaf is not the only candidate for restoration of the historic role of fire. Table Mountain pine, the shortleaf pine-bluestem ecosystem, and oak types can benefit from restoration of periodic burning.

Southern pines, in general, develop increasing fire resistance as they age, but longleaf pine is the only tree species able to cope with annual or biennial fires throughout its lifespan. This is the primary reason it once dominated about 75 million acres (Betts 1954, Frost 1993) stretching from southern Virginia through central Florida to east Texas. Chapman (1932) believed this forest type occupied the largest area in the United States dominated by one tree species. Longleaf pine also occurred in association with other species on an additional 18 million acres (Frost 1993).

The longleaf-grassland ecosystem is one of the most species-rich ecosystems found outside the tropics (Peet and Allard 1993). The flora and fauna that dominate this ecosystem have well-developed adaptations to chronic fire. This fire regime maintained a two-tiered structure of an open longleaf overstory and a diverse groundcover dominated by bunchgrasses. Density and phenology of numerous groundcover plants are influenced by the season of burn (Platt and others 1988, Streng and others 1993); simply reintroducing periodic burning, therefore, may not accomplish the desired restoration. About 191 taxa of vascular plants associated with the longleaf-bunchgrass system are classified as threatened or endangered (Walker 1993). The fauna also includes many endemics that are listed as threatened or endangered. Overviews of the plant and animal communities that form this ecosystem can be found in Bridges and Orzell (1989), Harcombe and others (1993), Myers and Ewel (1990), Platt and Rathbun (1993), Skeen and others (1993), Stout and Marion (1993), and Ware and others (1993).

Typical vegetation in the Ouachita Mountains at the beginning of the last century included open woodlands of pine and hardwood, with big bluestem and other grasses in the understory (Foti and others 1999). Fire exclusion and infrequent thinning of second-growth shortleaf pine and pine-hardwood stands resulted in denser stands than historical fire regimes would have produced. Restoration of the shortleaf pine-bluestem habitat is being attempted on 155,000 acres of the Ouachita National Forest in western Arkansas and eastern Oklahoma. Restoration treatments include reducing overstory basal area by harvesting and mechanical reduction of midstory trees, accompanied by reintroduction of fire. The midstory reduction treatments will reduce fuel loads and should lead to fewer wildfires.

The prescriptions include removal of most midstory hardwoods, thinning from below in overstory and midstory pines, and reintroducing surface fires on a 1- to 3-year return interval. These treatments have been effective in restoring many underrepresented species in the landscape, such as purple coneflower, bobwhite quail, red-cockaded woodpecker, Bachman's sparrow, and eastern wild turkey (Bukenhofer and Hedrick 1997). In addition, there is roughly seven times the preferred deer forage in treated versus untreated areas (Masters and others 1996).

The long-term effects of fire exclusion in the Appalachians are becoming increasingly apparent (Williams 1998). Most pine stands are now degraded and succeeding toward hardwood dominance (Williams 1998, Williams and Johnson 1992). The increased incidence of bark beetle attacks in these stressed, aging stands is accelerating this successional trend. On xeric mixed pine-hardwood ridges in the Southern Appalachians, fire has been advocated to restore diversity and productivity (Swift and others 1993; Vose and others 1994, 1997). A winter fire that reduces surface fuels, followed by a summer fire, can control competing hardwoods best (Elliott and others 1999).

Interest has been expressed in restoring Table Mountain pine (Waldrop and Brose 1999), a rare community type in the Southern Appalachians (Southern Appalachian Man and the Biosphere 1996). Questions regarding the necessity of crown fires to restore Table Mountain pine are still unresolved (Waldrop and Brose 1999, Whittaker 1956), but are the subject of ongoing studies. Extreme fire intensity may not be needed to regenerate Table Mountain pine (Waldrop and Brose 1999). Fires of low and medium-low intensity produced abundant pine regeneration, but may not have killed enough of the overstory to prevent shading. High-intensity fires, on the other hand, killed almost all overstory trees but may have destroyed some seeds. Fires of medium-high intensity may be the best choice; such fires killed overstory trees and allowed abundant regeneration.

A series of periodic fires prior to harvest of mature hardwood stands may increase the number of oaks in the advance regeneration pool (Brose and Van Lear 1998; Brose and others 1999a, 1999b; Little 1974), an important consideration in the reestablishment of stands with a large oak component. Periodic fires at intervals of several years favor species that are more fire-resistant than their competitors, and oak seedlings resist root-kill by fire better than their competitors (Niering and others 1970, Swann 1970, Teuke and Van Lear 1982, Thor and Nichols 1974). Many have noticed that intense fires in mixed hardwood stands may favor oak (Carvell and Maxey 1969, Keetch 1944), but this is not always the case, and competitors such as red maple may increase in abundance (McGee 1979). Much remains to be learned about the use of fire to alter species composition in hardwood stands.

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The southern forest resource assessment provides a comprehensive analysis of the history, status, and likely future of forests in the Southern United States. Twenty-three chapters address questions regarding social/economic systems, terrestrial ecosystems, water and aquatic ecosystems, forest health, and timber management; 2 additional chapters provide a background on history and fire. Each chapter surveys pertinent literature and data, assesses conditions, identifies research needs, and examines the implications for southern forests and the benefits that they provide.

Keywords: Conservation, forest sustainability, integrated assessment.